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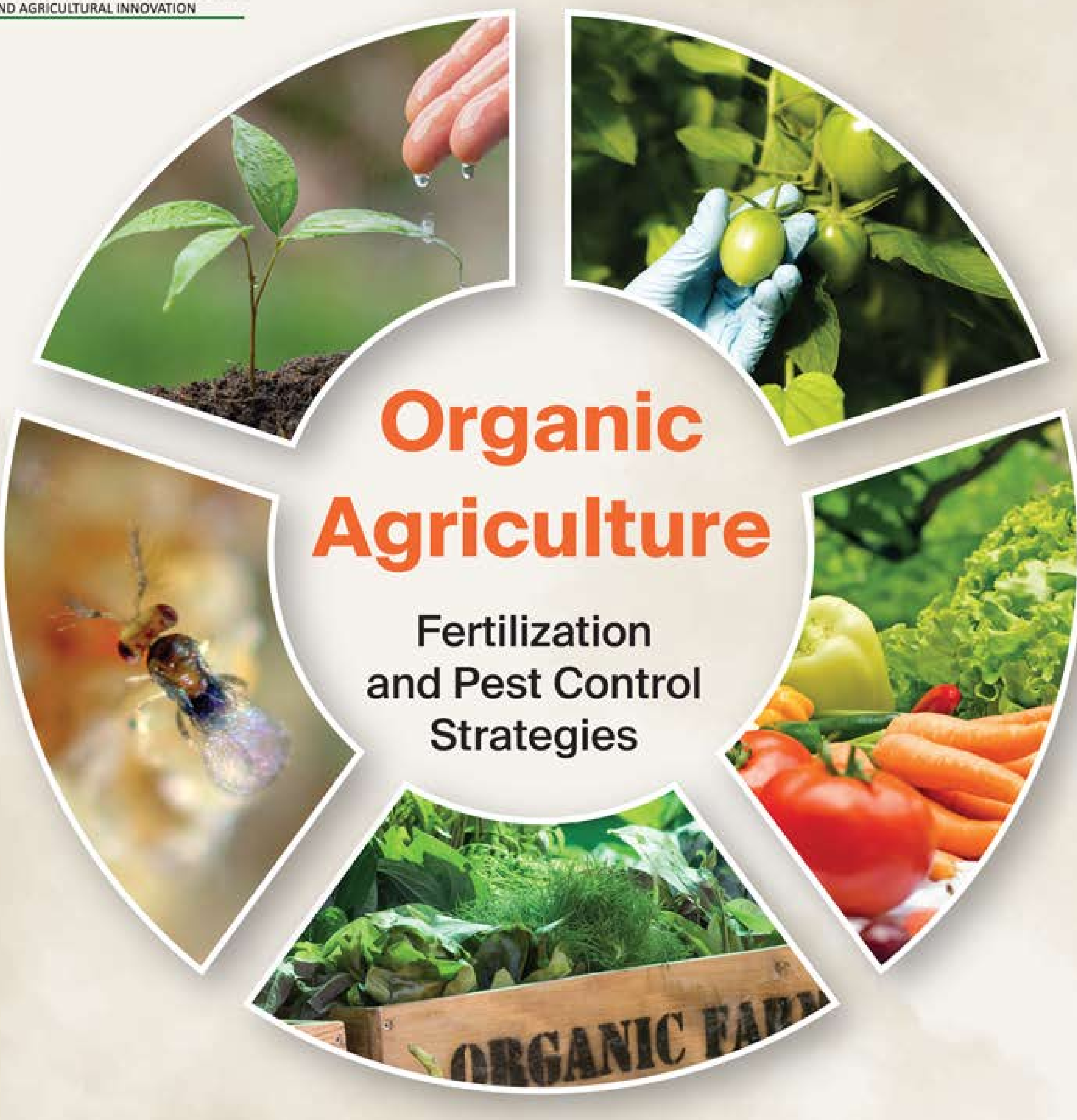

Organic Agriculture

Fertilization and Pest Control Strategies

2025

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Coordinated and Supervised
Dr. Abdelouahhab Zaid, Prof.

مع تحيات الأمانة العامة للجائزة

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FOREWORD

Since its inception in 2007, the General Secretariat of Khalifa International Award for Date Palm and Agricultural Innovation, has been committed to translating the vision of the UAE's wise leadership, through a clear strategic plan, aimed at developing the date palm cultivation and production sector, strengthening the agricultural innovation system, and disseminating specialized scientific knowledge nationally, regionally, and internationally. Throughout its journey, the Award has been inspired by the spirit of giving and the humanitarian vision rooted in the legacy of the late Sheikh Zayed bin Sultan Al Nahyan, “May God bless his soul”. As he set a pioneering model for sustainable development, and the advancement of both humanity and its surrounding environment.

This continued success and prestigious status achieved by the Award over the past sixteen years are a result of the unlimited support of the UAE’s wise leadership, led by H.H. Sheikh Mohamed bin Zayed Al Nahyan, President of the United Arab Emirates, “May God protect him”, and H.H. Sheikh Mansour bin Zayed Al Nahyan, UAE Vice President, Deputy Prime Minister, and Chairman of the Presidential Court, as well as the close follow-up of H.E. Sheikh Nahayan Mabarak Al Nahayan, Minister of Tolerance and Coexistence, Chairman of the Award’s Board of Trustees, and the close supervision of H.H. Sheikh Theyab bin Mohamed bin Zayed Al Nahyan, Deputy Chairman of the Presidential Court for Development and Fallen Heroes’ Affairs, Chairman of the Board of Trustees of the Erth Zayed Philanthropies foundation. This highlights the significant role of this sector as a strategic cornerstone in strengthening food security, supporting the national economy, and driving sustainable development.

Within the framework of this humanitarian and knowledge-based approach, the Award's General Secretariat continues its pioneering role in disseminating knowledge, and empowering stakeholders by publishing specialized scientific books, that contribute to the development of this vital sector. The “Organic Agriculture Fertilization and Pest Control Strategies” book serves an extension of such efforts, emphasizing the importance of promoting sustainable agricultural practices and improving the quality of agricultural production in line with Zayed's timeless vision to serve humanity and the environment.

Dr. Abdelouehhab Zaid, Prof.

Secretary General, Khalifa International Award
for Date Palm and Agricultural Innovation.

PREFACE

The organic agriculture system is often described as an “ancient system and a modern discovery.” This characterization does not suggest a return to the practices of ancient agriculture, such as purely traditional or natural farming. It is considered an ancient system because, historically, humans engaged in organized farming, relying exclusively on natural (organic) components for agricultural production without synthetic or artificial substances. They depended on nature to provide the necessary inputs for farming and used keen observation to address challenges like plant diseases and insect pests. Simple and non-complex methods, such as crop rotation and planting crops during periods less prone to disease and pest problems, were commonly employed for effective control.

Describing organic agriculture as a modern discovery highlights the evolution of ancient agricultural methods into a more structured system, supported by the introduction of scientific terminology to define its steps and practices. Some may perceive organic agriculture as merely a system that relies on recycling agricultural waste and avoiding the use of chemical pesticides and fertilizers, thereby reducing environmental pollution. While this understanding is accurate and forms a part of organic agriculture, it is essential to emphasize that the concept extends beyond these practices. Organic agriculture encompasses a comprehensive set of principles and a philosophical approach, centred on environmental conservation in a holistic sense.

Organic agriculture has experienced significant growth and rapid global expansion. In the early 1970s, the area cultivated under organic systems was relatively modest, estimated at approximately 1.15 million hectares. By 2000, this area had expanded to around 15 million hectares, and since then, organic agricultural land has continued to grow substantially. According to statistics published in 2024, organic agricultural land reached approximately 96.4 million hectares by the end of 2022, marking more than a sixfold increase over 22 years. In the Arab world, organic farming has also shown remarkable development. It is practiced in 15 Arab countries, covering approximately half a million hectares by the end of 2022.

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Chapter 1

1. History of Organic Agriculture

1.1 Agricultural Systems

1.1.1 Conventional Agriculture

Conventional or modern agriculture is the prevailing agriculture method, incorporating various inputs and supplies in agricultural production. This includes the use of manufactured chemical fertilizers and pesticides, aiming for maximum production yield without sufficient consideration for quality or nutritional value. Over the past years, numerous issues have emerged due to the reliance on modern farming practices, including the widespread use of manufactured fertilizers, chemical pesticides, and the introduction of improved or genetically modified seeds, alongside potentially harmful hormones.

All the above-mentioned inputs pose risks to agricultural soils, plants, animals, and humans, as the focus lies primarily on the appearance and quantity of the product rather than its taste and nutritional value. While modern agricultural practices successfully meet the market's demand for large quantities of food, this achievement comes at a cost – the detriment of soil health and human being. The adverse impacts of modern agriculture extend beyond individual health to encompass social, environmental, and agricultural aspects of our lives.

1.1.2 Natural Agriculture

Natural agriculture represents the oldest known agricultural system, dating back to ancient times. It relies solely on nature to fulfil the requirements of agricultural production. Our ancestors practiced natural agriculture, caring for the land and plants by harnessing the natural resources available in their environment. This, indeed, aligns with one of the fundamental goals of organic farming. Some might associate organic agriculture with a return to primitive farming practices reminiscent of our ancestors. However, the truth is that we can draw valuable lessons from their experience, emphasizing soil fertility and abundant production. By integrating these principles into the contemporary framework of organic agriculture, we can ensure the quality of agricultural products while still achieving plentiful yields.

1.1.3 Industrial Agriculture

Industrial agriculture, also known as Green Revolution Agriculture or Intensive Agriculture, emerged after World War II and shares similarities with traditional agriculture. In this system, high-quality varieties are cultivated, and production heavily relies on the application of fertilizers, manufactured chemical pesticides, and agricultural mechanization throughout all stages of production. Industrial agriculture can be viewed as an economic enterprise with a primary goal of short-term profitability achieved through the extensive utilization of modern technology and manufactured production requirements.

1.1.4 Organic Agriculture

The "Organic Agriculture" system is often regarded as an amalgamation of both "an old system and a modern discovery". This expression, however, does not imply a return to ancient natural or traditional agriculture practices. Instead, it acknowledges the historical foundation of organized agriculture where, since ancient times, humans relied on the use of natural, i.e., organic ingredients exclusively in agricultural production processes. No synthetic or unnatural materials were used during the production process.

The "old system" aspect refers to humanity's historical dependence on nature to provide all the necessary elements for agricultural production. Moreover, people relied on keen observations to navigate challenges in agricultural production, such as plant diseases and insect pests. This involved employing simple and uncomplicated methods, like aligning with the agricultural cycle and planting crops during periods when disease and pest-related issues are less prevalent, thus mitigating potential problems for agricultural production.

The characterization of organic agriculture as a "recent discovery" stems from the evolution of old or primitive agricultural methods. Over time, humans have refined these practices, developing scientific explanations and terminology for each step and process in the agricultural production cycle. Organic agriculture distinguishes itself by relying on environmentally friendly methods and strategies, avoiding the use of unnatural agricultural production requirements such as chemical fertilizers and pesticides. Organic agriculture is also known as biological or ecological agriculture, it represents an integrated approach aimed at establishing a sustainable ecosystem. This holistic system involves a series of processes that ultimately result in providing safe food and proper nutrition for humans, alongside the pursuit of social justice and the well-being of livestock.

Accordingly, organic production goes beyond a mere inclusion or exclusion of certain inputs. From this point of view, we can say that organic agriculture is a philosophy; therefore, all those working in the field of organic agriculture must believe and be convinced in it, to achieve success in applying this philosophy with all its ingredients.

In recent years, organic agriculture has experienced growth and dissemination due to an expanding knowledge base, heightened awareness, and a growing human demand for healthy food devoid of chemical residues from fertilizers and pesticides. These chemicals are recognized as contributors to environmental pollution and pose direct threats to human health.

Consequently, when the term "Organic Agriculture" is mentioned, it immediately recalls an agricultural system centred on abstaining from the use of chemical inputs in production. While the concept of abstaining from chemical inputs is correct and followed in organic farms, the true essence of the term "Organic Agriculture" goes even deeper. Organic agriculture is recognized as one of the forms of sustainable agriculture, extending beyond

a mere production system that involves the inclusion or exclusion of certain inputs. The comprehensive nature of organic agriculture becomes apparent as we delve further into its principles. In essence, organic agriculture represents an integrated system covering the production, preparation, processing, circulation, and marketing of agricultural products. This system employs modern methods and adheres to regulations established by local or international rules and standards.

1.1.5 Biodynamic Agriculture

In essence, biodynamic agriculture is fundamentally a form of organic agriculture, and it must adhere to all the methods, rules, and laws observed in the broader realm of organic agriculture. It is concerned with maintaining and strengthening the living system in the soil and nature in general, considering the effects of cosmic energy coming from the sun, moon, planets, and stars on the agricultural system. Accordingly, it is important to note that while we can say that biodynamic agriculture is considered an organic agriculture, the reverse is not true,

as not all-biodynamic agriculture practices fall under the umbrella of organic agriculture. Biodynamic agriculture, originating in Germany, has gained prominence and expanded to various regions. In this system, all the conditions and standards known in organic agriculture are meticulously followed, with the distinctive use of Biodynamic preparations (BD).

1.1.6 Permaculture

The term "Permaculture" is a blend word of permanent and agriculture, implying permanent or authentic agriculture. Coined in Australia by Bill Mollison and David Holmgren in the mid-1970s, permaculture initially focused on sustainable food production. Over time, its philosophy has evolved to encompass economic and social systems as well. Bill Mollison, an Australian ecologist and professor at the University of Tasmania, along with his student David Holmgren, articulated these ideas in several books, notably 'Permaculture One', Mollison and Holmgren (1990).

In the 1980s, Bill Mollison published the principles of perennial farming, describing it as "a perennial agricultural system for human settlements". He initiated training courses to disseminate his ideas globally. By the 1990s, permaculture had gained widespread popularity in the United States and became known in numerous countries worldwide. To this day, permaculture remains a flourishing global movement, primarily disseminated through courses and workshops titled 'Permaculture Agriculture,' often conducted outside academic frameworks.

Permaculture is recognized as a scientific and ethical approach with the goal of promoting a sustainable culture. This approach seeks to assist individuals in meeting their needs for food, shelter, and other essentials in a manner that not only benefits the environment but also avoids harm to it. It encompasses all components of the living and non-living environment, including soil, trees, air, animals, and more. In essence, permaculture doesn't have a fixed or specific definition due to its nature as a broad and continually evolving concept. It operates as a comprehensive and dynamic system that adapts to various contexts and challenges.

Permaculture manifests itself in diverse ways and operates on various levels. Essentially, it can be viewed as a set of sustainability methods, serving as a powerful tool for designing highly productive, sustainable, and self-sufficient systems. These systems aim to mimic the diversity, stability, and adaptability found in natural ecosystems. Bill Mollison succinctly captures the philosophy of permaculture, emphasizing it as a way of working with nature, not against it. It involves careful and conscious design rather than mindless toil and, fundamentally, represents a moral philosophy. Permaculture maintains that ethics should form the foundation of our interactions with the environment, the land, and society. What sets permaculture apart is its core set of three ethical principles, which every practitioner must adhere to:

1. **Caring for Earth:** Nurturing all its living and non-living components.
2. **Caring for People:** Meeting their material and moral needs.
3. **Limiting Resource Consumption:** Returning surplus to the Earth and people, also known as "Fair Share."

On the other hand, permaculture is characterized by:

- Dispensing with chemical fertilizers and pesticides.
- Producing natural bio-products with significant health benefits.
- Reduced effort in farming, eliminating the need for hoeing and chemical fertilization.
- Creation of a purer and healthier atmosphere on the farm, free from manufactured chemicals, fostering harmony among different plants, birds, and other beneficial organisms.
- Efficient water uses through innovative storage methods and reduction of evaporation by covering the soil surface with various materials (mulch).

1.1.7 Sustainable Agriculture

For over 40 years, the Food and Agriculture Organization of the United Nation (FAO) has defined sustainable agriculture as a system dedicated to preserving the environment and natural resources, preventing their deterioration, and simultaneously maintaining or increasing production. Achieving this goal involves harnessing technological and industrial advancements to fulfil current human needs while considering the needs of future generations for food and fibre.

In sustainable agriculture, soil preservation is prioritized by avoiding tillage, recognizing the detrimental impact it can have on soil biological processes and agricultural production. While sustainable agriculture shares similarities with permaculture, especially in the aspect of not tilling the soil to preserve biodiversity, it differs in that it may allow the use of certain industrial inputs and genetically modified crops. The Food and Agriculture Organization of the United Nation (FAO) has articulated four conditions that sustainable development in agriculture must fulfil:

1. Preserving the environment without causing deterioration.
2. Technical feasibility in application.
3. Economic viability.
4. Social acceptability as a sustainable farming method.

Sustainability, therefore, extends beyond safeguarding the natural resource base. For agriculture to be truly sustainable, it must fulfil the needs of both current and future generations for its products and services. This involves ensuring profitability, environmental health, and social and economic equity. Sustainable agriculture plays a pivotal role in advancing all four pillars of food security availability, access, utilization, and stability in a manner that is environmentally, economically, and socially responsible over time.

1.2 Differences between Agricultural Systems & Organic Agriculture

There are various agricultural systems, and we will explore the most significant ones recognized by specialists. Table 1.1. illustrates the fundamental distinctions between these agricultural systems and organic agriculture.

Table 1.1. Key Differences Between Agricultural Systems and Organic Agriculture.

Agricultural Systems	Relationship to Organic Agriculture
Conventional Agriculture	1. In production, conventional agriculture relies on synthetic chemical fertilizers and pesticides, whereas organic farming exclusively uses natural materials that are environmentally friendly. 2. Due to the use of unnatural inputs in conventional agriculture, it harms various elements of the environment. In contrast, organic farming preserves the environment, soil, animals, and humans. 3. Conventional agriculture prioritizes the quantity and appearance of the product, whereas organic agriculture focuses on the quality, taste, and nutritional value of the product. 4. Conventional agriculture methods can vary from one country to another and, at times, from one region to another. In contrast, organic farming adheres to established laws, regulations, and specific objectives. 5. There is no oversight or binding laws that determine production methods in conventional agriculture. In contrast, organic farming operates under specific and binding laws and regulations. Products are monitored by specialized bodies focused on the value and quality of the product, with certificates granted for organic products. 6. The primary goal of conventional agriculture is to maximize production for increased profitability. In contrast, the primary objective of organic farming is to preserve the environment, public health, and satisfy consumer needs. 7. Conventional agriculture disrupts the ecological balance, while organic farming maintains the natural ecological balance.
Natural Agriculture	1. In natural agriculture, manufactured chemical fertilizers and pesticides are not utilized. Organic agriculture, on the other hand, is an integrated system that goes beyond simply avoiding manufactured chemicals. It utilizes Earth's natural resources to meet agricultural production needs and undergoes scrutiny by specialized bodies to certify the resulting products as organic. 2. Natural agriculture relies on the natural resources available in the environment, with product credibility established through trust in the farms providing these natural products. In contrast, organic farming involves farmers adhering to the laws and regulations of organic farming, subjecting their farms to inspections by accredited inspectors from specialized centres, and obtaining organic certification for their products. 3. While natural agriculture is concerned solely with environmental aspects, organic farming extends its focus to environmental, social, and economic considerations, as will be detailed later.
Industrial Agriculture	1. Industrial agriculture relies heavily on the extensive use of manufactured production inputs such as fertilizers and chemical pesticides. In contrast, organic farming prohibits the use of such materials. 2. In industrial agriculture, biodiversity is economically inconsistent with the system's efficiency, leading to the predominance of mono-crop production. Conversely, organic agriculture prioritizes biodiversity conservation, actively encouraging its enhancement. 3. Industrial agriculture prioritizes quick profit and often neglects environmental and soil preservation. In contrast, organic agriculture places a strong emphasis on preserving, and even enhancing, the environment and agricultural soil.

Agricultural Systems	Relationship to Organic Agriculture
Biodynamic Agriculture	1. All biodynamic agriculture is considered organic, but not all organic farming follows biodynamic methods. Farmers adhering to biodynamic practices must comply with all the terms of organic farming. Biodynamic agriculture is a holistic system of farming developed by Rudolf Steiner in 1924. 2. Biodynamic preparations (BD) are utilized in biodynamic agriculture, and this aligns with the laws and regulations of organic farming. Authorities responsible for organic farming have not objected and permit the use of biodynamic preparations. 3. Biodynamic compost preparations (BD) consist of six plant preparations added to compost on the farm. These preparations are derived from various medicinal herbs and are symbolized by the following codes: • (BD-502): It is made from the flowers of yarrow (Achillea millefolium). • (BD-503): It is made from the flowers of German chamomile (Matricaria recutita). • (BD-504): It is made from stinging nettle (Urtica dioica). • (BD-505): It is made from the bark of Himalayan Oak bark (Quercus robur). • (BD-506): It is made from flower heads of dandelion (Taraxacum officinalis). • (BD-507): It is prepared from the flowers of valerian (Valeriana officinalis). 4. Additionally, there are two Biodynamic field spray preparations: • (BD-500): “Cow Horn Manure” applied to agricultural soil before planting. • (BD-501): “Cow Horn Silica” sprayed on the vegetative parts of plants during growth, particularly in the flowering period. 5. In biodynamic agriculture, the use of copper compounds is prohibited, whereas it is allowed in organic farming. 6. In Germany, biodynamic agriculture is a renowned brand exclusively monopolized by the Demeter Association. This association boasts a global network with 19 registration and regulatory bodies in Africa, Australia, Europe, and North America. It includes 3,500 participants across 35 countries, covering approximately one million hectares. Naturally, the Demeter Association is most celebrated for its origins in Germany. 7. The Demeter Association is responsible for establishing globally agreed-upon biodynamic agricultural systems and regulations, considering the local conditions of some countries. However, these regulations remain fully consistent with global regulations for organic agriculture.
Permaculture	1. Permaculture was developed before the idea of sustainability gained attention, as later developed by the United Nations. 2. The system is responsible for managing the waste generated from agriculture and, therefore, does not aim to pollute the surrounding environment. This means it does not contribute to an increase in nitrogen content in groundwater or the dispersal of weed seeds in the natural environment. 3. This system aims to mimic nature, and this is the most obvious difference between organic farming and permaculture. Bare soil is rarely present, and preserving soil and water takes top priority in this system. Seeds are produced on the farm, and intercropping is used for pest control. 4. The permaculture system aims to harvest and maximize water, sun, and other natural energies (such as wind, dust, leaves, and bird waste). 5. The goal of the permaculture system is to provide nutritious food and shelter for people, animals, and local birds.

Agricultural Systems	Relationship to Organic Agriculture
Sustainable Agriculture	1. Sustainable agriculture relies on minimizing soil disruption by avoiding ploughing and planting crops directly through the soil cover. This approach helps reduce atmospheric nutrient loss and ensures the sustainability of soil texture, aligning with organic agriculture in biodiversity conservation. 2. Sustainable agriculture differs from organic agriculture as it may overlook the use of certain industrial inputs in agricultural production, as well as the cultivation of genetically modified crops, which are not permitted in organic agriculture. 3. Sustainable agriculture aims to protect the soil from erosion caused by rain by maintaining a permanent cover of live or dry plant matter. This practice also prevents the growth of harmful weeds and is consistent with the objectives of organic agriculture. 4. Sustainable agriculture relies on employing an appropriate crop rotation, like organic agriculture, by cultivating different crops over several seasons. This strategy helps avoid the proliferation of insect pests, reduces their numbers, mitigates the spread of plant diseases, and maximizes the impact of plant nutrient utilization.

1.3 Fundamental Differences Between Organic and Conventional Agriculture

Based on the earlier definitions, several distinctions exist between organic and conventional agriculture. Table 1.2. illustrates the most significant differences between organic and conventional agriculture.

Table 1.2. Key Differences between Organic and Conventional Agriculture.

Organic Agriculture	Conventional Agriculture
Requires certification by recognized organic standards, ensuring adherence to specific guidelines and practices.	Generally, follows regulatory standards, but certification is not as standardized or specific.
There is constant supervision from the Inspection Office on all inputs, with the necessity to record everything that happens in agriculture, including the location of processing and the presence of documents for all agricultural operations.	It does not have any supervision, and it is not necessary to have documents related to agricultural operations.
Utilizes natural methods for pest and disease control, including companion planting, and biological controls.	Relies on chemical pesticides and herbicides to control pests, diseases and weeds.
Focuses on building soil fertility through composting, crop rotation, and organic matter. It emphasizes the health of the soil ecosystem.	Often involves intensive tillage and relies on synthetic fertilizers. Soil health may be compromised due to chemical inputs.
Internationally accredited certificates are issued for agricultural products from registered farms by the Organic Certification body.	No certificates are issued for agricultural products.
Aims to minimize environmental impact by promoting biodiversity, reducing chemical runoff, and conserving soil and water resources.	May have a higher environmental impact due to chemical usage, soil degradation, and potential water pollution.
Products are sold at special prices.	Products are sold at normal prices.
Prohibits the use of Genetically Modified Organisms (GMOs) in crops or livestock.	May involve the use of Genetically Modified Organisms (GMOs), especially in crops engineered for specific traits like pest resistance or increased yield.
Prohibits the use of growth regulators.	Growth regulators are allowed to be used.
Prohibits to treat seeds with chemicals during planting.	The seeds can be treated with chemicals during planting.

1.4 History of Organic Agriculture

Towards the end of the nineteenth century and the beginning of the twentieth century, agriculture experienced rapid development, thanks to scientific progress and technological innovations in agricultural equipment, especially tractors and soil tillage and flipping machinery. These advancements brought about fundamental changes in conventional agricultural methods. Following this era, research in plant breeding resulted in the development of hybrid seeds, significantly boosting agricultural production in terms of both quantity and quality.

With the adoption of these modern methods, the expanse of agricultural fields has markedly increased. Each large tract of land has now become specialized in cultivating specific crops, capitalizing on agricultural mechanization to achieve abundant yields. This marked the onset of the era known as the Green Revolution. The concept materialized in the latter half of the twentieth century when the focus shifted towards generating large quantities of food and optimizing agricultural output through the widespread application of modern techniques. This encompassed the use of mineral fertilizers and a variety of pesticides, including insecticides, fungicides, herbicides, and nematicides. Additionally, the cultivation of numerous crops involved the use of hybrid seeds, often necessitating the application of substantial amounts of chemical fertilizers to achieve prolific agricultural production.

The utilization of modern technology undeniably has played a significant role in boosting agricultural production, yet there have been negative aspects, particularly when not employed judiciously. While some societies have thrived for centuries relying on instinct and practicing natural agriculture without the use of modern technology or industrial inputs, the concept of so-called organic agriculture began to take shape, unfold, and gain traction in Central Europe and India at the beginning of the twentieth century.

The organic agriculture movement originated as a response from individuals passionate about agricultural affairs, opposing what is known as the industrialization of agriculture. Initially, this movement remained localized and tied to consumer awareness of agricultural production. However, as the differences between organic agriculture and the rise of new conventional agricultural practices became more apparent, public awareness of organic agriculture has steadily increased year after year.

Rudolf Steiner

This has led to the emergence of a prominent market for organic products.

The roots of the movement trace back to 1923 when a group of farmers in Germany sought the guidance of the philosopher and scientist Rudolf Steiner (1861 - 1925). Although born in Croatia, Steiner held Austrian citizenship. These farmers approached him to articulate his vision of agriculture and its harmonious relationship with nature. Prior to this, Steiner had already developed influential ideas in the realms of education and health.

In 1924, Rudolf Steiner published a series of lectures on the spiritual foundations for the development and renewal of agricultural methods. These lectures later formed the foundational principles of what would be recognized as 'Biodynamic agriculture.' This system is considered one of the earliest forms of organic agriculture and one of the pioneering movements in sustainable farming. In 2007, the Rudolf Steiner Centre for Biodynamic Agriculture was established in Croatia in Donji Kraljevec.

Rudolf Steiner's vision was grounded in a specific philosophy that relied on a 'comprehensive understanding of agricultural processes.' According to Steiner, the farm is regarded as a 'living being,' requiring harmony among all its members and components, including soil, humans, animals, plants, and nature.

From this perspective, biodynamic agriculture posits that plant diseases result from the disruption of harmonious interactions among environmental elements caused using synthetic chemical pesticides, which of course do not promote the stimulation and strengthening of the plant's immune system, or, in other words, the 'internal forces' that enable the plant to resist diseases.

Furthermore, Rudolf Steiner emphasized the need to activate and stimulate the release of nutrients from organic matter into the soil, emphasizing a reliance on these nutrients over the use of synthetic chemical fertilizers. Initially followed and believed by only a few, Steiner's ideas, presented in the form of lectures, gradually gained traction over the years. In many other countries, similar ideas promoting the concept of organic agriculture began to emerge and gain acceptance.

In 1931, the thoughts and philosophy of the British botanist Sir Albert Howard on organic farming became clear upon his return to England. Sir Albert Howard, often referred to as the spiritual father of modern organic farming in Britain, spent 26 years in India (1905-1931). In 1940, he published his well-known book titled "An Agricultural Testament," in which he drew on his study of traditional farming practices in India and Bengal. He became convinced that such practices were superior to modern scientific agriculture. Howard also discussed the significant role played by organic fertilizers when used in agricultural systems in tropical regions.

In his book, Howard described his ideas and concepts about organic farming, emphasizing the importance of converting farm waste into beneficial materials for building and maintaining soil fertility, including organic matter such as humus. He highlighted the connection between soil fertility, plant health, and animal well-being. According to what Albert Howard termed "The Law of Return," he strongly advocated for the recycling of all organic materials, including sewage water sediment, to return to agricultural soil, to enrich it. These ideas have become the foundation of what is now known as organic farming.

In 1939, Lady Eve Balfour of Britain became inspired by Sir Albert Howard's ideas, leading her to conduct the first comparisons between organic and conventional agriculture. Her experiences with organically produced crops were subsequently documented in her 1943 book, titled "Living Soil." Just three years later, in 1946, the Soil Association, marking the inception of the first organic farming organization, was established in Britain. This association has since become a crucial reference for groups advocating organic farming worldwide.

It is noteworthy that the term "organic farming" was first attributed to Lord Northbourne in his 1940 book, "Look to the Land." In this publication, he articulated the close relationship between environmental balance and agriculture, laying the groundwork for the conceptualization and promotion of organic farming practices.

The technological advancements during the Second World War paved the way for numerous innovations in the latter half of the twentieth century. This era saw the emergence of modern agricultural methods, including the widespread adoption of advanced irrigation techniques, chemical fertilizers, and various pesticides. Ammonium nitrate, initially employed in munitions during the war, became readily available and served as a cost-effective source of nitrogen for agriculture. Furthermore, military scientists developed DDT as a pesticide to control disease-carrying insects among soldiers. Post-war, DDT found extensive use in agriculture, marking the onset of an era characterized by the intensive application of various pesticides to manage agricultural pests.

Following World War II, adherents of Rudolf Steiner's philosophy in Germany established the "Demeter Association." This organization aimed to assist farmers, oversee agricultural production methods, and champion the products of biodynamic agriculture. However, due to the complexity of the philosophical ideas underpinning biodynamic agriculture, which posed challenges for ordinary farmers to comprehend, there arose a need to formulate a vision or approach to organic agriculture grounded in widely accepted scientific principles. In other words, there was a call for foundations that were more accessible and easily understood by most farmers.

In the 1950s, the concept of "sustainable agriculture" gained prominence as a scientific interest. Despite the prevailing focus on utilizing innovations and modern chemical discoveries in agricultural development research, there was a growing awareness of the need for sustainable practices.

In the 1960s, scientists Maria Müller and Hans-Peter Rusch took a significant step by establishing Biological (Organic) farms. Subsequently, these organic farms were collectively organized under the banner of the "Bioland Organization," officially founded in 1971 in Germany. This marked a crucial development in the formalization and collective promotion of organic farming practices.

During the 1970s, global movements and environmental organizations became increasingly invested in the cause of preserving the environment, sparking a heightened interest in organic agriculture. As the distinctions between organically produced food and conventionally cultivated products became clearer, one of the primary goals of the organic farming movements was to promote consumer awareness and encourage the consumption of organically grown crops. This effort was often articulated through marketing slogans such as "Know your farmer, know your food." The intention was to foster a deeper connection between consumers and the origins of their food, emphasizing the benefits and principles associated with organic agricultural practices.

On November 5, 1972, in the city of Versailles, France, the International Federation of Organic Agriculture Movements (IFOAM) was founded. This organization took on the responsibility of disseminating information pertaining to the principles, practices, standards, and regulations of organic agriculture. According to Geier (1998), in 1975, IFOAM had 50 members representing 17 countries. By 1984, this number had doubled, reaching 100 members from 50 countries.

The subsequent five years witnessed a period of remarkable expansion, with IFOAM's membership surging to 500 members across 75 countries. This rapid growth can be attributed to the increasing popularity of the organic farming system, the inclusion of numerous new farmers and traders, and a notable influx of members from the third world starting in 1986. The momentum continued, and as of the latest data available, IFOAM's membership has exceeded 781 organizations and companies, representing 188 countries. This sustained growth underscores the global embrace and ongoing support for organic agriculture principles.

In 1981, the “Bio-Suisse” organization was established in Switzerland as a federation of Swiss organic farmers. This organization stands as the principal organic farming association in Switzerland, boasting 32 member associations of organic farmers. Additionally, Switzerland is home to the FiBL Organic Agriculture Research

Institute. A total of 7,500 organic producers and organic gardeners in Switzerland are members of Bio- Suisse. In addition, more than 2,300 operations and producer groups worldwide are certified according to the Bio-Suisse standards. Their products appear on store shelves under the BIOSUISSE ORGANIC label.

In the 1980s, organic products experienced a significant global surge in popularity, particularly in European countries. Despite this growing trend, there were no established legislations or rules to regulate or define the characteristics of agricultural products sold under the label "organic product." Consequently, products produced through traditional methods were marketed using terms such as “Organic” or “Biological”. The rationale behind this practice often revolved around the argument that any agricultural food product could be considered biological, as it consisted of organic substances. However, this lack of clear regulations posed a challenge in distinguishing between products adhering to organic farming principles and those produced through traditional methods involving manufactured chemical fertilizers and pesticides. This ambiguity created a need for standardized guidelines to ensure the authenticity and integrity of products labelled as "organic."

In the 1990s, a global movement emerged as farmers and consumer groups advocated for governmental regulations, standards, and laws governing organic agricultural products. This collective effort resulted in the establishment of legal frameworks, laying the foundation for the certification of organic products. These regulations, once initiated and implemented, provided a basis for granting certificates to authentic organic products.

As a result, markets for the sale of organic products experienced significant economic growth and development. The demand for organically produced agricultural products surged, leading to an annual market growth rate of 20-30 %. The increased consumer awareness and preference for organic goods played a pivotal role in driving this remarkable expansion. The establishment of regulations not only ensured the authenticity of organic products but also contributed to the flourishing economic viability of organic markets worldwide.

Accordingly, in 1991, the countries of the European Economic Community (EEC) collectively endorsed regulations and standards to govern organic production. These regulations were formalized as EEC Regulation 2092/91, outlining the prescribed methods and practices to produce items bearing the label "Organic." Subsequently, in 2007, the European regulations governing organic farming underwent an update and were reissued as Regulation (EC) No. 834/2007, complemented by its executive regulations found in Regulation (EC) No. 889/2008.

A further development occurred in 2018 with the introduction of the new European Regulation (EC) No. 848/2018, slated to take effect from 2021. This regulation represents the latest evolution in the European Union's commitment to establishing and refining standards for organic farming, ensuring the continued integrity and transparency of the organic label within the region.

Building upon the developments, overarching regulations for organic agriculture have been instituted. These regulations encompass key aspects such as the transition period from conventional to organic agriculture, as stipulated by the law. Specifically, a minimum transition period of two years is mandated for vegetable and field crops, while a more extended transition period of at least three years is specified for permanent crops, including fruit trees. Integral to these regulations is the emphasis on enhancing soil fertility and vital activity through practices such as the application of compost. Additionally, organic farming principles encourage the cultivation of legumes and green fertilizers, along with the strategic use of plants with deep roots in agricultural rotation. These measures collectively contribute to the sustainable and ecologically sound practices promoted within the framework of organic agriculture.

Furthermore, these regulations encompass fundamental guidelines for effectively managing pests, diseases, and weeds. This involves the careful selection of appropriate plant species and varieties, implementing suitable crop rotation practices, and employing mechanical methods for pest control. The regulations emphasize a holistic approach that prioritizes the protection of natural enemies of pests and creates conditions conducive to their natural reproduction.

In addition to pest control measures, these regulations establish limitations on the agricultural production requirements permissible in organic agriculture. Notably, they explicitly prohibit the use of modified organisms or products derived from Genetically Modified Organisms (GMOs). The seeds, seedlings, or vegetative cuttings utilized in organic agriculture must be exclusively produced through organic methods, aligning with the commitment to maintaining the integrity of organic practices and ensuring the absence of genetically modified components.

Indeed, while organic agriculture boasts numerous advantages, there is a potential drawback stemming from some farmers who falsely market their products as organic without adhering to the correct principles and practices. This deceptive practice can mislead consumers and compromise the integrity of the organic label. To counteract this, consumers need to be informed that an agricultural product cannot be considered organic without a valid organic certificate obtained from recognized regional or international certifying bodies. It is crucial that these certifying offices hold accreditation from the relevant state authorities, ensuring their legitimacy and authority to grant organic certificates. These offices should employ experts and specialists who conduct thorough research, investigations, and quality control assessments on both existing organic farms and those transitioning to organic practices. This multi-faceted approach ensures the reliability of the organic certification process, maintaining trust in the organic label and upholding the principles of organic agriculture.

Certainly, in comparison to various farming systems, organic agriculture stands out with its specific and comprehensive regulations, standards, and techniques governing the entirety of agricultural production processes. Organic farming adheres to distinct systems and regulations throughout the production cycle.

Notably, there exists a robust system for the supervision and inspection of organic farms. This oversight is complemented by a certification process for organic products, offering consumers a level of assurance and confidence in the authenticity and adherence to organic principles. The meticulous nature of these regulations ensures that organic farming maintains a high standard of transparency and integrity, emphasizing sustainable and environmentally friendly practices. This structured approach not only distinguishes organic agriculture from other farming systems but also reinforces the credibility and trustworthiness of organic products in the eyes of consumers.

Chapter 2

2. Basics of Organic Agriculture

2.1 Definition of Organic Agriculture

Certainly, the term "Organic Agriculture" (OA) is often initially perceived as an agricultural system centred on recycling agricultural waste, eschewing synthetic pesticides and chemical fertilizers. This approach aims to mitigate environmental pollution, embodying a vital system derived from nature that refrains from relying on chemical inputs, a principle inherent in the correct concept and application of organic agriculture.

However, it is crucial to recognize that the true concept of organic agriculture extends beyond this practical understanding. Organic agriculture encompasses a set of rules and embodies a philosophical concept that transcends mere agricultural practices. While the avoidance of synthetic inputs is a fundamental aspect, organic agriculture is rooted in a holistic philosophy that considers the interconnectedness of ecological, social, and economic factors. This broader perspective ensures that organic farming is not just a set of techniques but a comprehensive approach to sustainable, regenerative, and ethical agricultural practices.

The terms organic agriculture, bio-agriculture, or ecological agriculture refer not merely to a set of specific inputs but to an integrated system guided by a set of principles. The goal is to establish a sustainable ecosystem that ensures safe food, promotes healthy nutrition, prioritizes livestock care, and upholds principles of social justice.

In essence, organic agriculture transcends a narrow focus on inputs and exclusions; it embodies a holistic approach that considers the preservation of the environment, economic considerations, and societal requirements. It is a dynamic and evolving system that seeks to balance the needs of the present without compromising the ability of future generations to meet their own needs. Thus, organic agriculture can be defined as a method that produces food and fibbers while actively preserving the environment, considering economic conditions, and aligning with the social needs of the community.

In September 2005, during the General Assembly of IFOAM - Organics International in Adelaide, Australia, a significant motion was passed to formulate a concise Definition of Organic Agriculture. Subsequently, a dedicated task force spent nearly three years crafting a definition that succinctly captured the four Principles of Organic Agriculture. This definition was ultimately adopted in Vignola, Italy. In 2008, during the General Assembly of the International Federation of Organic Agriculture Movements (IFOAM), the following definition of organic farming emerged because of this collaborative effort:

> **“Organic Agriculture is a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved”.**

From this perspective, organic agriculture seeks to establish a viable and sustainable agricultural ecosystem by fostering interaction and harmony with life systems and their natural cycles. It is important to note that the organic agriculture system primarily concerns itself with agricultural production processes rather than the product itself. However, when discussing the marketing or exportation of organic products, adherence to local or international standards and regulations becomes imperative. In this context, an organic (or bio) product is defined by its production, preparation, processing, and trading methods, all of which align with the terms, systems, regulations, or laws governing organic production. It is worth emphasizing that standards, regulations, and techniques of organic agriculture can vary from one country to another. Nevertheless, these standards and regulations are typically rooted in the overarching principles established by the International Federation of Organic Agriculture Movements (IFOAM).

As previously mentioned, IFOAM was founded in 1972 in Versailles, France, originating from six organizations. Within 15 years of its establishment, by 1987, the federation had expanded significantly, boasting 100 members across 25 countries. By 2002, the number of organizations affiliated with the federation had surged to 750, operating in 104 countries globally. By the end of 2016, IFOAM's influence had grown further, encompassing approximately 800 organizations active in 115 countries. Furthermore, in the FiBL survey in 2024, based on national data sources, data from certifiers and IFOAM-Organic International, the IFOAM membership has exceeded to 781 organizations and companies, representing 188 countries.

Accordingly, IFOAM assumed a crucial role in disseminating information on the principles, regulations, and practices of organic agriculture. Notably, IFOAM also took the lead in establishing benchmarks and global standards for the transition from conventional to organic agriculture, solidifying its position as a key authority in the organic farming community.

It is noteworthy that IFOAM's primary mission revolves around coordinating the global network of the organic movement. Operating as a democratic federation, IFOAM is committed to serving communities, with its essential functions being carried out by its International Council. Additionally, various committees, working groups, and teams are assigned specific tasks, contributing to the collaborative efforts within the Federation.

The overarching objectives and activities of IFOAM can be succinctly summarised as follows:

- **Global Coordination:** IFOAM strives to foster global coordination within the organic movement, ensuring a united and cohesive approach to advancing organic agriculture worldwide. Thus, Representing the organic movement at the global level in parliamentary and administrative forums and decision-making forums, and the IFOAM, for example, has an advisory status with the United Nations (UN) and the Food and Agriculture Organization (FAO).

- **Democratic Governance:** Functioning as a democratic federation, IFOAM emphasizes inclusive decision-making processes, involving its International Council, committees, and various working groups to ensure representation and diverse perspectives.

- **Information Dissemination:** IFOAM takes on the crucial role of disseminating vital information on the principles, regulations, and best practices of organic agriculture. This information serves to educate and guide stakeholders within the organic community.

- **Guarantee of the Quality of Organic Products:** Making the international guarantee of the quality of organic products a reality through the Accreditation Program in the IFOAM to ensure the equality of certification programs around the world, through the (IOAS) “International Organic Accreditation Service Ltd.”.

- **Setting Standards:** The federation plays a crucial role in establishing benchmarks and global standards for the transition from conventional to organic agriculture. This effort helps create a unified framework for organic practices on a global scale. In addition, the regulations are regularly revised and amended. The basic regulations and standards for organic agriculture issued by IFOAM are translated into 19 languages. It is worth noting that due to the diverse environmental conditions of different countries and regions, regional organizations can set appropriate controls for each region or country. These controls may sometimes be more stringent than the basic standards of IFOAM, which serve as the minimum requirements for organic farming systems.

- **Community Service:** IFOAM is dedicated to serving communities by working towards improving agricultural practices, enhancing environmental sustainability, and promoting organic principles. Additionally, it facilitates the exchange of knowledge and experience among its members and provides the public with information about organic agriculture.

- **Task-Specific Assignments:** IFOAM organizes various committees, working groups, and teams, each assigned specific tasks to address key challenges and advance the goals of the organic movement.

In essence, IFOAM plays a pivotal role in guiding, unifying, and advancing the principles and practices of organic agriculture worldwide.

In response to the growing need for a mechanism to instil confidence and facilitate trade in organic products, IFOAM established the International Organic Accreditation Service (IOAS) in 1997. This initiative arose from the necessity to oversee Certification Bodies (CBs) across different countries responsible for granting certifications in organic agriculture. The IOAS serves as a pivotal entity in ensuring the integrity and consistency of organic certifications globally.

Accreditation stands at the pinnacle of the certification and conformity assessment hierarchy within organic agriculture systems. The International Organic Accreditation Service (IOAS) plays a crucial role in this hierarchy as a non-profit organization responsible for accrediting Certification Bodies (CBs) globally. Its primary mission is to foster trust between CBs and the global market, creating a fair operating environment for producers. This trust ensures that consumers can rely on products bearing labels indicating adherence to organic agriculture systems. Through its work, IOAS contributes significantly to the credibility and transparency of the organic certification process worldwide.

2.2 Organic Product

The Organic Agriculture system primarily focuses on agricultural production systems rather than the product itself. Products generated under this system are termed organic or bio-products. For a product to be labeled as organic, it must originate from a farm that is subject to direct supervision and periodic inspection by an accredited Certification Body. This body, authorized by the accreditation authority, is responsible for granting the organic certificate.

The organic certificate serves as authentication, affirming that a specific product from a particular farm in a designated area adheres to the organic standards. The Certification Body has the authority to issue these certificates, providing tangible proof that the organic product was cultivated in compliance with the laws and regulations outlined in the standards of organic agriculture. Detailed discussions on these standards will follow later.

As previously discussed, the entity responsible for issuing organic certification is known as the Certification Body. This certification serves as concrete evidence that a specific product qualifies as an organic or bio-product. Notably, the Certification Body, which grants these certificates, differs from the entities establishing the standards and regulations for organic agriculture.

The International Organic Accreditation Service (IOAS) plays a crucial role by accrediting offices or bodies, namely Certification Bodies (CBs), worldwide. These accredited bodies are then authorized to issue organic certificates. It is essential to emphasize that agricultural products from farms lacking supervision and inspection by internationally or regionally accredited entities cannot rightfully claim to be organic products. Consequently, they cannot display any signage or phrase indicating their organic or bio-product status. This distinction underscores the importance of accreditation in upholding the authenticity of organic certifications.

It is a stipulation that any product labelled as "organic/biological" must originate from a farm subject to direct supervision and inspection by one of the regional or international bodies, namely a Certification Body. This Certification Body ensures that the product adheres to the fundamental specifications and standards of the organic agriculture system. The system mandates periodic inspections of farms, leading to the issuance of certificates affirming the validity of these products as organic/biological. Moreover, these bodies oversee the processing and marketing of the products to maintain compliance. Crucially, these regional or international bodies must possess an accreditation certificate from the International Organic Accreditation Service (IOAS). This accreditation ensures that the Certification Bodies are recognized and authorized entities, reinforcing the integrity of the organic certification process.

As a result, agricultural producers who are not under the supervision and inspection of any regional or international bodies, such as a Certification Body, cannot assert that their products meet the essential specifications and standards established by the competent authority. Consequently, these products are not eligible to carry any label or statement indicating that they are organic/bio products. Table 2.1. illustrates the labelling of organic products in various languages.

Table 2.1. Labelling Organic Products in Different Languages.

Language	Organic Product	Language	Organic Product
English	Organic	German	Ökologisch
French	Biologique	Danish	Økologisk
Italian	Biologico	Spanish	Ecologico
Portuguese	Biologico	Swedish	Ekologisk
Dutch	Biologisch	Finnish	Luonnonnukainen
Arabic	عضوي/حيوي		

2.3 Objectives of Organic Agriculture

Organic agriculture cares and encourages the adoption of systems and means that preserve the environment while reducing and rationing external inputs in agricultural production processes, in addition to its interest in economic and social aspects during production processes. Organic production and processing are based on several key objectives developed by the International Federation of Organic Agriculture Movements (IFOAM), which are summarised as follows:

- Produce High-Quality Healthy Food: To produce ample quantities of high-quality, healthy food, fibbers, and other products.
- Respect Natural Life Cycles: Dealing in line with the natural life cycles and living systems through soil, plants and animals within the production system, rather than seeking to dominate them.
- Consider Comprehensive Social and Environmental Dimensions: Considering the comprehensive social and environmental dimension of the system of production, processing and circulation of organic products, while providing an ecological system of continuity and quality.
- Maintain Long-Term Soil Fertility: Preserve soil fertility over the long term, utilizing modified local agricultural methods and biological and mechanical alternatives to enhance fertility.
- Promote Agricultural and Natural Biodiversity: Maintaining and promoting natural and agricultural biodiversity on the farm and its surrounding communities using sustainable production systems and the protection of the plant environment and wildlife.
- Protect Genetic Diversity: Maintaining and protecting genetic diversity through the management of genetic resources on the farm and prohibiting the use of any material containing Genetically Modified Organisms (GMOs).
- Safe and Healthy Water Use: Safely and healthily utilize water sources while preserving the living organisms they contain.
- Optimize Resource Use and Minimize Pollution: To use, as far as possible, the renewable resources in production and manufacturing systems and avoid pollution and waste. To work as much as possible, within a closed system, regarding organic matter and nutrient elements.
- Promote Local and Regional Production and Distribution: Encourage local and regional production and distribution, fostering community connections.
- Harmonious Relationship Between Crop and Livestock Production: Providing a harmonious and balanced relationship between crop production and livestock production.
- Ensure Livestock Well-Being: Provide livestock with conditions that allow them to perform all aspects of their innate behaviour.
- Use Sustainable Packaging Materials: Use recyclable, biodegradable, or recycled packaging materials.
- Enhance Biological Cycles: Encourage and enhance biological cycles within farming systems, involving microorganisms, soil flora and fauna, plants, and animals.
- Provide Quality of Life for Workers: Providing a quality of life that meets the basic needs of workers in the

organic production and manufacturing process within the framework of a safe and healthy work environment.

- **Support Integrated Chain of Production, Manufacturing, and Distribution:** Supporting the establishment of an integrated chain of production, manufacturing and distribution characterized by social justice and environmental responsibility.
- **Recognize and Preserve Local Knowledge:** Recognizing the importance of local and traditional innate knowledge of farming systems, protecting them and learning from them.
- **Avoid Pollution from Agricultural Techniques:** Avoid all forms of pollution that may result from agricultural techniques.

2.4 Principles of Organic Agriculture

IFOAM has grouped the goals of organic agriculture into four main groups that represent the basic principles of organic agriculture. These principles serve as the bedrock on which organic agriculture evolves and flourishes, envisioning a future where organic practices contribute to the enhancement of global agricultural methods and the stewardship of agricultural soils. Agriculture, being a fundamental human activity, plays a pivotal role in providing daily sustenance, encapsulating a wealth of historical, cultural, and societal values within its systems. The commitment to these principles reflects a broader perspective, aiming not only to meet immediate needs but also to foster sustainable and harmonious relationships between humans and the environment on a global scale.

The holistic application of the principles of organic agriculture extends beyond mere cultivation methods, encompassing the entire spectrum of agricultural practices. This includes the treatment of soils, water, plants, and animals throughout the production, preparation, and distribution of food and other goods. The principles go beyond the technical aspects of farming; they also address the broader spectrum of human interactions with living landscapes, relationships between individuals, and the responsibility of shaping a legacy for future generations.

These principles serve as a source of encouragement and inspiration for the diverse organic movement, guiding IFOAM in the development of positions, programs, and standards. They are not confined to a narrow perspective but are presented with a vision for their global adoption. The four principles of organic agriculture, as articulated and developed by the International Federation of Organic Agriculture Movements (IFOAM), encapsulate this comprehensive approach to sustainable farming and living. Luttikholt (2007) has published and detailed these four basic principles of organic agriculture developed by the International Federation of Organic Agriculture Movements, as follows:

2.4.1 The Principle of Health

"***Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible***."

The first principle of organic agriculture emphasizes that it should "sustain and enhance the health of soil, plant, animal, human, and planet as one and indivisible." This principle underscores the interconnectedness of the health of individuals and communities with the overall health of ecosystems. It recognizes that the well-being of people is intricately linked to the health of soils, plants, and animals. Health, according to this principle, goes beyond the absence of illness. It is viewed as the wholeness and integrity of living systems, encompassing physical, mental, social, and ecological well-being. In the context of organic agriculture, the vitality of the soil directly impacts the health of crops, which, in turn, influences the health of animals and ultimately contributes to human well-being. The principle further emphasizes key characteristics of health in the organic context, including immunity, resilience, and regeneration. These attributes are considered essential for maintaining the overall health of the interconnected systems within organic agriculture.

This statement encapsulates the overarching role of organic agriculture in promoting the health of ecosystems and organisms at every level, from the smallest in the soil to human beings. The primary aim of organic agriculture is to sustain and enhance the overall well-being of these interconnected systems, whether in farming, processing, distribution, or consumption. Organic agriculture is deliberately designed to produce high-quality and nutritious food that contributes to preventive health care and general well-being. As part of this commitment, organic practices refrain from the use of chemical fertilizers, pesticides, animal drugs, and food additives that may potentially have adverse health effects. By adopting such practices, organic agriculture seeks to offer a holistic and health-oriented approach to food production, prioritizing the long-term well-being of both ecosystems and individuals.

2.4.2 The Principle of Ecology

"***Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them***".

The second principle of organic agriculture asserts that it should be "based on living ecological systems and cycles, work with them, emulate them, and help sustain them." This principle roots organic agriculture within living ecological systems. It states that production should be based on ecological processes, and recycling. It emphasizes that nourishment and well-being are achieved by aligning production practices with the ecology of the specific environment. For crops, this means recognizing the significance of the living soil; for animals, it involves considering the broader farm ecosystem; and for fish and marine organisms, it requires understanding and respecting the aquatic environment. The principle underscores the importance of organic farming, pastoral practices, and wild harvest systems harmonizing with the cycles and ecological balances present in nature. While these cycles are universal, their operation is site-specific, necessitating that organic management be adapted to local conditions, ecology, culture, and scale.

To reduce inputs, organic agriculture promotes practices such as reuse, recycling, and efficient management of materials and energy, aiming to maintain and improve environmental quality while conserving resources. Ecological balance is a key goal, achieved through the thoughtful design of farming systems, the establishment of habitats, and the preservation of genetic and agricultural diversity. Furthermore, the principle emphasizes the collective responsibility of those involved in producing, processing, trading, or consuming organic products to protect and enhance the common environment, encompassing landscapes, climate, habitats, biodiversity, air, and water.

2.4.3 The Principle of Fairness

"*Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities*".

The third principle of organic agriculture underscores that it "should build on relationships that ensure fairness with regard to the common environment and life opportunities." Fairness, in this context, is defined by equity, respect, justice, and stewardship of the shared world, encompassing human relationships and interactions with other living beings. This principle asserts that all participants in organic agriculture, including farmers, workers, processors, distributors, traders, and consumers, should engage in human relationships that prioritize fairness at every level. It emphasizes providing everyone involved with a good quality of life, contributing to food sovereignty, and addressing the reduction of poverty. The overarching goal is to produce a sufficient supply of high-quality food and other products.

Furthermore, the principle insists on treating animals in a manner that aligns with their physiology, natural behaviour, and overall well-being. The management of natural and environmental resources used for production and consumption should adhere to principles of social and ecological justice and be held in trust for future generations. To achieve fairness, systems of production, distribution, and trade within organic agriculture should be open, equitable, and account for real environmental and social costs. The fundamental conditions for achieving social justice are summarised as follows:

- Prohibition of Child Labour and Forced Labour: The employment of children is not allowed, and forced labour is strictly prohibited.
- Respect for Human Rights and Social Justice: Production processes that violate human rights and involve clear cases of social injustice are not permitted.
- Workers' Right to Participation: Labour administration must allow workers to participate in unions, political activities, or other forms of popular participation.
- Equality in Employment Opportunities: Equality between workers is emphasized, ensuring that job opportunities are offered without discrimination based on gender, religion, or any other factors.

These fundamental conditions reflect a commitment to creating a social environment within organic agriculture that upholds principles of justice, equality, and respect for human rights. Thus, we must seek to establish a framework where all individuals involved in the organic production process, from workers to communities, are treated fairly and ethically.

2.4.4 The Principle of Care

"*Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment*".

The fourth principle of organic agriculture emphasizes that it "should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment." Recognizing organic agriculture as a living and dynamic system that responds to both internal and external demands, practitioners are encouraged to enhance efficiency and productivity. However, this should not come at the expense of jeopardizing health and well-being. The principle underscores the need for a cautious and responsible approach in managing, developing, and choosing technologies in organic agriculture. Due to the incomplete understanding of ecosystems and agriculture, careful consideration must be given to new technologies, and existing methods should be subject to regular review.

While science plays a crucial role in ensuring that organic agriculture remains healthy, safe, and ecologically sound, the principle acknowledges that scientific knowledge alone is insufficient. Practical experience, accumulated wisdom, and traditional and indigenous knowledge provide valuable solutions tested by time. To prevent significant risks, organic agriculture should adopt appropriate technologies and reject unpredictable ones, such as genetic engineering. Decision-making processes should be transparent and participatory, reflecting the values and needs of all stakeholders who might be affected. This approach ensures that the management of organic agriculture prioritizes the well-being of current and future generations and the environment.

2.5 Conversion From Conventional Agriculture to Organic Agriculture

In the past, many farmers relied on conventional agriculture methods and practices, commonly employing multiple cropping and intercropping with a variety of food crops on the same farm. This approach helped prevent the occurrence of plant disease epidemics or insect pest outbreaks. However, with the shift from conventional to modern intensive agriculture, characterized by large-scale mono-crop cultivation and greenhouse farming, there has been an increased reliance on chemical fertilizers and pesticides to combat insect pests due to the outbreak of some insect pests.

Due to the increase in soil problems and pests, some believe that increasing the doses or quantities of chemical fertilizers and pesticides is necessary to maintain high crop production. However, in such cases, production did not achieve any improvement because of the sharp deterioration in soil fertility. Pest problems also became more severe over time, necessitating increased use of chemical pesticides. Consequently, this led to the pollution of agricultural soil and its loss of fertility in areas that follow such methods and practices.

The intensification of chemical use is often considered necessary to maintain high crop production, particularly in countries like the United States of America. Unfortunately, this strategy has not yielded improvements in crop production; instead, it has led to a significant decline in soil fertility due to escalating soil problems and pest issues. Over time, the severity of pest problems has risen, necessitating even greater use of chemical pesticides. Consequently, agricultural soil has become polluted, resulting in a loss of fertility in areas employing such methods and practices.

Generally, several fundamental steps must be followed for a successful conversion from conventional agriculture to organic agriculture. These steps include:

- Soil Health Assessment: Conduct a comprehensive assessment of soil health, examining factors such as soil structure, nutrient levels, and microbial activity to understand the current state of the soil.
- Crop Rotation and Diversification: Implement crop rotation and diversification to break the cycle of pests and diseases, maintaining soil fertility, preventing erosion, and reducing reliance on chemical inputs.
- Cover Cropping: Introduce cover crops during fallow periods to protect and enhance soil fertility, contributing organic matter, improving water retention, and suppressing weeds.
- Compost and Organic Amendments: Replace chemical fertilizers with organic amendments like compost, manure, and green manure to improve soil structure and microbial activity.
- Integrated Pest Management (IPM): Adopt Integrated Pest Management (IPM) strategies, using beneficial insects, crop rotation, and companion planting to control pests and diseases.
- Weed Management: Implement weed management practices without synthetic herbicides, employing mechanical methods like mulching and hand weeding.
- Transition Period: Acknowledge the transition period from conventional to organic farming, adhering to organic practices without using prohibited synthetic inputs.
- Education and Training: Provide education and training on organic farming practices for farm workers and management to ensure a clear understanding of organic principles and techniques.
- Certification Process: Engage in the certification process if planning to market products as organic, meeting standards set by certification bodies, demonstrating compliance, and undergoing regular inspections.
- Record Keeping: Maintain detailed records of farming practices and inputs used, essential for the certification process and tracking the farm's progress.
- Market Research: Conduct market research to understand the demand for organic products, identifying potential markets and consumers interested in organic produce.
- Patience and Commitment: Recognize that the transition to organic farming is a gradual process requiring patience and commitment, as the benefits may take time to manifest.

By following these foundational steps, farmers can successfully transition from conventional agriculture to organic agriculture, promoting sustainability and environmentally friendly farming.

2.5.1 Conversion Period

The organic agriculture system requires the development of nutrient-rich, fertile soil free from chemical pollutants or residues. Achieving this goal involves a crucial phase known as the "Conversion Period," during which the transition from conventional or traditional to organic production takes place. While this period may not be sufficient to fully enhance soil fertility and restore environmental balance, it marks the initiation of all the prerequisites of organic agriculture.

The Conversion Period marks the initiation of all requirements of organic agriculture. It entails adhering to specific standards and regulations governing organic production systems and methods. During this period, farmers commit to practices that comply with the standards of organic agriculture, demonstrating discipline and organization in implementing legal requirements and labelling protocols.

Organic standards and regulations not only prohibit the use of synthetic fertilizers and chemical pesticides but also promote various agricultural practices aimed at ensuring sustainable production on the farm. The duration of the Conversion Period varies based on factors such as previous land use and the environmental condition of the farm undergoing conversion. In essence, the Conversion Period serves as a critical transition phase where farmers embrace organic principles and practices, laying the groundwork for sustainable and environmentally friendly agricultural production.

The conversion process is a critical phase that necessitates oversight from a Certification Body, an inspection entity responsible for granting certificates of organic agriculture to the farm and its products. This Certification Body plays a crucial role in ensuring that the conversion adheres to organic standards and practices.

It is noteworthy that when determining the conversion period, it is advisable to establish a specific timeframe from the last date on which any prohibited substance or practice was utilized in organic farming. This recommendation emphasizes the commitment to transitioning away from conventional methods and substances, aligning with the principles of organic agriculture. The precision in defining this period adds transparency to the conversion process and underscores the dedication to adopting organic practices that promote environmental sustainability and soil health.

In general, arable crops are eligible for organic certification if they adhere to the standards and regulations of organic farming for a minimum period of 24 months before the commencement of the production cycle. Conversely, permanent crops, such as fruit trees, can be certified as organic if the farm management regulations and standards have been implemented organically for at least 36 months before production begins.

It is important to note that the conversion period may be adjusted by the inspection and certification body based on environmental conditions and the prior use of the land. For instance, the conversion period may be reduced to 12 months for virgin lands that have not been previously cultivated. The "Certification Body" also has the authority to permit the sale of plant products under the label "Organic Agriculture Product during the Conversion Period" if the specified conditions are met for a duration of no less than 12 months, as detailed in Table 2.2.

Table 2.2. Conversion Period from Conventional to Organic Agriculture.

Farm	Conversion Period to Organic Agriculture (Months)	
	Arable Crops (Vegetables)	Permanent Crops (Fruit trees)
Planted	24	36
Virgin	12	24

2.5.2. Conversion Phases

Before embarking on the conversion from conventional to organic agriculture, farmers must address a series of questions with care and impartiality. These questions are crucial in assessing the feasibility and understanding of the conversion process to organic agriculture. Generally, the conversion involves several phases, which can be categorized into three consecutive phases:

2.5.2.1 Preparation Phase

There is a fundamental difference between farmers' behaviour and understanding of ways to solve agricultural problems in conventional agriculture compared to organic agriculture. In conventional agriculture, addressing agricultural problems involves relying on specific inputs to achieve a good crop in terms of quantity and quality. Problem-solving follows a linear path by identifying precise problem limits and prescribing treatments, mainly with chemical inputs.

In contrast, organic agriculture is based on biological thinking, requiring a deep understanding and linking of everything to nature, the environment, and its variables. This approach necessitates thorough and comprehensive preparations for all agricultural activities and materials permitted in accordance with national or international standards for organic agriculture.

A crucial aspect of the preparation phase involves establishing a detailed and masterful system for documenting all agricultural processes and methods used. During this phase, several key points should be considered, and important studies conducted, along with meticulous data compilation. These considerations include:

- Choose the Location of the Organic Farm

Ensure that the selected site for conversion and the implementation of organic agriculture systems is suitable by carefully examining the following points:

  » Soil quality and fertility.
  » The quality and availability of irrigation water on the farm, considering its salinity.
  » The availability of compost inputs from plant and animal residues.
  » The types of pests and diseases prevalent in the surrounding areas, along with the quality and extent of grass spread in the region.

- Prepare Detailed Maps of the Farm

Create comprehensive maps of the farm for inspection purposes by the certification body, providing detailed information about the areas intended for conversion to organic agriculture. Clearly outline which parts or units of the farm will continue to use traditional farming systems if specific areas are converted to organic agriculture.

- Prepare a Historical Record of the Farm

This includes compile data on the size and topography of the farm, its previous crops production and quality systems, the prevalent climate and infrastructure of the farm or region, and all chemical transactions conducted on the farm during the three years leading up to the decision to transition to organic agriculture.

- Prepare a Comprehensive Plan for the Conversion to Organic Agriculture

This plan must include the following points:

» Choosing Crops and Species: Focus on disease-resistant species, if possible.

» Determining Seed Sources: Seeds, seedlings, or tubers used must be from organic sources. Coordination with the organic certification body is required for approval if organic sources are not available. Use of genetically modified seeds and plant materials is not allowed.

» Fertilization Program: Develop a comprehensive plan to maintain and enhance soil fertility. Evaluate the availability of plant and animal residues for compost preparation and establish suitable storage methods. Ensure that compost is stored in appropriate areas to shield it from the sun and maintain hydration, avoiding excessive wetness.

» Crop Rotation: Preparing a suitable crop rotation, for vegetable and field crops. Avoid growing crops from the same family consecutively, for example: not to grow potatoes after tomatoes and vice versa.

» Plant Protection Plan: Develop a comprehensive plan for pest control, including methods like crop rotation, mulching, mixed cropping, and the use of certified biopesticides produced in accordance with organic agriculture standards.

» Isolation or Separation of the Organic Agriculture Unit: If a specific part of the farm is converted to organic agriculture, ensure the isolation or separation of the organic agriculture unit, although this is not usually recommended. However, when this happens, organic products must be isolated from traditional farming products, noting that it is not allowed to grow the same crop or type of plants at the same time in both the part of the farm designated for organic agriculture and the other designated for conventional agriculture.

» Trading and Marketing Plan: Develop a plan for the trading and marketing of organic products. Store organic products separately from traditional farming products and establish a market for organic products.

» Documentation: Implement comprehensive models to document all activities on the organic farm. Document dates for all agricultural operations, including cultivation, fertilizer use, pest and disease prevention, and treatment dates. Finally, quantities and quality for each organic crop.

» Selecting the Organic Certification Body: Choose the organic certification body and enter a specific contract with them. Under this contract, the certification body will issue a certificate for the farm's products, indicating their organic nature. A label will be placed on these products showing the name of the certification body. The certification body conducts the initial inspection of the farm after completing the preparation phase for the transition to organic agriculture. All activities, methods, and plans to be used are discussed during this inspection to ensure that they comply with local or international organic agriculture standards and regulations.

2.5.2.2 Implementation Phase

The process of conversion to organic agriculture requires fundamental or radical changes at the farm level, particularly in the soil, as healthy and fertile soils are the basis or key to the organic farming system. Here, the focus of farm management must be on maintaining and improving soil fertility and maintaining its vitality and microorganisms. Additionally, attention must be given to fostering biodiversity and supporting insect natural enemies such as predators and parasites on the farm.

During the implementation phase, various methods to improve soil fertility and pest control must be tested, recognizing that not all methods will work successfully on every farm. Livestock production is crucial during this phase as it helps produce compost in sufficient quantities. Organic fertilizer, a key component of organic agriculture, is created through composting. Using hay, straw, or other plant materials as animal bedding can enhance the quality of compost by retaining animal urine. It is important to ensure that the plant materials used are sourced from organic farms or those free from chemical treatments like pesticides and herbicides.

In the realm of pest control, certain plants possess insect-repellent qualities, and others can serve as attracts for the natural enemies of pests. These companion plants can be strategically grown between main crops in organic farms, a topic to be discussed later. In situations where standard agricultural practices prove inadequate for pest control, biological control methods become invaluable. Mass production of predators and parasites, or their introduction and subsequent release into organic farms, is particularly beneficial for managing various pests such as thrips, whiteflies, aphids, scale insects, and mites, especially in greenhouse crops.

2.5.2.3 Consolidation Phase

The consolidation phase signifies full integration into the organic agriculture system. During this phase, the primary focus is on precisely and conclusively modifying all processes implemented in organic agriculture. It is essential to acknowledge that additional research and experiments are necessary, particularly on traditional methods that have not been utilized, for potential future incorporation into organic agriculture practices.

2.5.3 Barriers to Conversion to Organic Agriculture

Despite the growth and prevalence of organic agriculture in developed countries, its adoption remains limited in many developing nations. Several reasons contribute to this limitation, which can be summarised as follows:

- **Insufficient Knowledge:** Lack of understanding on how to transition from traditional to organic agriculture.
- **Lack of Expertise:** The shortage of technical staff knowledgeable about organic agriculture poses a critical barrier. Convincing farmers about the benefits and providing guidance during the conversion period requires expertise and trust. Without knowledgeable support, farmers may hesitate due to uncertainty about the transition process, potential yields, and market access. Addressing this shortage through training programs, workshops, and partnerships between agricultural institutions and farmers could help bridge this gap and encourage more widespread adoption of organic farming practices.
- **Limited Research:** Inadequate research on organic agriculture tailored to the unique environmental conditions of each country.
- **Government Support:** The lack of government support for farmers transitioning to organic agriculture is a significant challenge. It often involves higher initial costs and changes in farming practices that require support and encouragement. Without incentives or assistance from agricultural ministries, farmers may be reluctant to make the switch despite potential long-term benefits for sustainability and health. This issue underscores the need for policies that promote and facilitate sustainable farming practices.
- **Private Sector Involvement:** Insufficient participation from the private sector in promoting organic agriculture, potentially due to a lack of information regarding its benefits and economic, environmental, and social significance. This lack of information is, in turn, linked to a shortage of technical staff to advocate for organic agriculture practices.

Addressing these barriers requires comprehensive efforts, including education, research, government support, and collaboration between various stakeholders in the agricultural sector.

2.6 Environmental Benefits of Organic Agriculture

Organic agriculture offers several environmental advantages, contributing to sustainable and eco-friendly farming practices. Here are key environmental benefits associated with organic farming.

2.6.1 Climate Change

Carbon dioxide (CO_2) resulting from the burning of fuels is one of the most significant pollutants introduced by humans into the air. CO_2 is formed when organic materials such as coal, wood, paper, and petroleum oil are burned. Undoubtedly, the excessive use of fuel and deforestation, leading to a reduction in green areas on the planet (Desertification), has contributed to the high levels of CO_2 gas in the atmosphere. This, in turn, has led to a rise in the global temperature of the planet, known as the Global Warming phenomenon.

The Food and Agriculture Organization of the United Nations (FAO) has indicated that improved agricultural practices can contribute to the storage of a proportion of carbon from the atmosphere generated by human-induced emissions. The key to this lies in increasing the amount of plant materials in the soil, thus absorbing larger amounts of carbon dioxide from the atmosphere and converting it into plant materials consisting mainly of carbon, a process known as carbon capture and sequestration. "Humus" is known to be the key to soil fertility and is a product of the decomposition of dead plant and animal remains by microorganisms.

The low levels of humus in soils around the world have led to the emission of billions of tons of carbon dioxide into the air, making traditional agriculture one of the largest contributors to global warming. This contributes to the warming of the global surface temperature and the occurrence of the so-called climate change.

Adrian (2006) stated that a 22-year study at the Rodale Institute in the USA showed that organic agriculture had reduced CO2 emissions from the soil. Organic agriculture had increased soil organic matter by 15-28 %, the equivalent of locking up over 1.5 tons of CO2 per hectare. This would mean that if only 10,000 medium-sized farms in a country transitioned to organic production, the carbon that would accumulate in their soil would be the equivalent of taking over 1 million cars off the roads. Additionally, the physicist Amory Lovins estimates that by simply increasing organic matter in the world's most depleted soils, this would absorb as much carbon as all human activity emits, as the soil acts as a reservoir for precipitating carbon dioxide (CO_2) from the atmosphere.

In fact, organic agriculture contributes to controlling climate change by reducing the emission of greenhouse gases (GHGs) from both greenhouses and open farms. These gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Organic agriculture systems emit significantly smaller quantities of these three gases compared to conventional agriculture.

Research indicates that carbon dioxide (CO_2) emissions per hectare from organic agriculture systems are 48 to 66 % lower than those from conventional systems. A study by Haas and Köpke (1994a) calculated (CO_2) emissions from organic agriculture in Germany. They found that a hectare of organic agriculture emits 0.5 tons of carbon dioxide (CO_2), whereas a hectare of conventional agriculture emits 1.3 tons of carbon dioxide (CO_2), representing an estimated increase of 61.5 %.

Similar results have been observed for nitrogenous products and methane. According to studies by Haas and Köpke (1994b) and Stolze *et al*. (2000), the substantial difference in carbon dioxide emissions between organic and conventional agriculture can be attributed to the following factors:

- In organic agriculture, soil fertility is sustained and enhanced using compost, while the application of synthetic fertilizers and pesticides is prohibited. This practice increases the proportion of organic matter (humus) in the soil. The microorganisms responsible for breaking down humus exhibit a ratio of 30 parts carbon to one part nitrogen. Numerous field experiments have demonstrated that organic fertilizers, when compared to mineral fertilizers, lead to an increase in soil organic carbon. Consequently, substantial amounts of carbon dioxide from the atmosphere are absorbed into the soil.
- Organic agriculture attributes nearly 70 % of its CO_2 emissions to fuel consumption and machinery production. In contrast, conventional systems allocate 75 % of CO_2 emissions to N-fertilizers, feedstuff, and fuels (Hass *et al*., 1995).
- Organic agriculture diminishes the reliance on non-renewable energy by minimizing agrochemical needs, as these typically entail substantial fuel consumption. Moreover, organic agriculture plays a role in alleviating the impacts of global warming by enhancing its capacity to absorb carbon into the soil.

- Appropriate management practices in organic agriculture, such as minimizing tillage and incorporating nitrogen-fixing leguminous plants, contribute to the creation of carbon sinks. This enhances productivity and creates favourable conditions for carbon storage in the soil.

2.6.2 Organic Agriculture and Biodiversity

Stolze *et al*. (2000) demonstrate that flora and fauna biodiversity on organic land is higher than on conventional land. Due to the ban on synthetic pesticides and nitrogen fertilizers, organic farms create conditions that positively impact wildlife and contribute to landscape conservation. At the farm level, organic agriculture can enhance habitat diversity by providing a wide range of niche habitats, breeding opportunities, and a better food supply. Research conducted in Europe and the United States indicates that organic agriculture promotes increased biodiversity, including a rise in the populations of insects, birds, and beneficial microorganisms within and around the farm.

Pfiffner *et al*. (2001), in a review of 44 research studies involving 55 farms, demonstrated that biodiversity, as well as the numerical abundance of different species, increased in 49 farms. Organic agriculture was found to maintain and increase the number of insects that play a role in pollinating plants. Table 2.3. illustrates the impact of organic agriculture on biodiversity by comparing the effects of organic (ORG) and conventional (CON) agriculture on fauna, based on a review of 44 research studies conducted in Europe and the USA (on-farm and plot trials). It is worth noting that the Bio Suisse standard in Switzerland stipulates that areas designated to promote biodiversity must constitute at least 7 % of the total area of an organic farm.

Table 2.3. Effects of Organic (ORG) and Conventional (CON) Agriculture on Fauna (Review of 44 Research Studies Involving 55 Farms Worldwide).

Group	Abundance (Number of Individuals)			Species Diversity (Number of Species)		
	ORG > CON	ORG = CON	ORG < CON	ORG > CON	ORG = CON	ORG < CON
Earthworms	17	1	0	4	3	0
Carabids	13	2	0	6	2	0
Spiders	6	1	0	0	0	0
Birds	5	0	0	2	0	0
Diplopoda	4	0	0	1	1	0
Bugs	2	1	0	1	1	0
Mites	2	0	1	1	0	0
Total	**49**	**5**	**1**	**15**	**7**	**0**

2.6.3 Organic Agriculture and Genetically Modified Organisms (GMOs)

It is important to acknowledge that the use of Genetically Modified Organisms (GMOs) carries economic benefits. According to Christou *et al*. (2006), in the United States of America in 2003, six Genetically Modified (GM) crops, i.e. canola, corn, cotton, papaya, zucchini, and soybeans, contributed to the production of 2.4 million tons of food and fibbers. This resulted in a boost in farm incomes by approximately 1.9 billion US dollars. Moreover, the adoption of these GM crops led to a reduction in pesticide usage by an estimated 21 thousand tons. Shelton *et al*. (2002) further noted that the use of GM cotton significantly decreased insecticide usage in both developed and developing countries, accompanied by a notable increase in returns and profitability.

Despite the mentioned benefits, it is important to note that the use of Genetically Modified Organisms (GMOs) is prohibited in organic agriculture systems throughout all stages of organic food production. Since the potential side effects of GMOs on the environment and human health are not yet fully understood, organic agriculture adopts a precautionary approach, prohibiting the use of

GMOs not only in the European Union but also in many countries worldwide. Additionally, organic certification documents must confirm that GMOs have not been intentionally used in the production and manufacturing of these organic products.

On October 19, 1998, during the 12th Scientific Conference of the International Federation of Organic Agriculture Movements (IFOAM) in Argentina, participants issued the Mar del Plata Declaration. Over 600 delegates from more than 60 countries unanimously voted to exclude the use of Genetically Modified Organisms (GMOs) in food production and agriculture. Since then, GMOs have been categorically excluded from organic agriculture. The declaration issued by the conference stated the following:

We, the undersigned participants at the 12th Scientific Conference of the International Federation of Organic Agriculture Movements (IFOAM) in Mar del Plata, Argentina, call on governments and regulatory agencies throughout the world to immediately ban the use of genetic engineering in agriculture and food production since it involves:

- **Unacceptable threats to human health.**
- **Negative and irreversible environmental impacts.**
- **Release of organisms of an un-recallable nature.**
- **Removal of the right of choice, for both farmers and consumers.**
- **Violation of farmers' fundamental property rights and endangerment of their economic independence.**
- **Practices, which are incompatible with the principles of sustainable agriculture as defined by IFOAM.**

Moreover, during the IFOAM meeting in New Delhi, India, on November 12, 2017, a strong stance was taken, reiterating that Genetically Modified Organisms (GMOs) obtained through modern genetic engineering techniques have no place in organic food production systems and organic agriculture. The participants affirmed their commitment to consumers, pledging to exclude GMOs from organic production systems.

2.6.4 Organic Agriculture and Water Pollution

The contamination of groundwater with fertilizers and chemical pesticides poses a significant challenge in many agricultural areas. Organic agriculture, which prohibits the use of these substances, eliminates the risk of pesticides and chemicals seeping into groundwater. Furthermore, nitrate leakage rates are markedly lower in organic agriculture compared to conventional agriculture. Well-managed organic agriculture systems, with their enhanced nutrient retention capacity, contribute significantly to reducing the risk of groundwater contamination. Numerous studies conducted by scientists across different regions consistently demonstrate a substantial and noticeable decrease in nitrate leaching into terrestrial water in organic agriculture, as highlighted in Table 2.4.

Table 2.4. Nitrate Leaching Rates per Hectare from Organic Farming Compared to Conventional Farming Systems.

Reduction of Nitrate Leaching Rates in Organic Farming Compared to Conventional Farming	Authors
> 50 %	Smilde (1989)
> 50 %	Verejken (1990)
57 %	Paffrath (1994)
40 %	Blume et al., (1993)
50 %	Reitmayr (1995)
40 %	Berg et al., (1997)
64 %	Haas (1997)

2.7 Regulations or Standards of Organic Agriculture

As previously mentioned, organic agriculture constitutes an integrated agricultural system encompassing the entire process from the cultivation of seeds or seedlings to the delivery of organic products to the end consumer. This comprehensive system includes the production, preparation, processing, distribution, and marketing of organic products, all regulated by local or international standards and regulations. Given the diverse environmental conditions in different states and regions, it is imperative to establish organic agriculture systems and regulations tailored to the specific needs of each locality. Therefore, regional organizations must establish appropriate frameworks and oversight mechanisms for organic agriculture in each state or region, which may involve standards and controls that are more stringent than the minimum requirements set by the International Federation of Organic Agriculture Movements (IFOAM).

With the significant rise in demand for organic products and their higher prices compared to conventional ones, measures were needed to protect consumers who purchase products labelled as organic. To regulate the process of labelling and ensure its legitimacy, standards and regulations for producing organic products were deemed essential. These regulations aim to prevent any unauthorized individuals or entities from labelling or marketing a product as organic unless it meets specific criteria. To promote the export of organic products and incentivize farmers and companies to engage in this sector, the Organization for Economic Co-operation and Development (OECD) established regulations governing organic agriculture on June 24, 1991. These regulations, outlined in Regulation No. (EU 2092/91), represent one of the earliest standards for organic agriculture. Over time, these regulations have been regularly updated, with the latest revision occurring in 2007 under Regulation (EC) No. 834/2007, complemented by its executive regulations in 2008 under Regulation (EC) No. 889/2008. These regulations and their amendments are consistently renewed and enforced for all organic products entering the European market.

Furthermore, various countries have established their own regulations and standards for organic agriculture. Examples include the **N**ational **O**rganic **P**rogram of the United States of America (**NOP**) and the **J**apanese **A**gricultural **S**tandard (**JAS**). Many other countries, including Australia, Bulgaria, Canada, Switzerland, Sweden, Denmark, China, India, Ireland, and New Zealand, have also implemented specific regulations or standards for organic agriculture. Additionally, some countries, like Tunisia, Turkey, and Egypt, have regulations equivalent to European standards. They have established offices for the registration and certification of organic agricultural products, enabling local marketing or export of these products internationally.

It is essential to note that most regulations or standards for organic agriculture cover fundamental principles that must be followed. These include considerations related to the location of the farm, the surrounding areas, and their impact on the farm plants. The regulations also specify the duration required for the transition from traditional to organic agriculture. This conversion period typically should not be less than two years for arable crops, such as vegetable crops and field crops, and not less than three years for permanent crops, such as fruit trees.

Additionally, these regulations outline principles for enhancing soil fertility and bioactivity. This involves practices such as cultivating legumes and green fertilizers, incorporating deep-rooted plants into crop rotations, and utilizing animal manure and plant residues for organic fertilizer, specifically in the form of compost. The regulations also mandate the use of microorganism preparations, as specified in these standards. Furthermore, they provide guidelines for pest, disease, and weed control. The regulations detail the permissible methods for manufacturing organic products, how these products can be traded post-harvest, and the rules governing their transportation between locations or countries. Here, we will review into some of these regulations that govern organic agriculture worldwide.

2.7.1 European Organic Regulations

European regulations governing organic agriculture are among the oldest and most renowned standards overseeing the production and distribution of organic products. On June 24, 1991, the Organization for European Economic Co-operation (OEEC) established the regulations for organic agriculture under Regulation No. (EU 2092/91). Over the years, numerous amendments have been introduced to these regulations. On June 28, 2007, the OEEC updated the regulations and issued Regulation No. 834/2007. Subsequently, on September 5, 2008, the executive regulations of organic agriculture, Regulation No. 889/2008, were issued. These regulations were effectively implemented in January 2009, replacing Regulation No. (EU 2092/91). The European Regulations for organic agriculture are based on many fundamental principles and rules that must be followed for the production, processing, and distribution of organic products. These regulations, rules, or standards include the following:

- Establishing a General Framework: The regulations create a general framework for rules regulating the production, labelling, and control of organic products. This framework ensures protection for organic agriculture and those involved in organic production. It also promotes fair competition among producers of labelled products and ensures market transparency at all stages of production and manufacturing. Ultimately, this contributes to enhancing consumer confidence in these products and improving their perception.
- Incorporating Organic Information: Given that organic agriculture involves distinctive production methods at the farm level, it is crucial to convey this information on the product labels. This involves explicitly stating that the components were cultivated using organic agricultural practices and that the overall production adheres to established organic agriculture rules and regulations.
- Applying Minimum Organic Regulations: Since both producers and consumers are interested in products labelled as organic, it is imperative to apply minimum organic regulations and rules. This ensures that these products align with the established standards associated with existing labels.
- Restrictions on Fertilizers and Pesticides: Organic production systems must incorporate well-defined and explicit restrictions on the use of fertilizers and pesticides known for their adverse environmental effects or for leaving residues in agricultural products.
- Defining Agricultural Processes: As organic agriculture encompasses diverse agricultural processes and restricts the use of synthetic fertilizers and slow-release soil amendments, it is essential to define these processes and outline conditions for the use of specific unprocessed materials.

2.7.2 National Organic Program of the USA (NOP)

The **N**ational **O**rganic **P**rogram (**NOP**) regulates the production and distribution of organic products in the United States, closely aligning with European regulations. This program addresses both the microbiological and chemical safety of organic products. Key features of the NOP include:

- Transition Period: The transition period from conventional to organic agriculture is set at 36 months for both perennial crops (e.g. fruit trees) and seasonal crops (e.g. vegetable crops).
- Labelling Requirements: The program specifies that organic products must bear the label "100 % organic" to ensure clarity and consumer trust, rather than just "organic".

2.7.3 Japanese Agricultural Standard (JAS)

The **J**apanese **A**gricultural **S**tandard (**JAS**) regulates the standards for the production and distribution of organic products in Japan. Issued by the Japanese Ministry of Agriculture, Forestry, and Fisheries (MAFF) on January 20, 2000, and introduced in April 2001, this standard closely mirrors European regulations and the U.S. organic agriculture program. Notably, it elevates the management and product quality system to an advanced stage compared to the U.S. organic agriculture program. Key features of the JAS include:

- Responsibility: The JAS places the responsibility of adhering to these standards on both the producer and exporter.
- Grading Classification: It achieves this through the establishment of a JAS Grading classification manual, outlining the process of classifying products according to Japanese organic agriculture standards.
- Internal Inspections: The standard necessitates the appointment of a qualified team to conduct internal inspections during the stages of production, processing, and mobilization. This ensures the accurate implementation of organic regulations in accordance with the Japanese standard before labelling these products as organic.

2.8 Organic Certificates

When deciding to convert to organic agriculture, the farm manager or owner must initiate practical steps to obtain organic certificates for their agricultural products. The initial step involves registering the farm as an organic farm with one of the specialized and accredited inspection offices and certification bodies. These entities are dedicated to ensuring the implementation of organic farming regulations and standards by producers, manufacturers, and exporters of organic products. These specialized offices play a crucial role in the process by registering, inspecting, and ultimately issuing certificates that confirm the products were produced in accordance with organic agriculture regulations. These regulations may be based on standards from various regions, such as European, American, Japanese, or other applicable standards.

For instance, European states may accept the import of organic products from countries adhering to EU organic agriculture regulations. This certification process ensures that consumers receive authentic organic products, fostering trust and supporting the growth of the organic agriculture sector globally. For these specialized offices to carry out inspections and grant organic certificates, there must be accreditation bodies located in each country worldwide. These bodies are authorized to examine the operations of inspection offices and verify that they conform to the regulations and standards of organic agriculture. Each certification office is then granted a certificate from the International Organic Accreditation Service Ltd. (IOAS), which conforms to the requirements of "ISO 17065 - The Standard for Certification Bodies." This certification authorizes the office to carry out inspections and certifications for organic products, as well as the processing and export of organic products. Consequently, a contractual agreement must be established between the owner or manager of the organic farm and the inspection and certification body. This contract should include several key items, with the most important being:

- **Clarification of Regulations:** Detailed regulations must be applied at both the farm level and the factory where organic products are processed for either local consumption or export. Comprehensive information about the specific unit of the organic farm to which the certificate will be issued is essential. Additionally, regulations should address maintaining soil fertility, specifying inspection dates, and outlining crop rotation, including the types of plants and sources of seeds and seedlings.
- **Comprehensive Farm Records:** It is crucial to categorize various farm records, including those illustrating agricultural processes, sampling, contract renewals, and other pertinent items, to provide a comprehensive overview.

Maintaining various farm records is of paramount importance in organic agriculture. All agricultural operations must be accurately documented in these records, which must be made available to inspectors from the certification office. Among the crucial documents required on an organic farm are the registration request, farm map, approval requests from the inspection office (including authorization for specific fertilizers and plant protection materials), as well as sales records, various invoices, actual production quantities, and warehouse records. During inspections, inspectors check the following:

1. **Source of Seeds and Seedlings:** Verification of the origin and quality of seeds and seedlings used.
2. **Agricultural Plan:** Including crop rotation for arable crops.
3. **Farm Records:** Comprehensive records of all agricultural operations.
4. **Compost Source:** Ensuring the compost used complies with organic standards.
5. **Plant Protection Materials:** Approval and usage records.
6. **Irrigation Water Source:** Verification of the water source and its suitability for organic farming.
7. **Storage Procedures:** Proper storage of various materials.
8. **Farm Animal Production:** Inspection of animal husbandry practices, if applicable.

At the end of the inspection visit, the inspector compiles a detailed report on the organic agriculture unit, including the expected amount of organic production for each crop during the season. This report is then jointly signed by both the owner or farm manager and the inspector. Based on this report, the Accreditation Manager of the Office of Organic Certification grants approval to the farm and its products, designating them as organic.


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Chapter 3

3. Growth of Organic Agriculture

3.1 Distribution of Organic Agricultural Land Worldwide

The Research Institute of Organic Agriculture in Switzerland (FiBL) and the International Federation of Organic Agriculture Movements (IFOAM) annually prepare detailed statistical studies on organic agriculture worldwide. These collected data are published in a statistical book that provides insights into the growth of organic agriculture across all continents and countries, along with details on organic products in terms of their production and consumption globally.

The Research Institute of Organic Agriculture (FiBL), or Forschungsinstitut für Biologischen Landbau in German, was founded in 1973 and has been in Frick, Switzerland, since 1997. It stands as one of the world's leading research and information centres for organic agriculture, fostering close connections between various research areas and ensuring the rapid transfer of knowledge from research to consulting and practical applications in organic agriculture. FiBL actively participates in numerous international projects, contributing not only to research, consultancy, and training but also to development cooperation efforts.

According to the survey published by FiBL & IFOAM (2024) on organic agriculture worldwide, both organic agriculture land and organic retail sales continued to grow, reaching another all-time high by the end of 2022. Additionally, the most recent data from IFOAM – Organics International in 2022 reveals that 75 countries have effectively enacted comprehensive regulations governing organic agriculture. Furthermore, 19 countries have put in place organic regulations that are not yet fully enforced, and 14 countries are presently in the process of drafting legislation, as illustrated in Table 3.1.

On the other hand, the total global area of organic agriculture as of late 2022 was estimated to be about 96.4 million hectares, including areas undergoing the conversion period from traditional to organic agriculture. There has been an estimated increase of about 20.3 million hectares in the organic agriculture area in 2022 compared to 2021, reflecting a growth rate of about 26.6 %. In addition to organic agricultural land, there are additional organic areas such as wild collection areas, constituting approximately 35 million hectares.

A significant increase in organic agricultural land was recorded in several countries during 2022. In Australia, the increase in organic agricultural land was estimated at over 17.3 million hectares (representing about a 48.6 % increase). In India, almost 2.1 million hectares more were added (representing about a 77.8 % increase), and in Greece, there was an increase of almost 0.4 million hectares (representing about a 73.0 % increase). In summary, 79 countries witnessed an expansion of their organic agricultural land, whereas 42 countries reported a decrease. Additionally, the organic agricultural area in 40 countries either remained unchanged or had no new data available.

Table 3.1. Organic Regulations Worldwide by Region in 2022.

Continent	Drafting	Fully Implemented	Not fully Implemented	Total
Africa	5	1	4	10
Asia	7	11	10	28
Europe		41	2	43
Latin America & the Caribbean	2	16	3	21
North America		2		2
Oceania		4		4
Total	**14**	**75**	**19**	**108**

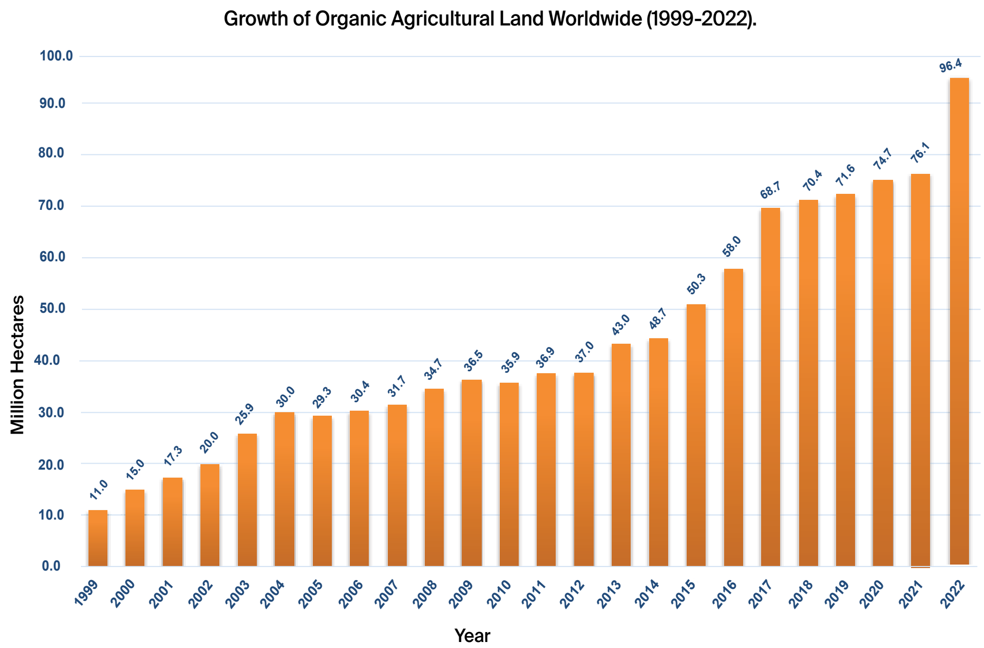
Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

In the statistics for organic agricultural land area published in 2024, covering data until the end of 2022, there was a notable increase in organic agricultural land across all continents. Oceania experienced the highest absolute and relative growth, with an estimated increase of 47.8 % (17.2 million hectares), followed by Asia with a growth of 35.9 % (2.3 million hectares) and North America with a growth of 10.7 % (0.35 million hectares).

In general, organic agriculture worldwide is experiencing rapid growth. In the early seventies, the cultivated area under the organic farming system was modest, estimated at about 1.15 million hectares. This area then increased to approximately 15 million hectares in 2000, further expanding to 20 million hectares in 2002. Since that year, the organic agricultural land area has seen significant growth, reaching about 96.4 million hectares at the end of 2022, thus it was nearly quintupling in 20 years.

Figure 3.1. illustrates the progression and expansion of global organic agricultural land areas from 1999 to the conclusion of 2022.

Figure 3.1. Growth of Organic Agricultural Land Worldwide (1999-2022).



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.2. illustrates the global distribution of organic agricultural land areas from 2015 to 2022. During this period, there was an increase in organic agricultural land across all continents. Notably, Oceania, including Australia, emerged as the leading continent in terms of organic agricultural land, where in 2015 the estimated area was approximately 22.8 million hectares, and by 2022, it had surged to about 53.2 million hectares.

The countries in the European continent ranked second in terms of the area of organic agricultural land. In 2015, the estimated area was about 12.7 million hectares, and by 2022, it had increased to 18.5 million hectares. Following this, the Latin American continent secured the third position, with the area of organic agricultural land reaching approximately 6.7 million hectares in 2015 and then increasing to about 9.5 million hectares in 2022.

In Asian continent countries, the area of organic agricultural land was estimated at about 4 million hectares in 2015, increasing to about 8.8 million hectares in 2022. Meanwhile, in North America, the area of organic agricultural land was estimated at about 3 million hectares in 2015, experiencing a modest increase to 3.6 million hectares in 2022. Lastly, the countries of the African continent had an estimated organic agricultural land area of about 1.7 million hectares in 2015, which then increased to about 2.7 million hectares in 2022. Figure 3.2. illustrates the percentage distribution of organic agricultural land across the continents of the world until the end of 2022.

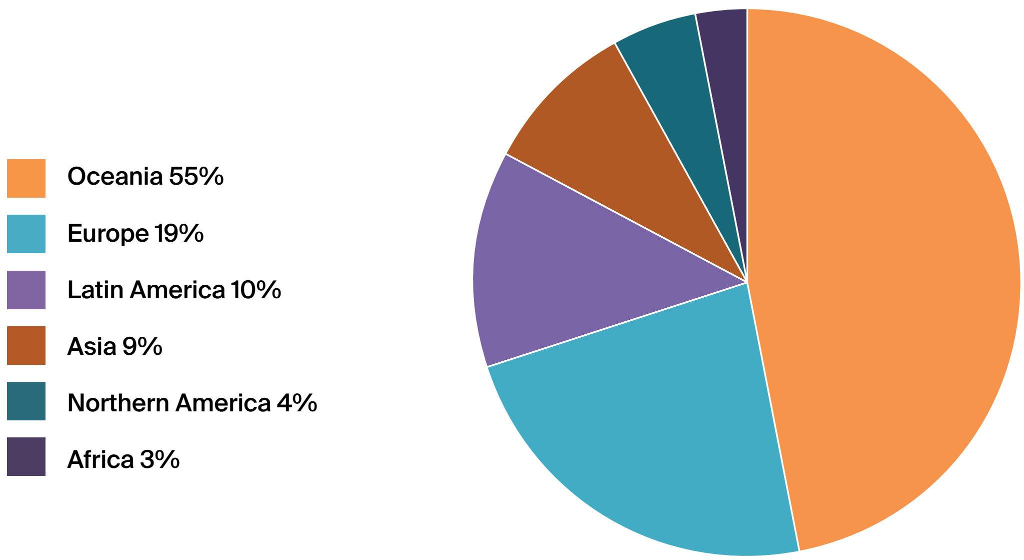
Table 3.2. Organic Agricultural Land Area Worldwide (2015-2022).

Continent	Organic Agricultural Land / (Million Hectares)							
	2015	2016	2017	2018	2019	2020	2021	2022
Oceania	22.8	27.4	5.9	36.0	36.0	36.0	36.0	53.2
Europe	12.7	13.5	14.4	15.6	16.5	17.1	18.2	18.5
Latin America	6.7	7.1	8.0	8.0	8.3	9.9	9.5	9.5
Asia	4.0	4.9	6.0	6.4	5.9	6.1	6.5	8.8
North America	3.0	3.1	3.2	3.3	3.6	3.7	3.3	3.6
Africa	1.7	1.8	2.0	1.9	2.0	2.3	2.6	2.7
Total	**50.9**	**57.8**	**69.5**	**71.2**	**72.3**	**75.1**	**76.1**	**96.4**

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Figure 3.2. Global Distribution of Organic Agricultural Land in 2022.

Global Distribution of Organic Agricultural Land in 2022.



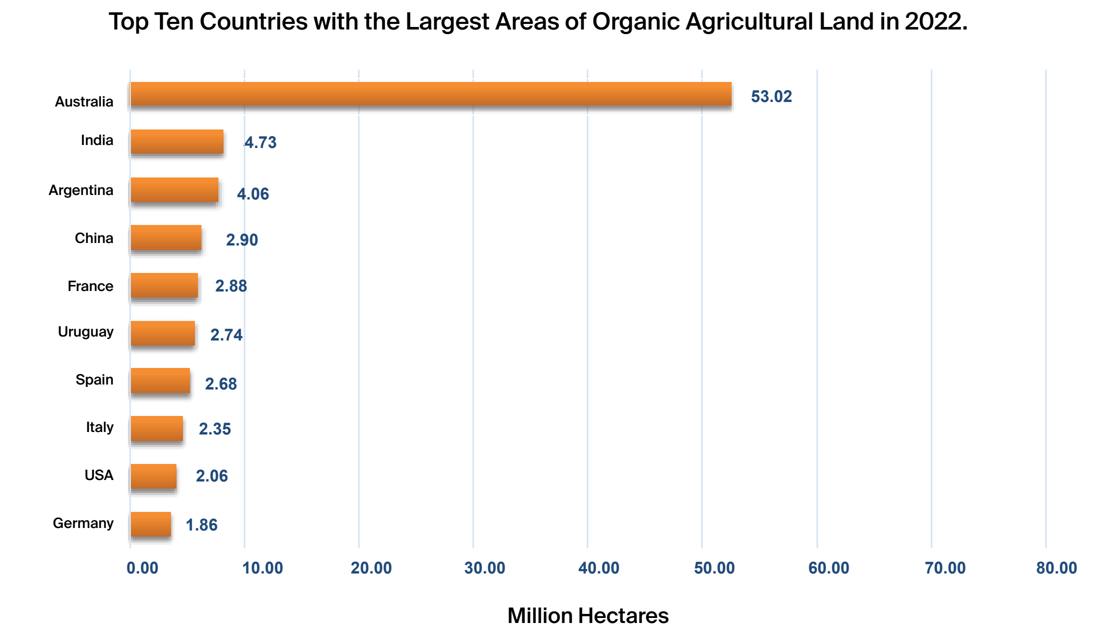
Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Figure 3.3. shows the ten countries with the largest organic agricultural areas, totalling 79.3 million hectares (82 % of the world's organic agricultural land).

Australia leads the list of countries with the largest area of organic agricultural land, estimated at 53.02 million hectares, followed by India with 4.73 million hectares, Argentina with 4.06 million hectares, China with 2.90 million hectares, and France with 2.88 million hectares. Uruguay follows with 2.74 million hectares, Spain with 2.68 million hectares, Italy with 2.35 million hectares, the United States of America with 2.06 million hectares, and Germany with 1.86 million hectares.

The global organic share of agricultural land was 2 % in 2022. The region with the highest organic share of total agricultural land was Oceania, accounting for 14.3 %, followed by Europe with 3.7 % and Latin America with 1.3 %. Within the European Union, the organic share of total agricultural land reached 10.4 %. In other regions, the share was less than 1 %.

Figure 3.3. Top Ten Countries with the Largest Areas of Organic Agricultural Land in 2022.



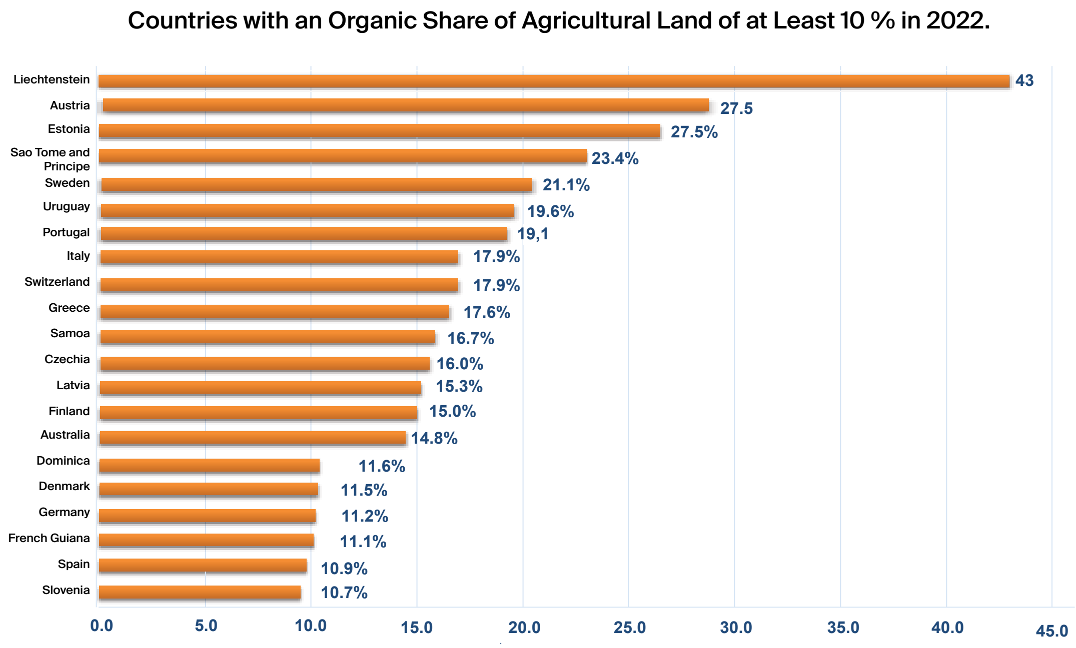
Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

In some countries, the proportion of organic agricultural land was significantly high. For example, it accounted for approximately 43 % in Liechtenstein, 27.5 % in Austria, 23.4 % in Estonia, and 21.1 % in Sao Tome and Principe. Moreover, there were 17 countries where the ratio of organic farmland area to their total agricultural land area exceeded 10 %, as shown in Figure 3.4.

There has been a notable global growth in organic agricultural land, with the area expanding from about 11 million hectares in 1999 to around 96.4 million hectares in 2022, as previously mentioned. In 2022 alone, there was an estimated increase of approximately 20.3 million hectares in organic agricultural land compared to 2021, indicating a growth rate of around 26.6%.

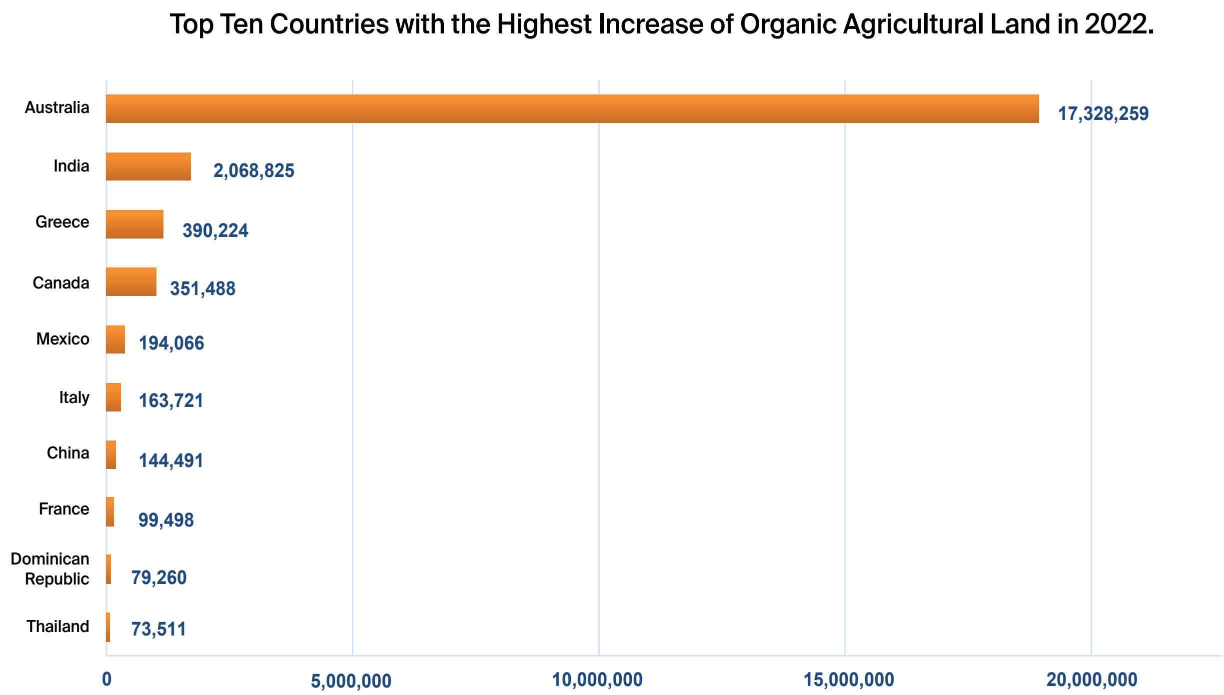
According to statistics conducted in 2022 and published in 2024 by FiBL & IFOAM – Organics International, many countries experienced a significant increase in organic agricultural land. Figure 3.5. illustrates the top ten countries with the highest increase in organic agricultural land in 2022.

Figure 3.4. Countries with an Organic Share of Agricultural Land of at Least 10 % in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Figure 3.5. Top Ten Countries with the Highest Increase of Organic Agricultural Land in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.2 Organic Producers Worldwide

Statistical studies until the end of 2022 indicate that the global number of organic producers stands at approximately 4.5 million. This marks an increase of nearly 919,000 producers, or 25.6 %, compared to 2021. These organic producers adhere to the principles of organic farming in the production of agricultural products. Notably, almost 93 % of these producers were distributed across Asia (60.6 %), Africa (21.7 %), and Europe (10.7 %). While Asia, Europe, and Oceania saw an increase in the number of organic producers, Africa, North America, and Latin America experienced a decrease in their organic producer numbers in 2022.

India leads the rankings in terms of the number of organic producers, boasting around 2.5 million, followed by Uganda with 404,246 organic producers, and Thailand with 121,540 organic producers. Table 3.3. outlines the top ten countries worldwide in terms of the number of organic producers, and Table 3.4. showcases the number of organic producers across continents from 2015 to the conclusion of 2022.

Table 3.3. Top Ten Countries with the Most Organic Producers in 2022.

Country	Number of Organic Producers
India	2,480,859
Uganda	404,246
Thailand	121,540
Ethiopia	121,480
Congo D.R.	118,203
Peru	107,868
Italy	82,593
Kenya	64,156
Madagascar	61,974
Tanzania	61,558

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.4. Distribution of Organic Producers by Region (2015 - 2022).

Region	Number of Organic Producers							
	2015	2016	2017	2018	2019	2020	2021	2022
Asia	851,016	1,108,040	1,231,159	1,307,220	1,589,490	1,811,209	1,782,125	2,782,678
Africa	719,720	741,367	806,877	786,808	850,490	968,233	1,034,043	975,334
Europe	349,261	373,240	397,146	419,019	430,742	417,987	446,529	480,135
Latin America	457,677	458,532	460,443	227,609	224,388	262,115	278,391	270,217
Northern America	19,138	18,422	22,966	20,008	22,153	22,448	24,361	23,948
Oceania	22,021	27,366	26,750	20,859	18,416	15,930	18,479	24,466
Total	**2,418,833**	**2,726,967**	**2,945,341**	**2,781,523**	**3,135,679**	**3,497,922**	**3,583,928**	**4,502,778**

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.3 Organic Agriculture in the Continents

3.3.1 Oceania Continent

This region includes Australia, New Zealand, and Pacific Island nations such as Fiji, Papua New Guinea, Tonga, Vanuatu, among others. In Oceania, over 53 million hectares of farmland were managed organically in 2022. The area of organic farmland in Oceania has increased more than tenfold since 2000, when it was only 5.3 million hectares. Oceania accounted for over 55 % of the world's organic farmland. Australia led with more than 53,016,000 hectares under organic management in 2022, followed by New Zealand (over 79,000 hectares), Samoa (over 47,000 hectares), and Papua New Guinea (nearly 20,000 hectares). Over 99.7 % of Oceania's organic farmland was in Australia.

Organic farmland in Oceania constituted 14.3 % of the continent's total agricultural land in 2022. Samoa had the highest share of organic area at 16.7 %, followed by Australia at 14.8 %, and the Solomon Islands at 6.5 %.

Organic farmland in Oceania experienced a notable increase of over 17 million hectares, or 47.8 %, from 2021 to 2022. From 2013 to 2022, Oceania's organic farmland grew by 207 %, significantly outpacing the global growth rate of organic farmland. This growth was primarily driven by substantial increases in Australia.

Nearly 99 % of the organic farmland in Oceania, equivalent to over 52,540,000 hectares, comprises permanent grassland or grazing land, primarily located in Australia. Only a small portion of the organic farmland, totalling 51,406 hectares, is allocated for arable crops. The main arable crop group in 2022 was cereals, covering 41,293 hectares. Permanent crops represented approximately 0.1 % of the total organic farmland in Oceania, with key crops including grapes (5,783 hectares), fruits (4,567 hectares), and coffee (2,770 hectares).

In Oceania, there were more than 24,400 organic producers, with the highest numbers in Papua New Guinea (18,984), followed by Samoa (1,857), and Australia (1,635). Oceania accounted for only 0.5 % of the world's organic producers. Compared to 2021, there was an increase of 5,987 organic producers, representing a 32% increase. Additionally, a total of 130 exporters and 1,756 processors were counted in the region.

The combined organic retail sales in Australia and New Zealand amounted to over €1.5 billion in 2022. Per capita consumption of organic food products in these two countries reached nearly €49 per person annually in 2022. The leading exporter in Oceania was New Zealand, exporting more than 29,400 metric tons of products, with over 46 % being apples and over 32 % being kiwis. Papua New Guinea followed, exporting almost 2,500 metric tons, primarily coffee, and Australia exported about 1,394 metric tons.

Comprising more than 13,675 metric tons and almost two-thirds of the organic exports from Oceania, temperate fruits (exclusively apples) were the most important product group, followed by tropical and subtropical fruits (9,472 metric tons, exclusively kiwis), beverages (5,038 metric tons, mainly grape wine), and coffee (2,498 metric tons).

3.3.2 Europe Continent

In June 2018, the European Union introduced Regulation 2018/848, focusing on the production and labelling of organic products. Initially slated to take effect on January 1, 2021, its implementation was postponed by one year, shifting the start date to January 1, 2022. Additionally, in June 2018, the European Commission released its proposal for the Common Agricultural Policy (CAP) from 2021 to 2027. A new feature of the CAP is the proposed environmental schemes, which provide a good opportunity to compensate farmers who want to do more for the climate and the environment.

In 2022, the development of the organic sector in Europe exhibited various trends in key indicators. While organic farmland and the number of producers increased, retail sales and EU organic imports declined. Both the organic farmland and the market will need to grow at a faster rate to achieve the 25 % organic area share goal by 2030, as outlined by the European Commission (2020) in its Farm to Fork strategy for the European Union. The Farm to Fork (F2F) Strategy is part of the European Union's Green Deal, which aims to make the EU climate-neutral by 2050. The F2F Strategy is a policy framework setting out policy goals and initiatives designed to make the European Union's food system more sustainable and environmentally friendly.

In 2023, two of the secondary regulatory acts underwent regular amendments. Specifically, the implementing regulation (EU) 2021/1165, containing the lists of authorized products and substances for use in organic production, and the implementing regulation (EU) 2021/2325, which establishes the lists of third countries and third-country control bodies recognized based on equivalence under the relevant Article of the previous organic regulation, were each subject to two amendments within the course of the year.

By the end of 2022, Europe managed 18.5 million hectares of land organically, constituting approximately 19 % of the global organic agricultural land. Within the European Union (EU), the organic land area totalled 16.9 million hectares. France retained its status as the leading country in terms of organic farmland, boasting nearly 2.9 million hectares, followed closely by Spain with 2.7 million hectares, Italy with 2.3 million hectares, and Germany with 1.9 million hectares. These four nations collectively oversee more than half of Europe's organic farmland.

Organic farmland in the European Union saw an increase of 0.8 million hectares, while Europe experienced a more modest rise of 0.2 million hectares compared to 2021, primarily due to substantial decreases in Russia and Ukraine. This signifies a 1.0 % increase in Europe and a 5.1 % increase in the EU. The main contributors to this growth were Greece, Italy, and France, collectively adding over 600,000 hectares. Conversely, Ukraine and Russia saw significant decreases, totalling a reduction of 600,000 hectares. The most notable relative increases were observed in Greece, Kosovo, and Bulgaria, while the highest relative decreases occurred in Russia (-71 %) and Ukraine (-37 %).

Organic farmland in Europe represented 3.7 % of the total agricultural land, whereas within the European Union, it accounted for 10.4 %. Globally, Liechtenstein had the highest organic share of all farmlands in Europe at 43.0 %, followed by Austria, the EU country with the highest organic share of agricultural land at 27.5%. Additionally, several EU countries are approaching the goal, including Estonia at 23.0 % and Sweden at 20.2 %.

In both Europe and the EU, arable land stands as the predominant land use type, constituting 45 % of organic farmland, followed closely by permanent grassland at 40 %, and permanent crops at 13 %. Cereals emerged as the primary arable crop group, covering 2.9 million hectares in Europe (2.6 million hectares in the EU), while olives dominated the permanent crops category, occupying 0.6 million hectares.

A noteworthy development between 2021 and 2022 was the significant 6 % increase in the oilseed sector within the European Union (EU). This surge was propelled by concerns regarding potential disruptions to oilseed supplies from Ukraine and Russia due to ongoing conflicts. Ukraine holds a pivotal position in exporting organic products to Western countries. Among the key organic products exported by Ukraine are cereals, oil crops, legumes, wild cherries, mushrooms, nuts, and herbs.

On the contrary, there was a decrease in organic farmland allocated to oilseed cultivation across Europe, mainly due to a decline in organic farming activities in Russia. Dry pulses emerged with the highest area share, surpassing 24.5 % in the EU.

In 2022, Europe boasted over 480,000 organic producers, with nearly 420,000 operating within the EU, with the highest numbers recorded in Italy with 82,593 organic producers. The number of producers witnessed a 7.5 % increase in Europe and a 9.5 % increase in the European Union. Moreover, there were 91,775 organic processors in Europe, marking a 3.9 % increase from 2021, and 85,956 in the European Union, indicating a 3.4 % increase. Italy led in the number of processors with 23,602 establishments.

In contrast to previous years, there was a decline in the number of importers: Over 7,600 (2.6 %) were registered in Europe, and more than 6,400 (1.8 %) in the European Union. Germany boasted the highest number of importers at 1,944.

Data on organic imports to the European Union in 2022 revealed that 2.73 million metric tons of organic products were imported, indicating a decrease of 5.1 % compared to 2021. Ecuador emerged as the largest supplier, providing 0.35 million metric tons of organic products. The primary product group consisted of tropical fruits, predominantly bananas, amounting to 0.87 million metric tons, which experienced a decrease of 3.4 %. However, there were increases in oilseed imports, particularly soybeans. The Netherlands, serving as a re-exporter for other European countries, held the position of the largest EU importer.

In 2022, organic retail sales in Europe increased to a value of €53.1 billion, with €45.1 billion attributed to the EU, solidifying the EU's position as the second-largest single market for organic products globally, following the United States. Germany led the European market with €15.3 billion in retail sales, making it the second-largest market globally.

Despite Germany's strong performance, both the European and EU organic markets experienced declines of 2.2 % and 2.8 %, respectively, in 2022. However, there were notable exceptions in some countries such as Estonia, the Netherlands, and Austria, where retail sales increased during the same period. Over the period from 2013 to 2022, the values of organic retail sales in Europe and the European Union more than doubled, showcasing significant growth in the organic market over the past decade.

Globally, European countries lead in organic food sales shares as percentages of their respective food markets. Denmark had the highest global organic market share at 12.0 %, followed by Austria at 11.5 %, and Switzerland at 11.2 %.

In 2022, European consumers spent an average of €64 on organic food per person, while it reached €102 in the EU. Per capita consumer spending on organic food has doubled over the past decade. Swiss and Danish consumers topped the list, spending the most on organic food at €437 and €365, respectively.

3.3.3 Asia Continent

In 2023, the organic sector in Asia continued to undergo significant developments. The Chinese government implemented revisions to its organic product certification regulations, which came into effect on November 1, 2022. Furthermore, mutual recognition arrangements for organic product certification were established between China and New Zealand. South Korea encountered challenges as government budget cuts impacted funding for environmentally friendly agriculture. Consequently, amendments were introduced to certification processes to address concerns about the unintentional contamination of organic products.

Meanwhile, Bhutan implemented its Local Organic Assurance System, while India witnessed increasing adoption of the Participatory Guarantee System (PGS). In Indonesia, the Indonesia Organic Alliance introduced its own iteration of PGS called "PAMOR Indonesia".

Many countries in the region experienced rapid growth in private enterprises engaged in the organic market, with Bangladesh being particularly notable. Several governments initiated comprehensive plans to bolster the organic sector. Japan assumed a leading role by implementing Japan's Sustainable Food Systems Strategy (MeaDRI), titled "Measures for Achievement of Decarbonization and Resilience with Innovation," across 47 prefectures. Japan also recognized ninety-one local municipalities as "Organic Villages." The Kingdom of

Saudi Arabia developed an integrated support system for its organic sector, covering legal, supervisory, technical, and logistical aspects. These developments underscore the increasing significance of organic agriculture in Asia, with various countries making significant strides in regulation, certification, and market expansion.

In Asia, organic land management expanded to encompass more than 8.8 million hectares in 2022, representing 9 % of the world's organic farmland. India led the region with over 4,726,000 hectares under organic management, followed by China with nearly 2,900,000 hectares, Thailand with over 241,000 hectares, and the Philippines with almost 229,000 hectares. These four countries accounted for more than 91 % of Asia's organic farmland.

The organic land in Asia witnessed a significant increase of more than 2.3 million hectares from 2021 to 2022, marking a 35.9 % growth rate. Over the decade from 2013 to 2022, organic farmland in Asia surged by 161 %, significantly surpassing the global growth rate of organic farmland. Organic farmland in Asia accounted for 0.5 % of the continent's total agricultural land in 2022, falling below the global organic area share of 2.0%. Timor-Leste boasted the highest organic area share at 8.5 %, followed by India at 2.6 % and Sri Lanka at 2.4 %.

Nearly 40 % of the organic farmland in Asia is dedicated to arable crops, covering 3,498,356 hectares. Key crops in this category include cereals, primarily wheat and rice, covering 1,807,067 hectares, and textile crops covering 634,054 hectares, mainly in India. Additionally, oilseeds cover 611,075 hectares, predominantly in China.

Permanent crops accounted for approximately 12 % of total organic land in Asia in 2022. Key crops in this category include coconuts covering 250,263 hectares, mainly in the Philippines, and tea and mate covering 217,750 hectares, along with nuts covering 152,265 hectares, primarily in China.

There were nearly 2,729,000 organic producers in Asia, with the majority located in India, which boasts the largest number of farmers worldwide, totalling almost 2,481,000. More than 60 % of the world's organic producers were in Asia. Compared to 2021, there was an increase of nearly 947,000 organic producers (+53.1 %), primarily attributed to the rise in producers reported from India (+946,553). Additionally, a total of 940 exporters and 12,969 processors were reported in the region.

Data on organic retail sales in Asia is limited, as only 10 countries with organic farmland provided organic retail sales figures. Among these countries, updates for 2022 were provided by China, Japan, Saudi Arabia, and South Korea. The total reported organic retail sales in 2022 exceeded €15.0 billion. However, the absence of retail sales figures from other Asian countries does not imply the absence of a domestic market for organic products. Many countries in the region have developed robust local markets for organic products, contributing to the overall growth and sustainability of the organic sector in Asia.

In 2022, almost 614,384 metric tons of products were exported from Asia to the EU and US, constituting 12.5 % of all organic imports to these countries/trade blocs. Since 2018, there has been a consistent yearly decline, amounting to a total reduction of 32.9 % or 330,158 metric tons.

The largest Asian exporter to the US and EU was China, with more than 199,000 metric tons of products, mainly oil cakes, rice, and sugar, followed by India with almost 176,000 metric tons, primarily oil cakes and rice, and Pakistan with over 51,000 metric tons, mainly rice.

3.3.4 Latin America and the Caribbean Continent

In Latin America and the Caribbean, more than 9.5 million hectares were managed organically in 2022. Almost 10 % of the world's organic farmland was in this region. Argentina had the largest area of farmland under organic management with almost 4.1 million hectares, followed by Uruguay with more than 2.7 million hectares, Brazil with nearly 1.0 million hectares, and Mexico with close to 0.4 million hectares. These four countries accounted for more than 86% of the region's organic farmland.

In 2022, organic farmland in Latin America and the Caribbean accounted for 1.3% of the continent's total agricultural land, falling below the global organic area share of 2.0%. Uruguay led the region with the highest organic area share at 19.6%, followed by Dominica at 11.6%, and French Guiana at 11.1 %.

Organic land in Latin America and the Caribbean increased by nearly 53,000 hectares (+0.6 %) in 2022. Over the decade from 2013 to 2022, organic farmland in the region grew by 42%, which is notably slower than the global growth rate of organic farmland. Only 6.3 % of organic farmland in Latin America and the Caribbean is allocated for arable crops, totalling 604,459 hectares. Key arable crops in the region include cereals, covering 143,711 hectares mainly in Bolivia; sugarcane, occupying 91,553 hectares primarily in Paraguay and Argentina; and oilseeds, spanning 57,038 hectares, mainly in Bolivia.

Permanent crops accounted for approximately 10.7 % of total organic land in Latin America and the Caribbean in 2021. Among the key crops were Coffee: 421,965 hectares, mainly in Peru, Mexico, and Colombia; Cocoa with 200,760 hectares, mainly in the Dominican Republic and Peru; Tropical and subtropical fruit with 102,446 hectares, mainly in Mexico, Ecuador, the Dominican Republic, and Peru.

Almost 75 % of the organic farmland in Latin America and the Caribbean consists of permanent grassland, totalling 7,120,297 hectares. This grassland is mainly located in Argentina, Uruguay, and Brazil, which together represent 97.2 % of the total organic grassland/grazing areas in the region.

3.3.5 Northern America Continent

In North America, more than 3.5 million hectares were managed organically in 2022, representing nearly 3.8 % of the world's organic farmland. Among the two countries reporting organic farmland in North America, the United States had the largest farmland area under organic management, totalling 2,060,741 hectares, followed by Canada with over 1,567,000 hectares. In North America, organic land witnessed a 10.7 % increase, equivalent to an additional 351,488 hectares from 2021 to 2022. While the United States experienced a decline in organic farmland, Canada saw an increase. Over the period from 2013 to 2022, organic farmland in North America grew by 19.0 %.

In 2022, organic farmland in North America represented 0.8 % of the continent's total agricultural land, which was lower than the global organic area shares of 2.0 %. The United States reported a share of 0.5 %, while Canada had 2.7 % of its farmland dedicated to organic farming.

More than 44 % of the organic farmland in North America was used for arable crops, totalling 1.6 million hectares. Key arable crops included cereals with 705,834 hectares, oilseeds with 195,232 hectares, and dry pulses with 151,950 hectares. Permanent crops accounted for approximately 8 % of total organic land in North America in 2022. Key permanent crops included berries with 23,819 hectares, temperate fruit with 18,815 hectares, and grapes with 18,535 hectares. In North America, there were over 23,948 organic producers in total, with 17,445 producers counted in the US and 6,503 in Canada.

In 2022, organic retail sales in North America reached €64.4 billion, followed by the European Union. The USA, the largest single market globally, reported retail sales of €58.6 billion, while Canada reported €5.8 billion.

Data on US organic imports and exports have been available since 2014, while data on organic export volumes to the European Union have been available since 2018. In 2022, over 222,995 metric tons of products were exported from North America to the EU, US, and Canada, constituting 4.6 % of all organic exports to these regions. Over the 5-year period from 2018 to 2022, North American exports increased by almost 76%, growing significantly faster than global organic exports to the EU and US, which grew by only 9% in the same period.

The primary North American exporter was Canada, shipping over 214,091 metric tons of products, primarily cereals and soybeans. Of this total, nearly 193,000 metric tons were exported to the US, while more than 30,000 metric tons were sent to the EU. Additionally, US exports to the EU amounted to over 8,900 metric tons.

The most significant product group in North American organic exports, comprising almost 142,000 metric tons and accounting for nearly 64 % of the total exports, was cereals, primarily maize, oats, and wheat. This was followed by oilseeds, with 29,752 metric tons exported, mainly soybeans, and fresh vegetables, with 17,031 metric tons exported, primarily cucumbers, tomatoes, and peppers.

3.3.6 Africa Continent

In 2022, Africa's total organic farmland area surpassed 2.7 million hectares, comprising over 2.8 % of the world's organic farmland. Uganda leads African countries with more than 505,000 hectares under organic management, followed by Tanzania (over 313,000 hectares), Ethiopia (over 238,000 hectares), and Tunisia (nearly 228,000 hectares). These four countries collectively account for nearly half of Africa's organic farmland.

Compared to 2021, organic land in Africa expanded by over 127,500 hectares in 2022, marking a growth rate of 4.9 %. From 2013 to 2022, organic farmland in Africa grew by 127 %, outpacing the global organic farmland growth rate. Organic farmland in Africa constituted 0.2 % of the continent's total agricultural land in 2022, which is below the global organic area share of 2.0 %.

Sao Tomé and Principe boasted the highest organic area share at 21.1 %, placing it among the 21 countries worldwide where organic farming covers more than 10 % of total farmland, and one of the four countries exceeding 20 %. Following Sao Tomé and Principe, Sierra Leone and Réunion both had organic farmland shares of nearly 5 %.

More than half of Africa's organic farmland, totalling 1,603,945 hectares, is dedicated to permanent crops. Key crops include cocoa, covering 312,857 hectares primarily in Sierra Leone and the Democratic Republic of Congo; coffee, with 264,488 hectares mainly in Ethiopia; and nuts, spanning 257,737 hectares primarily in Kenya, Burkina Faso, and Côte d'Ivoire. Arable land accounted for approximately 34 % of total organic land in Africa in 2021. Among the key crops in this category were textile crops, covering 318,101 hectares mainly in Tanzania; oilseeds, occupying 264,487 hectares mainly in Togo; and root crops, with 66,303 hectares.

Africa had more than 975,000 organic producers in 2022, with the largest numbers located in Uganda, totalling over 400,000. This means that more than a fifth of the world's organic producers were in Africa. However, compared to 2021, there was a decrease of almost 59,000 producers (5.7 % decrease), mainly due to a significant reduction in the number of producers in Tanzania. Additionally, there were 1,302 exporters and 1,595 processors counted.

In 2022, Africa exported over 555,000 metric tons of organic products to the EU and US, accounting for 11 % of all organic exports to these regions. Over the 5-year period from 2018 to 2022, African exports increased by almost 90 %, significantly outpacing the global organic export growth rate to the EU and US, which grew by only 9 % in the same period.

3.4 Growth of Organic Agricultural Land

The area of organic agricultural land experienced exponential growth in 2022, expanding more than eightfold compared to its extent in 1999, which was approximately 11 million hectares, to reach a total of 96.4 million hectares. In 2022 alone, the organic agricultural land area increased by 20.3 million hectares compared to 2021, representing a remarkable growth rate of 26.6 %.

More than two-thirds of the organic farmland consisted of grassland and grazing areas, totalling over 67.6 million hectares, which saw a substantial 25.5 % increase in 2022. Arable land, comprising nearly 15.1 million hectares, accounted for 15.6 % of the total organic agricultural land. Despite a slight 0.7 % decrease since 2021, this category was primarily used for cultivating cereals (including rice), producing green fodder, oilseeds, textile crops, and dry pulses.

Permanent crops made up 6.6 % of the total organic agricultural land, totalling over 6.2 million hectares. Compared to the previous survey, there was a modest increase of more than 48,000 hectares (0.8 %). Significant crops in this category included nuts, olives, coffee, grapes, and cocoa.

In addition to land dedicated to organic agriculture, there are other areas designated for various organic activities. The largest portions of these areas are allocated to wild collection areas and beekeeping. Additionally, non-agricultural areas include aquaculture, forests, and grazing areas on non-agricultural land. In total, these areas amount to 34.6 million hectares. When combined with organic agricultural land, the total organic area reaches 132.4 million hectares.

As of the end of 2022, a total of 188 countries worldwide were practicing organic agriculture. Among these, 75 countries had fully implemented organic farming rules and standards. Table 3.5. illustrates the extent of the growth of organic agriculture during the previous two decades, from 1999 until the end of 2022. Meanwhile, Table 3.6. showcases the growth of organic agriculture worldwide for the year 2021-2022, highlighting a notable increase in organic agricultural land.

In 2022, the regions with the largest organic agricultural land areas were as follows: Oceania led with 53.2 million hectares, constituting over half of the world's organic agricultural land (55.2 %). Europe followed closely with 18.5 million hectares (19.2 %), then Latin America with 9.5 million hectares (10 %), Asia with 8.8 million hectares (9.1 %), Northern America with 3.6 million hectares (3.7 %), and Africa with 2.7 million hectares (2.8 %).

Table 3.5. Organic Agriculture Growth During (1999-2022) and Top Countries in 2022.

Indicator	1999	2022	Top Countries
Organic agricultural land (Million hectares)	11	96.4	Australia (53.0 million ha.). India (4.7 million ha.). Argentina (4.1 million ha.).
Number of countries with organic activities	------	188	
Organic share of total agricultural land	------	2.0 %	Liechtenstein (43.0 %). Austria (27.5 %). Estonia (23.4 %).
Organic producers	200 (Thousands)	4.5 (Million)	India (2,480,859). Uganda (404,246). Thailand (121,540).
Wild collection and further non-agricultural areas (Million hectares)	4.1	34.6	Finland (6.9 million ha.). India (4.4 million ha.). Zambia (3.2 million ha.).
Organic market (Billion Euros)	15.1 (2000)	134.8 (2022)	USA (€58.6 billion). Germany (€15.3 billion). China (€12.4 billion).
Number of countries/territories with organic regulations	------	75 (fully implemented) 14 (drafting)	
Number of affiliates of IFOAM - Organic International	------	781 (2022)	Germany: 80 affiliates. China: 52 affiliates. India: 49 affiliates. USA: 45 affiliates.

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.6. Growth of Organic Agriculture Worldwide during 2021 - 2022.

Region	Organic Agriculture Land (Million Hectares)	
	2021	2022
Oceania	35,985,809	53,194,639
Europe	18,258,903	18,450,355
Latin America	9,484,391	9,537,387
Asia	6,496,002	8,830,990
North America	3,276,330	3,627,818
Africa	2,607,489	2,735,006
Total*	76,108,924	96,376,196

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

*Total includes correction value for French overseas department.

3.5 The Global Market for Organic Products

In 2022, organic food and drink sales reached nearly €135 billion, according to FiBL. However, discrepancies exist between the sales figures reported by FiBL and Ecovia Intelligence, likely due to differences in methodologies. Ecovia Intelligence reported global retail sales exceeding €127.7 billion in 2022.

Organic food sales have shown a compound annual growth rate of 10 % over the past decade, rising from €47.6 billion in 2012. The highest growth was observed in 2020, with total retail sales of organic food and beverages reaching approximately €121 billion, increasing further to around €125 billion in 2021. The surge in demand for organic and health foods during the coronavirus pandemic contributed significantly to this growth, as consumers sought to bolster their personal immunity.

North America and Europe collectively dominate global organic food sales, accounting for a combined 90 % share. North America's revenue share has been increasing, driven by relatively higher growth rates compared to Europe. Additionally, the strengthening of the US dollar in foreign exchange markets has further boosted revenue.

The North American market for organic products reached a valuation of €63.7 billion in 2022. Organic food and beverage sales experienced a modest increase of about 4% during this period. Most of the revenue comes from the US market, which remains the largest in the world. Consumer demand for organic products continues to be robust in both the US and Canadian markets.

The European market for organic food and beverages reached approximately €51.3 billion in 2022. Despite this overall market size, Germany and France, the two largest markets in Europe, reported negative growth during that year. The ongoing conflict in Ukraine has exacerbated production, distribution, and retailing costs across the continent.

Since the conflict began in February 2022, European countries have been grappling with inflationary pressures. Organic food retailers have been significantly impacted by rising energy costs, food prices, and labor expenses, with many reporting negative sales. Conversely, large food retailers, particularly discounters, have experienced relatively less impact from the challenging economic conditions in Europe.

The Asian market ranks as the third largest globally, highlighting its significant presence in the organic products industry. Additionally, organic product markets in Australasia and Latin America also hold considerable importance. Although the African market for organic food and beverages is growing, it is starting from a relatively small base.

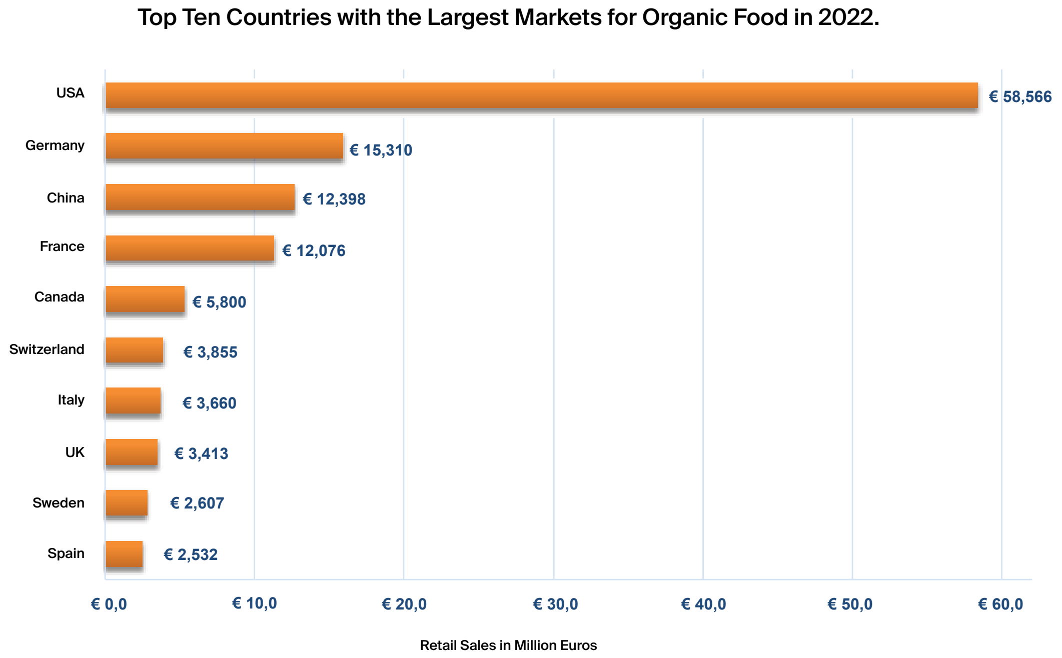
In 2022, the United States emerged as the largest single market for organic food, with sales reaching €58.6 billion, followed closely by the European Union at €45.1 billion. Germany, China, and France also featured prominently among the top markets, with sales figures of €15.3 billion, €12.4 billion, and €12.1 billion, respectively. Regionally, North America led the way with total sales amounting to €64.4 billion, followed by Europe at €53.1 billion and Asia at €15.0 billion.

Switzerland boasted the highest per-capita consumption of organic products in 2022, with an impressive figure of €437. Noteworthy organic market shares were observed in Denmark (12.0 %), Austria (11.5 %), and Switzerland (11.2 %), underscoring their strong positions in the organic food market.

Figure 3.6. displays the top ten countries with the largest markets for organic food in 2022. The data, sourced from the Switzerland Organic Agriculture Research Institute (FiBL) and the German Agricultural Market Information Company (AMI), offer valuable insights into the leading players in the global organic food market. Meanwhile, Figure 3.7. illustrates the share of each country in the

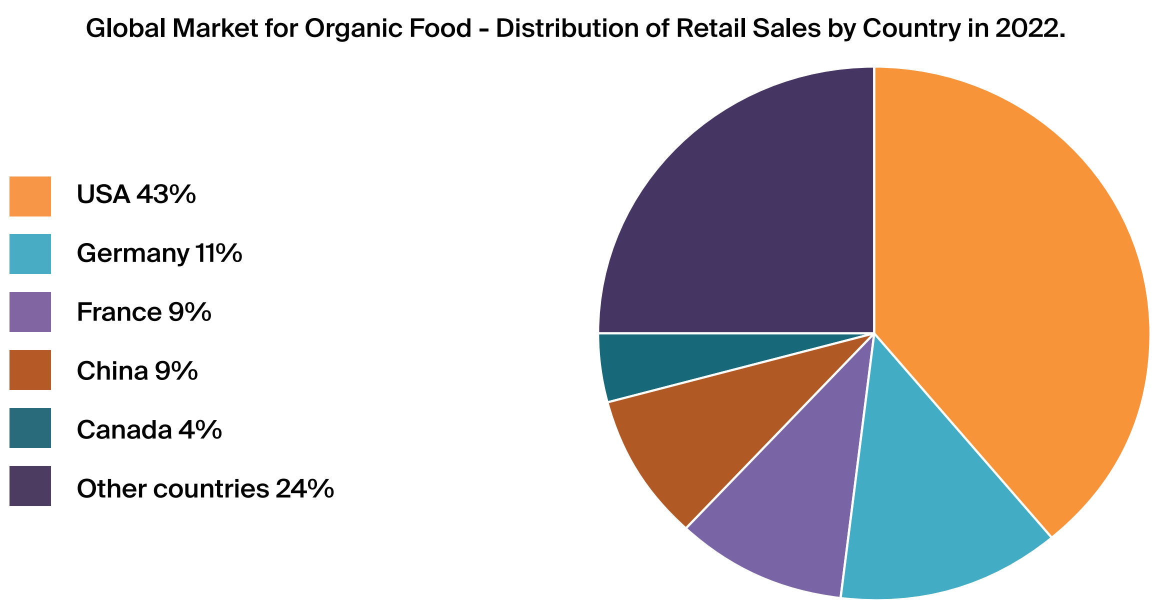
global retail sales of organic food for the same year, which published in 2024.

Figure 3.6. Top Ten Countries with the Largest Markets for Organic Food in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Figure 3.7. Global Market for Organic Food - Distribution of Retail Sales by Country in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.6 Distribution of Organic Areas

The findings of the survey, jointly conducted by the Research Institute for Organic Agriculture in Switzerland (FiBL) and the International Federation of Organic Agriculture Movements (IFOAM), and published in 2024, revealed significant insights into the extent of organic agricultural land by the end of 2022.

According to the survey, the total area of organic agricultural land reached approximately 96.4 million hectares worldwide. Notably, grassland and grazing areas accounted for the majority, comprising over two-thirds of the organic agricultural land, totalling more than 67.6 million hectares. This category experienced a remarkable 25.5 % increase in 2022.

In contrast, cropland areas, including arable land with 15.1 million hectares and permanent crops with 6.4 million hectares, constituted a smaller portion, totalling 21.5 million hectares. Despite their smaller share, these areas play a vital role in organic agriculture.

Table 3.7. presents an overview of the distribution of various organic areas globally, totalling approximately 132.4 million hectares. These areas encompass organic agriculture, natural pastures, forests, organic aquaculture, wild crops, wild apiaries, and other categories. The largest segments within organic land include organic agricultural land, comprising approximately 96.4 million hectares, and wild crops and apiaries, totalling around 34.6 million hectares.

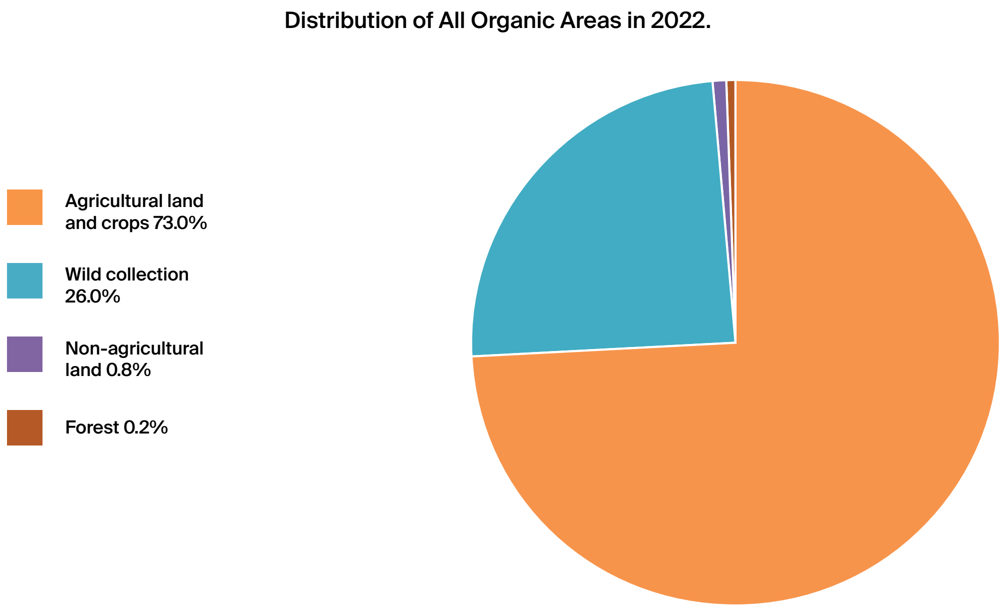
Figure 3.8. depicts the distribution ratios of these important organic areas up to the end of 2022. Organic agricultural land represents the majority, constituting approximately 73 % of the total, while wild areas encompass about 26 %. Forests and other organic areas make up the remaining 1 %.

Table 3.7. World Organic Areas (Hectares) - Agricultural Land and Further Organic Areas by Region in 2022.

Region	Agriculture	Aquaculture	Forest	Wild Collection*	Other non agri. land	Total (ha)
Africa	2,735,006		71,497	10,711,955	40	13,518,498
Asia	8,830,990	47,748		7,053,415	360	15,932,513
Europe	18,450,355			11,305,648		29,756,003
Latin America	9,537,387	138	42,305	5,338,894	989,840	15,908,563
Northern America	3,627,818		2,943	163,942	47,475	3,842,179
Oceania	53,194,639			60,633		53,255,272
Total**	96,376,196	47,899	302,475	34,634,487	1,075,861	132,436,914

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture. Blank cells: No data available.
* Wild collection and beekeeping areas. ** Total includes correction value for French overseas departments.

Figure 3.8. Distribution of All Organic Areas in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.8. provides an overview of organic areas dedicated to Arable crops, Permanent crops, and Permanent Grassland across continents until the end of 2022. In contrast, Figure 3.9. illustrates the proportions of distribution of main land use types and key crop categories within organic land areas in 2022.

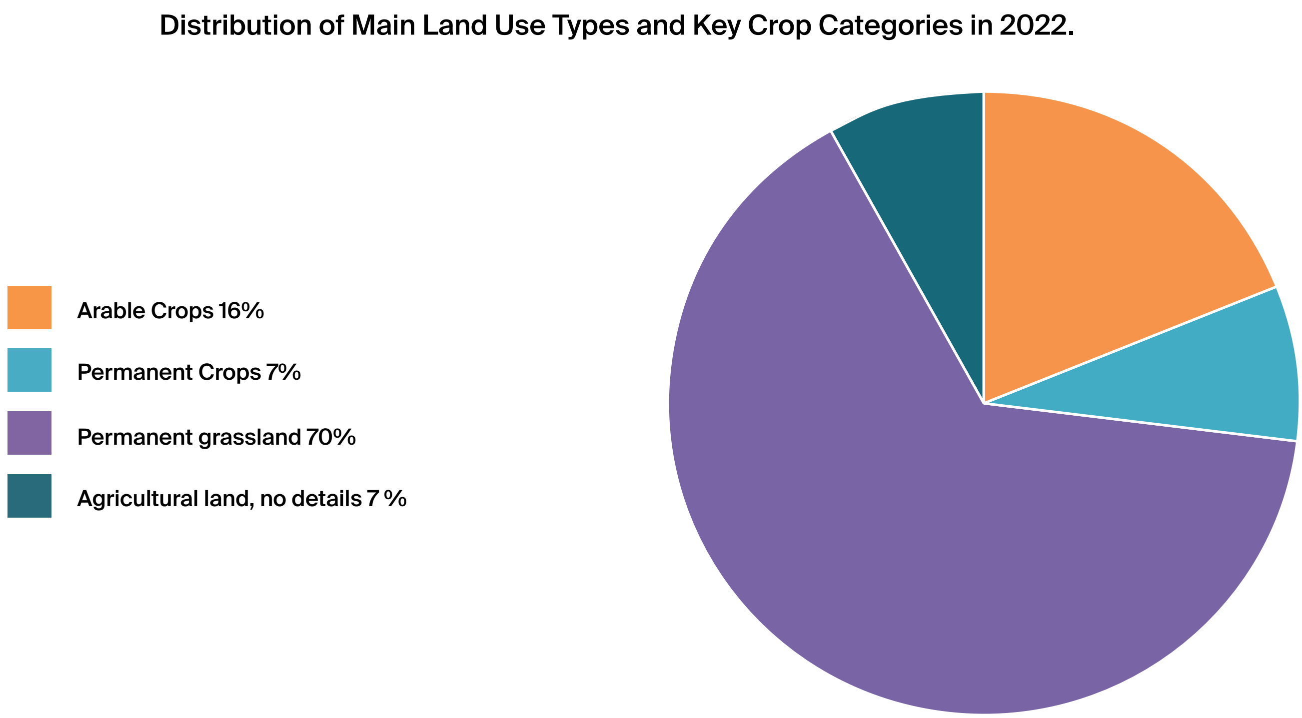
Table 3.8. Land Use in Organic Agriculture (Hectares) by region in 2022.

Region	Arable Crops	Permanent Crops	Permanent Grassland	Total**
Africa	926,357	1,603,945	5,752	2,735,006
Asia	3,498,356	1,071,170	8,720	8,830,990
Europe	8,383,545	2,366,600	7,411,249	18,450,355
Latin America	604,459	1,021,394	7,120,297	9,537,387
Northern America	1,609,910	282,951	536,875	3,627,818
Oceania	51,406	34,409	52,540,881	53,194,639
Total**	15,074,033	6,380,469	67,623,775	96,376,196

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

** Totals include other agriculture areas, land for which no details were available, and correction values for some countries for land with double cropping for one year.

Figure 3.9. Distribution of Main Land Use Types and Key Crop Categories in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7 Distribution of Organic Farmland Crops

By the end of 2022, organic agricultural farmland covered approximately 21.5 million hectares. Table 3.9. presents the most significant groups of arable and permanent crops in organic agricultural lands as of the end of 2022. The data indicates that organic arable land, amounting to over 15.1 million hectares, represented 15.6 % of the world's organic agricultural land and 1.1 % of the world's total arable cropland. Compared to 2021, organic arable land decreased by 0.7%. Europe led in organic arable land, accounting for nearly 56 %, followed by Asia 23 % and North America 11 %. The majority of organic arable cropland was allocated to cereals (including rice, covering 5.6 million hectares), green fodder (3.3 million hectares), and oilseeds (1.8 million hectares). In 2022, the regional distribution of organic arable cropland was as follows: Europe 55.6%, Asia 23.2 %, North America 10.7 %, Africa 6.1 %, Latin America 4.0 % and Oceania 0.5%.

Permanent crops covered over 6.4 million hectares, representing 3.6 % of the world's permanent cropland. Compared to 2021, there was a slight increase of over 48,000 hectares, or 0.8 %. Permanent cropland comprised 7% of organic agricultural land, with the majority located in Europe (37.1 %, approximately 2.4 million hectares), followed by Africa (25.1 %, over 1.6 million hectares), and Asia (16.8 %, almost 1.1 million hectares).

The primary permanent crops in organic agricultural land include nuts and olives (approximately 0.9 million hectares), grapes (about 0.6 million hectares), cocoa (around 0.5 million hectares), and temperate fruits (roughly 0.3 million hectares). Additionally, tropical and subtropical fruits cover an estimated area of 0.3 million hectares, while coconut occupies a similar area. Citrus comprises approximately 0.1 million hectares.

Table 3.9. Area of Crop Categories for Arable and Permanent Crops in Organic Agriculture Worldwide Until the End of 2022.

Arable Crops	Area (Hectares)	Permanent Crops	Area (Hectares)
Cereals	5,641,202	Nuts	885,017
Green fodder	3,313,912	Olives	852,649
Oilseeds	1,822,606	Coffee	761,424
Textile crops	1,043,294	Grapes	561,503
Dry pulses and protein crops	740,306	Cocoa	515,214
Fresh vegetables and melon	503,456	Fruit, temperate	331,605
Medical and aromatic plants	159,118	Fruit of tropical and subtropical	295,133
Root crops	203,654	Coconut	289,420
Sugarcane	107,926	Medical and aromatic plants	223,969
Industrial crops	7,757	Citrus fruit	115,346
Mushrooms and truffles	13,445	Berries	87,517
Strawberries	3,453	Tea/Mate, etc.	248,003
Total **	**15,074,033**	**Total**	**6,380,469**

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.
** The total includes groups of some organic crops for which no details, and correction values for some countries for land with double cropping for one year.

Table 3.10. provides a comprehensive breakdown of organic agricultural land areas up to the end of 2022, sourced from statistics published by FiBL and IFOAM in 2024. The table showcases various categories of organic agricultural land, contributing to a total area of approximately 96.4 million hectares.

Table 3.10. Various Organic Agricultural Land Areas Until the End of 2022.

Organic Agriculture Land	Area (Hectares)
Arable Crops	15,074,033
Permanent Crops	6,380,469
Permanent Grasslands	67,623,775
Organic Agricultural Land Without Details	7,297,919
Total	96,376,196

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.1 Organic Arable Crops

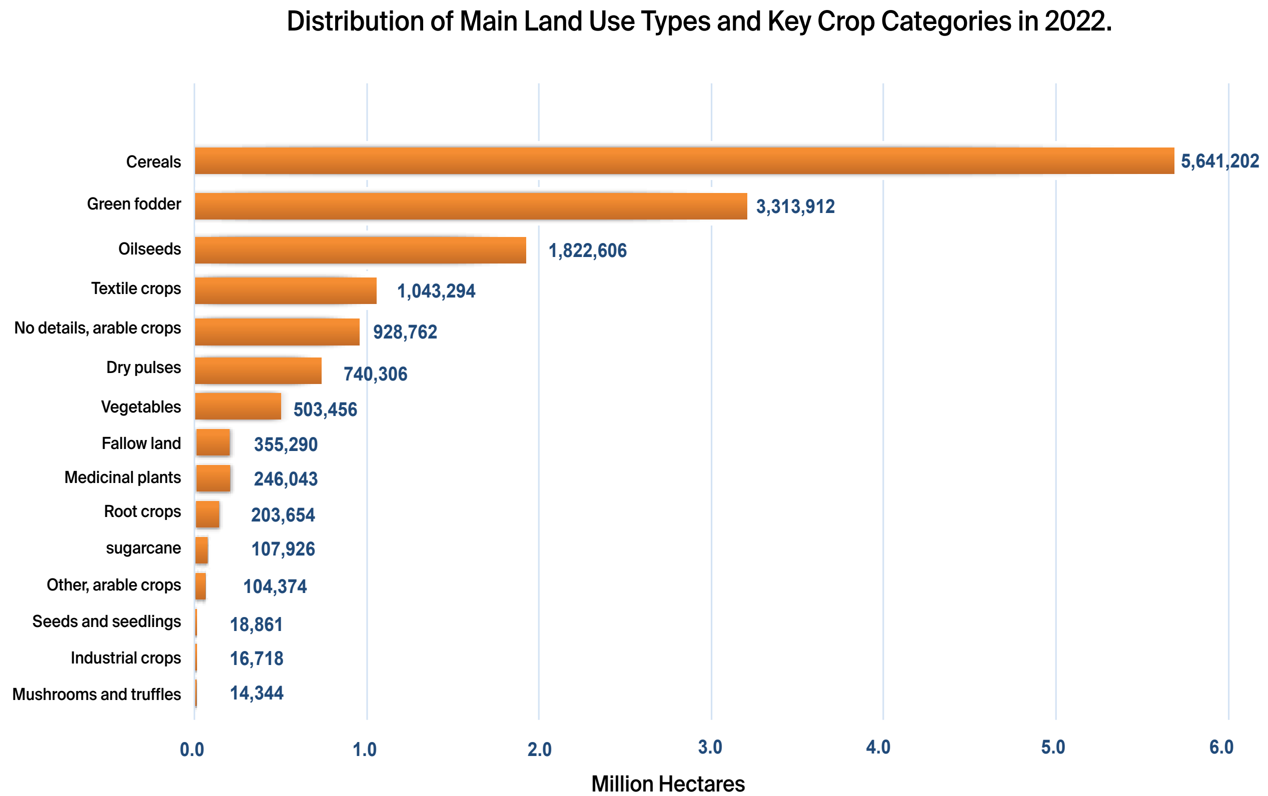
Figure 3.10. illustrates the distribution of the most significant organic arable cropland areas as of the end of 2022. These areas, totalling more than 15.1 million hectares, constitute approximately 15.6 % of the world's organic agricultural land and account for 1.1 % of the total area devoted to arable crops globally, according to FAO STATISTICS (2022). The figure highlights key categories, including cereals and rice crops (5.6 million hectares), green fodder (3.3 million hectares), oilseeds (1.8 million hectares), textile crops (one million hectares), dry pulses (0.7 million hectares), and vegetables (0.5 million hectares).

3.7.1.1 Cereals Crops

Cereal crops encompass a variety of grains such as wheat, barley, oats, grain maize, rice, rye, triticale (a hybrid of wheat and rye), millet, and others. According to FAO STATISTICS (2022), India ranks first globally in terms of the area dedicated to cereal crops, with approximately 102 million hectares. China follows closely behind with about 98 million hectares, followed by the United States of America with approximately 53 million hectares, and the Russian Federation with around 45 million hectares.

In 2022, the global area under organic management for cereal crops exceeded 5.6 million hectares, representing approximately 0.76 % of the total global cereal area. This marks a significant increase from 2004 when organic cereal crop cultivation covered only 1.3 million hectares. Among organic cereal crops, wheat constitutes the largest proportion, accounting for approximately 39.3 % of the total, followed by rice at 12.7 %, oats at 10.7 %, maize at 8 %, barley at 7.6 %, rye and maslin at 4.3 %, spelt at 1.6 %, and other cereals at 15.8 %.

Figure 3.10. Distribution of Organic Arable Cropland by Crop in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.1.2 Oilseeds Crops

In 2022, approximately 1.8 million hectares, or 0.5 % of the global oilseed area, was under organic management. This figure represents a significant increase compared to 2004 when organic oilseed crop cultivation covered only 144,000 hectares. Oilseed crops include soybeans, sunflower, linseeds, sesame, rapeseed, peanuts, mustard, and others. Among organic oilseed crops, soybeans account for the largest proportion, covering approximately 58.6 % of the total organic oilseed crop area, followed by sunflower at 16.8 %, rapeseed at 5 %, sesame at 4.3 %, safflower at 0.6 %, with the remaining 14.7 % consisting of other organic oilseeds.

According to FAO STATISTICS (2022), India, Brazil, the United States of America, and China are the leading countries in terms of oilseed crop cultivation, with each country having an estimated area of oilseed crops exceeding 25 million hectares.

Based on statistical data published by FiBL & IFOAM (2024), Table 3.11. presents the top countries with the largest areas of organic cereal and organic oilseeds crops until the end of 2022.

Table 3.11. Countries with the Largest Organic Areas of Cereals & Oilseeds crops in 2022.

Organic Cereals		Organic Oilseeds	
Country	**Area (Hectares)**	**Country**	**Area (Hectares)**
China	1,464,600	**China**	508,000
France	436,840	**Ukraine**	135,238
Germany	412,000	**Togo**	135,122
USA	405,742	**France**	133,206
Italy	330,352	**USA**	118,896
Canada	300,092	**Romania**	101,375
Spain	242,721	**India**	87,300
Thailand	198,370	**Canada**	76,336
Poland	148,394	**Austria**	54,851
Austria	141,684	**Russia**	53,398
Romania	130,930	**Germany**	43,300
Ukraine	129,578	**Ghana**	38,120
Sweden	121,782	**Italy**	33,941
Lithuania	119,984	**Mexico**	20,769
Bolivia	98,564	**Sudan**	19,894

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.1.3 Dry Pulses Crops

The area of organic dry pulses crops reached 740,000 hectares by the end of 2022, marking a more than ninefold increase from 2004 when it was estimated at only 79,000 hectares. This area represents approximately 0.9 % of the total area planted with dried pulses crops worldwide, which is estimated at 82.4 million hectares according to FAO STATISTICS (2022). Dry pulses crops, including peas, lentils, beans, lupines, and other dried and protein-rich pulse crops, contribute significantly to global agriculture.

The main countries with the largest areas of dry pulses, according to FAO STATISTICS (2022), are India, Niger, and Myanmar. Meanwhile, in 2022, the leading countries in terms of organic dry pulses crops include France, Canada, Poland, Italy, Germany, Spain, the USA, and Lithuania.

3.7.1.4 Vegetable Crops

Organic vegetable crops covered an estimated 503,000 hectares by the end of 2022, marking a fourfold increase compared to the 2004 estimates of 105,000 hectares. This expansion signifies a growing trend towards organic farming practices globally. Organic vegetable cultivation now constitutes approximately 0.9 % of the total area devoted to vegetable crops worldwide, which amounts to about 58 million hectares, as reported by FAO STATISTICS (2022).

The leading countries in terms of vegetable crop cultivation, according to FAO STATISTICS (2022), include China, India, Nigeria, and Indonesia. These nations have substantial agricultural sectors and play significant roles in global food production. Organic vegetable cultivation encompasses a variety of vegetable types, with a particular emphasis on root tubers and bulb vegetables, followed by leafy vegetables, fruit vegetables, and fresh vegetables.

The countries with the largest area of organic vegetable crops until the end of 2022 include the United States of America, China, Italy, France, Mexico, Egypt, and Spain, each with more than 25,000 hectares dedicated to organic vegetable cultivation. The distribution of organic vegetables in 2022 reflects a diverse range of types, with root tuber and bulb vegetables accounting for 15.9 %, leafy vegetables for 12.5 %, fruitful vegetables for 12.2 %, fresh pulses for 9.1 %, fresh vegetables and melons for 5.3 %, and other vegetables for 45 %.

Table 3.12. provides an overview of the countries with the largest areas of organic dried pulses and organic vegetable crops until the end of 2022, based on statistical data published by FiBL & IFOAM (2024).

3.7.2 Organic Permanent Crops

In 2022, permanent crops occupied more than 6.4 million hectares, accounting for 3.6% of the world's permanent cropland, as reported by statistical data from FiBL & IFOAM (2024). Compared to 2021, there was a slight increase of over 48,000 hectares, or 0.8 %. Seven percent of the total organic agricultural land consisted of permanent cropland. Most of this land was in Europe, with almost 2.4 million hectares (37.1 %), followed by Africa with over 1.6 million hectares (25.1 %), and Asia with nearly 1.1 million hectares (16.8 %).

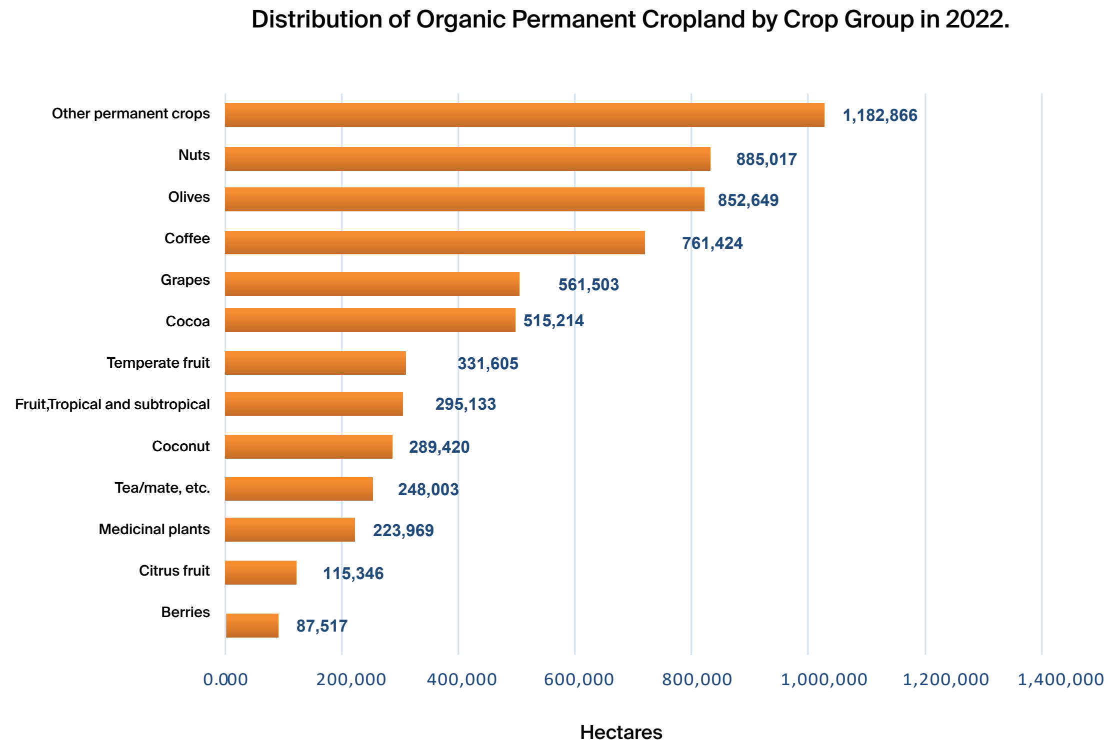
Figure 3.11. illustrates the distribution of the most significant permanent organic crops until the end of 2022. Among these crops, nut trees cover approximately 0.9 million hectares, representing roughly 14 % of the total area dedicated to organic permanent crops. Following closely are olive trees, occupying about 0.9 million hectares (represents about 13 %), while coffee cultivation spans approximately 0.8 million hectares (represents about 12 %). Grapes and cocoa also feature prominently, with respective areas of about 0.6 million hectares (represents about 9 %) and 0.5 million hectares (represents about 8 %), according to data from FiBL & IFOAM (2024).

Table 3.12. Countries with the Largest Organic Areas of Dry pulses & Vegetable Crops in 2022.

Organic Dry Pulses		Organic Vegetable Crops	
Country	**Area (Hectares)**	**Country**	**Area (Hectares)**
France	177,869	USA	97,127
Canada	127,935	China	69,400
Poland	58,076	Italy	59,280
Italy	53,754	France	43,234
Germany	53,000	Mexico	38,401
Spain	63,542	Egypt	25,796
USA	24,015	Spain	25,031
Lithuania	19,720	Germany	17,016
Denmark	18,333	Canada	16,880
Kazakhstan	17,875	Netherlands	10,405
Greece	17,165	UK	9,800
Argentina	15,393	Kenya	9,394
Sweden	14,640	Poland	8,240
Türkiye	11,789	Austria	6,048
Austria	11,753	Portugal	5,613

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Figure 3.11. Distribution of Organic Permanent Cropland by Crop Group in 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.2.1 Olives

Organic olive tree cultivation encompassed approximately 852,649 hectares until the end of 2022, marking a substantial increase compared to the estimated 315,000 hectares in 2004. This area constitutes over two and a half times the organic olive tree acreage recorded two decades prior. Notably, organic olive trees now occupy around 8 % of the total global olive tree area, which stands at approximately 10.7 million hectares according to FAO STATISTICS (2022).

The leading countries in organic olive cultivation by 2022 were Spain, with approximately 262,379 hectares, followed by Italy with around 243,089 hectares, and Tunisia with about 173,171 hectares. Greece and Turkey followed closely with approximately 58,840 hectares and 56,014 hectares, respectively. Remarkably, Europe accounted for around 71 % of global organic olive production, with North African countries contributing approximately 28 %.

3.7.2.2 Grapes

The global area of organic grape cultivation reached approximately 561,503 hectares by the end of 2022, marking a substantial increase from the 88,000 hectares recorded in 2004. This area accounts for approximately 7.7% of the total global grape cultivation area, estimated at 7.3 million hectares according to FAO STATISTICS (2022).

Europe dominates organic grape cultivation, representing about 83 % of the total area. France leads in organic grape cultivation with approximately 157,358 hectares, followed closely by Spain with around 149,934 hectares and Italy with about 127,638 hectares. China and the United States also contribute significantly, with approximately 18,000 hectares and 17,111 hectares, respectively. Table 3.13. provides a detailed overview of the countries with the largest areas dedicated to organic olive and grape cultivation until the end of 2022, based on statistics compiled by FiBL & IFOAM (2024).

Table 3.13. Countries with the Largest Organic Areas of Olive & Grape Trees in 2022.

Organic Olive		Organic Grape	
Country	**Area (Hectares)**	**Country**	**Area (Hectares)**
Spain	262,379	**France**	157,358
Italy	243,089	**Spain**	149,934
Tunisia	173,171	**Italy**	127,638
Greece	58,840	**China**	18,000
Türkiye	56,014	**USA**	17,111
Portugal	25,633	**Germany**	13,800
Argentina	7,713	**Austria**	9,901
France	7,073	**Argentina**	9,838
Morocco	5,903	**Türkiye**	9,573
Palestine	4,656	**Chile**	6,590
Croatia	1,956	**Australia**	5,783
Cyprus	1,586	**Greece**	4,716
Egypt	1,103	**Mexico**	4,301
Chile	1,081	**Portugal**	4,000
USA	666	**South Africa**	3,786

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.2.3 Coffee

Organic coffee cultivation has seen a remarkable expansion, with approximately 761,424 hectares under organic management by the end of 2022. This marks a significant increase from the 176,000 hectares recorded in 2004, representing over fourfold growth in organic coffee farming. The organic coffee acreage now constitutes about 7.3 % of the global coffee cultivation area, which is estimated at around 10.5 million hectares, according to FAO STATISTICS (2022).

Among the top coffee-producing countries, Brazil leads with approximately 1.8 million hectares dedicated to coffee cultivation. Following Brazil is Indonesia with around 1.3 million hectares, Colombia with about 0.8 million hectares, Central African Republic with a similar area, and Ethiopia with approximately 0.7 million hectares.

In 2022, Ethiopia leads the roster of countries with the largest areas of organic coffee trees, boasting approximately 174,552 hectares. Following closely is Peru, with around 156,277 hectares, while Mexico maintains a substantial presence with about 102,392 hectares. Colombia also features prominently in the list, with roughly 74,600 hectares dedicated to organic coffee cultivation. Notably, South American and African nations collectively account for about 87 % of the global organic coffee tree acreage.

3.7.2.4 Cocoa

Organic cocoa cultivation expanded significantly by the end of 2022, with approximately 515,214 hectares dedicated to organic cocoa trees. This figure reflects a substantial increase compared to the 46,000 hectares recorded in 2004, marking a growth of over eleven times. The area of organic cocoa trees now constitutes about 5 % of the total global cocoa tree acreage, estimated at 10.2 million hectares according to FAO STATISTICS (2022).

The largest cocoa-growing countries, Côte d'Ivoire and Ghana, collectively contribute nearly 60 % of the world's cocoa production. Côte d'Ivoire boasts the largest cocoa-growing area, covering approximately 3.7 million hectares. Following closely are Indonesia and Ghana, each with around 1.5 million hectares, while Nigeria follows with about 1.1 million hectares dedicated to cocoa cultivation.

By the end of 2022, Sierra Leone emerged as one of the most significant countries with the largest area of organic cocoa trees, covering approximately 162,498 hectares. Following closely is the Dominican Republic, with about 114,811 hectares, trailed by the Democratic Republic of the Congo with approximately 90,540 hectares, and Peru with around 52,786 hectares devoted to organic cocoa cultivation.

Notably, more than 60 % of organic cocoa trees are in Africa, spanning 312,857 hectares, while nearly 40 % are found in Latin America, covering 200,760 hectares.

Table 3.14. provides a detailed overview of the countries with the largest organic areas of coffee and cocoa trees by the end of 2022, based on statistics from FiBL & IFOAM (2024).

Table 3.14. Countries with the Largest Organic Areas of Coffee & Cocoa Trees in 2022.

Organic Coffee		Organic Cocoa	
Country	Area (Hectares)	Country	Area (Hectares)
Ethiopia	174,552	Sierra Leone	162,498
Peru	156,277	Dominican Rep.	114,811
Mexico	102,392	Congo D.R.	90,540
Colombia	74,600	Peru	52,786
Honduras	43,105	Ghana	16,482
Tanzania	32,481	Tanzania	15,244
Timor-Leste	32,311	Ecuador	10,753
Indonesia	31,355	São Tomé and Príncipe	7,077
Uganda	23,103	Madagascar	6,490
Congo D. R.	19,777	Côte d'Ivoire	5,476
Nicaragua	19,516	Bolivia	4,603
Guatemala	12,520	Uganda	4,288
Sierra Leone	8,989	Nicaragua	4,044
Brazil	4,636	Haiti	2,994
Lao P.D.R.	4,094	Dominica	2,907

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.2.5 Tropical and Subtropical Fruits

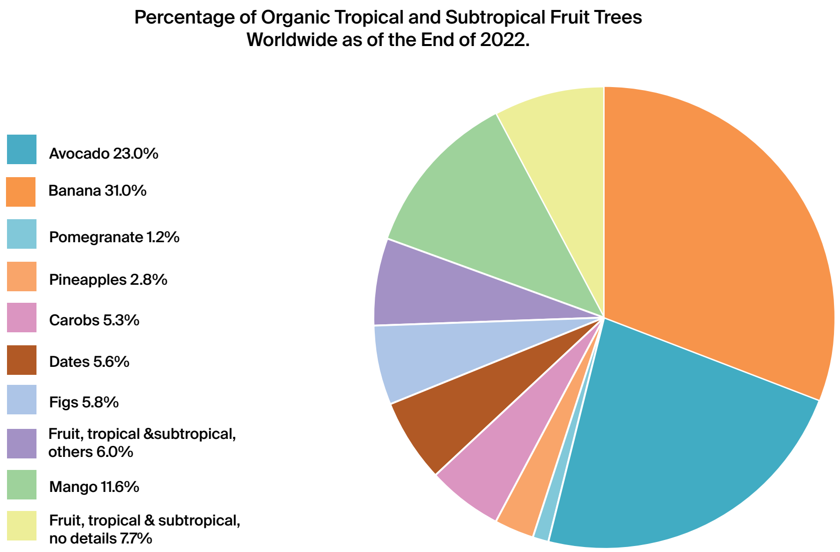
In 2022, approximately 295,000 hectares were under organic management for tropical and subtropical fruits, marking a significant increase from 2004 when organic cultivation covered only 41,000 hectares, representing an increase of over sevenfold.

Organic tropical and subtropical fruit areas comprise approximately 1.2 % of the total worldwide tropical and subtropical fruit areas, estimated at 24.8 million hectares according to FAO STATISTICS (2022). The top five countries in the production of these fruits are India, China, the Philippines, Brazil, and Thailand, each cultivating more than 1 million hectares.

In 2022, the leading countries in terms of organic tropical and subtropical fruit cultivation were Mexico, with 30,060 hectares, followed by Ethiopia with 29,729 hectares, Ecuador with 25,006 hectares, and the Philippines with 24,532 hectares.

Among organic tropical and subtropical fruits, bananas ranked first, covering 31.0 % of the total area, followed by avocados at 23 %, mangoes at 11.6 %, figs at 5.8 %, and date palm at 5.6 %. The Dominican Republic is renowned as a major exporter of organic bananas, while Mexico stands out for organic mangoes and avocados. Figure 3.12. illustrates the percentage areas of organic tropical and subtropical fruit trees worldwide as of the end of 2022.

Figure 3.12. Percentage of Organic Tropical and Subtropical Fruit Trees Worldwide as of the End of 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.2.6 Temperate Fruits

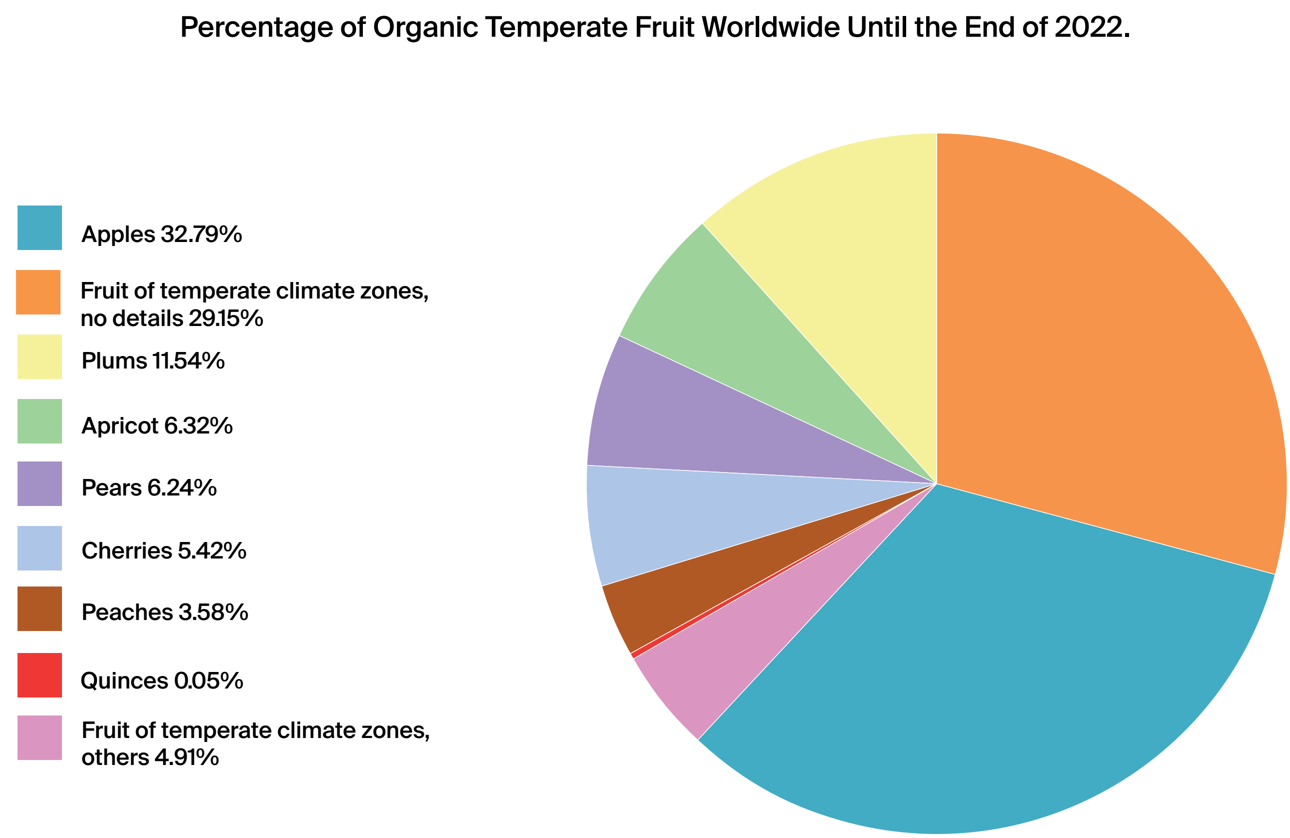
In 2022, the cultivation of organic temperate fruits covered approximately 332,000 hectares, marking a significant increase from the 97,000 hectares recorded in 2004. This expansion represents more than a threefold increase over the years. The area dedicated to organic temperate fruits accounts for approximately 2.6 % of the total global area of temperate fruits, estimated at 12.6 million hectares according to FAO STATISTICS (2022). The leading countries in temperate fruit production include China, Italy, France, Turkey, Poland, USA, Germany, Argentina, Spain, and Romania.

China emerged as one of the leading countries in organic temperate fruit cultivation in 2022, with approximately 126,000 hectares dedicated to this sector. Following China, Poland and Italy also made significant contributions, with approximately 30,714 and 30,354 hectares respectively.

Among organic temperate fruits, apples hold the highest share at 32.8 %, followed by plums at approximately 11.5 %, and apricots at 6.3 %. Figure 3.13. illustrates the percentage distribution of organic temperate fruits worldwide.

Table 3.15. presents the countries with the largest organic areas of tropical and subtropical fruits as well as temperate fruits until the end of 2022. Meanwhile, Table 3.16. provides a breakdown of organic tropical and subtropical fruit areas by continent, alongside temperate fruit areas, based on statistical data published by FiBL & IFOAM (2024).

Figure 3.13. Percentage of Organic Temperate Fruit Worldwide Until the End of 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.15. Countries with the Largest Organic Areas of Tropical & Subtropical and Temperate Fruits in 2022.

Organic Tropical & Subtropical Fruits		Organic Temperate Fruits	
Country	Area (Hectares)	Country	Area (Hectares)
Mexico	30,060	China	126,000
Ethiopia	29,729	Poland	30,714
Ecuador	25,006	Italy	30,354
Philippines	24,532	France	28,048
Türkiye	20,546	USA	18,146
Dominican Republic	18,813	Türkiye	14,017
Tunisia	17,066	Romania	9,541
Kenya	15,818	Spain	9,293
Burkina Faso	13,930	Germany	9,238
Peru	11,356	Hungary	7,453
Italy	10,956	Bulgaria	7,255
Spain	9,893	Argentina	7,156
Colombia	7,305	Chile	4,059
Saudi Arabia	6,000	Czechia	3,401
Madagascar	5,361	Congo D.R.	2,927

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.16. Organic Tropical & Subtropical and Temperate Fruits Area by Continent Until the End of 2022.

Organic Tropical & Subtropical Fruits		Organic Temperate Fruits	
Continent	Area (Hectares)	Continent	Area (Hectares)
Latin America	102,446	Europe	166,941
Africa	98,425	Asia	127,542
Europe	46,065	North America	18,815
Asia	43,901	Latin America	12,598
North America	4,125	Africa	5,708

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.7.2.7 Citrus Fruits

In 2022, organic citrus cultivation covered over 115,000 hectares worldwide, marking a fourfold increase from the 29,000 hectares reported in 2004. This area accounts for approximately 1.1 % of the world's total citrus cultivation area, estimated at 10.6 million hectares according to FAO STATISTICS (2022). The leading countries in citrus production, based on FAOSTAT data, include India with 0.9 million hectares and Brazil with 0.8 million hectares.

Between 2013 and 2015, there was a notable decrease in the organic citrus area, estimated at about 13 %. In 2013, the organic citrus area stood at approximately 82,000 hectares, declining to about 71,000 hectares by 2015, as reported by FiBL & IFOAM (2017). Furthermore, in 2022, there was a further decline in organic citrus area, with a decrease of 3.3 % (equivalent to -3,955 hectares) compared to 2021.

These reductions in organic citrus production areas have been observed since 2005, following a peak increase. One potential contributing factor to this trend is the impact of citrus greening disease, caused by a type of mycoplasma transmitted by two species of Citrus Psylla: The Asian Citrus Psyllid (*Diaphorina citri*) and The African Citrus Psyllid (*Trioza erytreae*).

In 2022, the organic citrus production landscape encompassed various fruits, including oranges, limes, sweet lemons, grapefruits, tangerines, pomelos, and others. Oranges comprised approximately 27% of organic citrus fruit, while lemons and limes accounted for 21 %. Tangerines made up about 5 % of the organic citrus production, with grapefruits and pomelos contributing 2 %. However, specific crop details were unavailable for approximately 44 % of the organic citrus area. Figure 3.14. illustrates this distribution.

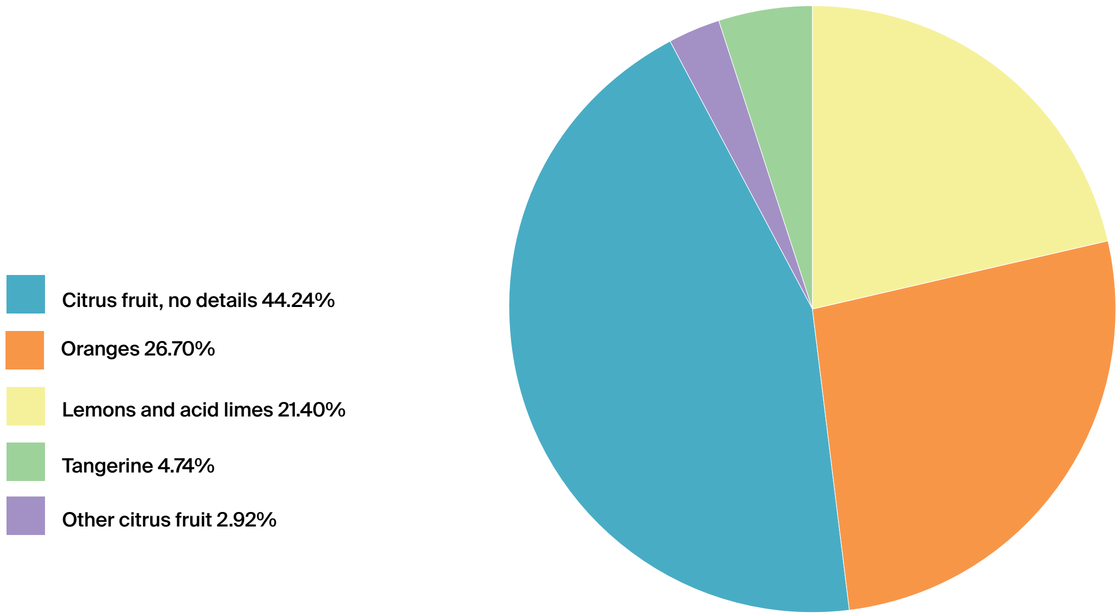
Table 3.17. illustrates the countries with the largest areas of organic citrus fruits according to statistics compiled by FiBL & IFOAM (2024). Across different production regions, Europe emerged as the primary hub for organic citrus production, totalling over 61,200 hectares. Italy led the region with 31,218 hectares, closely followed by Spain with 25,821 hectares.

Latin America also made significant contributions, covering 28,565 hectares. Mexico led the region with over three-quarters of the total hectares, amounting to 21,492 hectares. Argentina followed as the second-largest contributor with 3,342 hectares by 2022.

Despite favourable climatic conditions for organic citrus cultivation, Africa lagged with only 6,534 hectares in 2022. Notable African producers of organic citrus included Morocco with 1,935 hectares, Egypt with 1,303 hectares, and South Africa with 1,099 hectares.

Figure 3.14. Percentage of Organic Citrus Fruit Worldwide Until the End of 2022.

Percentage of Organic Citrus Fruit Worldwide Until the End of 2022.



Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

Table 3.17. Countries with the Largest Organic Areas of Citrus Fruits in 2022.

Country	Area (Hectares)
Italy	31,218
Spain	25,821
Mexico	21,492
China	13,000
USA	5,477
Argentina	3,342
Greece	2,136
Morocco	1,935
Egypt	1,303
South Africa	1,099
Ghana	1,047
Guatemala	935
France	812
Ecuador	722
Türkiye	708

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.

3.8 Organic Agriculture in the Arab World

A 2024 survey conducted by the Research Institute of Organic Agriculture (FiBL) in Switzerland and the International Federation of Organic Agriculture Movements (IFOAM) reveals significant progress in organic agriculture across the Arab world. By the end of 2022, organic farming practices were adopted in 15 Arab countries, covering approximately half a million hectares of cultivated land. The region also saw a substantial increase in organic producers, totalling around 16,000 individuals. This marks a significant improvement over 2015, when the total organic agricultural area was 442,000 hectares, with only 8,000 organic producers.

In addition to cultivated organic farmland, there is a significant area of wild organic land, totalling approximately 363,000 hectares across the Arab world. Morocco stands out as the largest Arab country in terms of wild organic land areas and natural products, boasting approximately 268,000 hectares. Morocco's wild organic products include a variety of forest products, pastures, and medicinal and aromatic plants.

The distribution of organic agricultural land in the Arab world is concentrated in several key countries. Tunisia, Egypt, Saudi Arabia, Morocco, Palestine, the United Arab Emirates, and Syria collectively account for over 97 % of the total organic agricultural land area in the region.

In 2022, Tunisia had the largest expanse of organic farmland in the Arab world, encompassing an estimated area of approximately 227,582 hectares. This accounted for over half of the total organic farmland in the Arab world and made up around 2.3 % of Tunisia's total agricultural land. The country also boasted a significant number of organic producers, totalling 9,249 individuals.

Notably, organic olive trees dominated Tunisia's organic land area, constituting approximately 78 % of the total organic agricultural land, with an impressive area of 178,171 hectares dedicated to organic olive cultivation.

Following Tunisia, Egypt secured the second position with approximately 116,000 hectares of organic agricultural land in 2022. This area accounts for approximately 25 % of the total organic agricultural land in the Arab world and represents around 3 % of Egypt's overall agricultural area. As of 2022, Egypt has a total of 970 organic producers actively engaged in organic farming practices.

Egypt holds the distinction of being the first Arab country to implement organic agriculture systems, achieving this milestone in the 1970s. Pioneering this movement, Egypt established SEKEM Company, the first agricultural enterprise dedicated to organic farming in the region. SEKEM preceded all other Arab agricultural initiatives in adopting documented organic agriculture practices and has contributed significantly to the global organic agriculture movement recognized by the Food and Agriculture Organization of the United Nations (FAO). Additionally, Egypt stands out as the largest producer of organic cotton in the Arab world. As of 2020, the country has 18 producers engaged in organic cotton cultivation, covering an estimated area of approximately 198 hectares.

Sudan follows Egypt as the next significant country in organic agriculture, boasting approximately 70,177 hectares of organic farmland. This represents around 14 % of the Arab world's total organic farmland but only 0.1 % of Sudan's overall agricultural land. Impressively, Sudan saw remarkable growth in its organic land area, expanding by 69,217 hectares in 2022. By 2022, arable land dominated the organic landscape in Sudan, covering the largest portion with 53,115 hectares, followed by permanent crops accounting for 5,327 hectares.

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The Kingdom of Saudi Arabia follows closely with approximately 23,315 hectares of organic agricultural land as of 2022, which represents about 5 % of the total organic area in the Arab world. In Saudi Arabia, there were a total of 512 organic producers actively engaged in organic farming practices. Saudi Arabia boasts substantial areas dedicated to tropical and subtropical fruits, estimated at around 6,000 hectares, with organic date palm cultivation covering approximately 3,000 hectares. Organic date production is particularly significant in Saudi Arabia, with an estimated 88 producers, 42 of whom are transitioning to organic status. By 2021, Saudi Arabia's annual production of organic dates reached approximately 14,000 tons.

Next, the Kingdom of Morocco has approximately 18,531 hectares of organic agriculture as of 2022, representing about 0.1 % of the total organic agricultural land in the Arab world. Morocco's organic agricultural landscape includes significant areas dedicated to organic olive trees, estimated at 5,903 hectares, and organic citrus cultivation covering approximately 1,935 hectares. In 2022, Morocco boasted a total of 470 organic producers actively involved in organic farming practices.

In the United Arab Emirates (UAE), the total area of organic agricultural land reached approximately 5,419 hectares by 2022, accounting for about 1.4 % of the total organic agricultural land in the Arab world. The UAE's organic agricultural sector includes the cultivation of medicinal and aromatic plants, with wild collection covering an area of 2 hectares. By 2022, the UAE had 152 organic producers actively engaged in organic farming practices.

The State of Palestine boasts approximately 4,830 hectares of organic agricultural land, with organic olive cultivation dominating the landscape, covering 4,656 hectares as of 2022. The number of organic producers in Palestine was estimated at 1,504 in 2022.

In Syria, the area of organic agricultural land was estimated to be around 20,000 hectares in 2019, representing approximately 0.1 % of the total organic agricultural land in the Arab world.

The Sultanate of Oman has undertaken an ambitious project to establish one of the largest organic date palm plantations globally, aiming to plant one million date palm trees. By 2017, approximately 200,000 organic date palm trees had been planted in the Al-Dhahirah Governorate alone as part of this initiative.

Date palm cultivation is widespread, with approximately 30 countries around the world engaged in this practice. The global population of date palms is estimated to be around 120 million trees, producing approximately 7.5 million tons of dates according to FAO STATISTICS (2022).

Notably, about 70 % of the world's date palms are found in the Arab world, and Arab countries collectively account for approximately 67 % of the global production of dates. Tunisia, Saudi Arabia, the United Arab Emirates, and Egypt are recognized for having some of the largest areas of organic date palm cultivation globally, solidifying their prominence in the Arab world.

Organic agricultural land accounts for about 8.8 % of the total agricultural area across Arab countries. Countries such as Tunisia, Egypt, and those within the Gulf Cooperation Council (GCC) have specific standards and regulations governing the organic agriculture system. These standards are mandatory for all involved in the production, processing, and trading of organic products, ensuring compliance with both domestic market requirements and those of foreign export markets.

Tunisia holds the distinction of being the first Arab country to align its organic agriculture regulations with those of the European Union (EU), streamlining the process of exporting organic agricultural products from Tunisia to any EU member country.

Table 3.18. presents the area of organic agricultural land and the number of organic producers in Arab countries until the end of 2022, along with the share of organic agriculture in the total agricultural area in each country. These statistics are based on data compiled by FiBL & IFOAM in (2024).

Table 3.18. Area of Organic Agricultural Land in Arab Countries Until the End of 2022.

Country	Area of Organic Agricultural Land (Hectares)	Number of Organic Producers	Share of Organic Agriculture (%)
Tunisia	227,582	9,249	2.3
Egypt	116,000	970	3.0
Sudan	70,177	2	0.1
Saudi Arabia	23,315	512	0.01
Morocco	18,531	470	0.1
United Arab Emirates	5,419	152	1.4
State of Palestine	4,830	1,504	1.0
Jordan	1,478	16	0.1%
Lebanon	1,466	124	0.2
Algeria	1,071	74	0.003
Comoros	699	2	0.5
Iraq	63	1	0.001
Kuwait	25	1	0.02
Sultanate of Oman	7	1	0.0005
Syria	19,987 (2019)	2458	0.1
Total	**490,650**	**15,536**	**8,83 %**

Source: FiBL & IFOAM – Organics International (2024): The World of Organic Agriculture.


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Chapter 4

4. Soil fertility & fertilization strategies in Organic Agriculture

4.1 Soil Fertility

The 32nd President of the United States, Franklin Delano Roosevelt, aptly stated in 1937:

"The nation that destroys its topsoil destroys itself".

This sentiment rings true because soil, its fertility, and its preservation form the cornerstone of agricultural progress in any nation.

Soil management is paramount to the success of organic agriculture. All practices within organic farming aim to maintain and improve soil fertility. The nourishment and preservation of soil fertility stand as one of the primary goals of organic agriculture. By enriching the soil and increasing its organic matter content, plants receive the necessary nutrients for their growth and development.

Fertile soils with a balanced nutritional content play a crucial role in organic agriculture by promoting robust plant growth. Consequently, organic farming often yields high-quality crops in comparable or even superior quantities to those of traditional agriculture. This reality contradicts the misconception that organic farming leads to a scarcity of crops in both quantity and quality, an erroneous belief. Organic agriculture prioritizes providing plants with all the necessary nutrients for optimal growth, resulting in bountiful harvests of high-quality produce. In fact, organic crops are no less in quality compared to those grown through conventional agricultural practices.

Hence, it can be asserted that nurturing the soil to enhance its fertility is essential for nourishing plants. This principle underscores the importance of 'feeding the soil to feed the plants.' There are various methods employed to achieve this, including adding compost, utilizing green manure, employing cover crops, and implementing appropriate crop rotation.

It is noteworthy that one of the rules and standards governing organic agriculture stipulates that virgin land, which has not been previously cultivated, must undergo a minimum period of 12 months before its products are eligible for organic certification. This requirement ensures that the virgin soil has had time to develop and become biologically active. During this period, microorganisms in the soil proliferate and flourish, thereby contributing essential nutrients to facilitate the natural growth of plants. Adhering to the rules and standards of organic agriculture when cultivating virgin land allows to produce high-quality organic crops in both quantity and quality.

Soil fertility is commonly assessed based on the availability of organic matter, which originates from both plant and animal sources. The percentage of organic matter in agricultural soil can vary significantly depending on environmental conditions. It may exist in minimal quantities or exceed 15-20 %. However, high temperatures can accelerate the decomposition of organic matter, leading to the conversion of nutrients into forms less beneficial for plant growth.

In dry and semi-arid regions, as well as areas with sandy soils low in organic matter, it is essential to consistently supplement agricultural soils with organic matter to enhance their properties and boost productivity across various crops. Soil organic matter serves as a reservoir of nutrients crucial for plant growth, contributes to soil structure improvement, and aids in the formation of complex granules.

Additionally, organic matter plays a vital role in soil aeration and root penetration by mitigating groundwater levels through efficient water leaching. Moreover, the colloidal granules of organic matter possess numerous negative charges, enhancing their capacity to absorb nutrients and ultimately increasing soil fertility.

Throughout history, humans have recognized the significance of incorporating organic matter into soil to enhance its properties and maintain fertility. Ancient civilizations, such as the Egyptians, depicted in temple drawings, demonstrated this understanding by separating wheat spikes during harvesting to collect grains while leaving crop residues from stalks and leaves for animal grazing. Subsequently, the remaining plant and animal residues were integrated into the soil, enriching its fertility and organic matter content.

The concept of the importance of organic matter, or humus, in relation to soil fertility gained widespread recognition from the 16th century onward. This theory can be traced back to the philosopher Aristotle (350 B.C.), who proposed that plants derive their nutrients through their roots from humus, which is decomposed organic matter. Upon the plant's death, its roots contribute to the formation of humus, perpetuating the cycle.

4.1.1 Importance of Organic Matter (Humus)

Humus in soil is formed through the gradual decomposition of organic matter by soil microorganisms, rather than chemical reactions. One of its key characteristics is its dark brown or black colour, along with its aromatic nature. Humus does not dissolve in water but forms a colloidal solution. However, it dissolves significantly in dilute alkaline solutions, especially when boiled, resulting in a dark-coloured extract. Upon neutralization with mineral acids, a large portion of this extract precipitates.

Humus is distinguished by its high carbon content, which exceeds that found in plant and microbial bodies, typically ranging from 55 % to 58 %. This elevated carbon percentage is attributed to the presence of lignin. Additionally, humus contains a considerable amount of protein, which may reach up to 17 %.

Green plant residues serve as the primary material for the formation of humus. These residues undergo transformation through the biological interactions of microorganisms present in the soil. Humic substances are characterized by compounds with large molecular weights, formed through the polymerization and condensation of various molecules with low molecular weights. Humus primarily comprises Fulvic acid, Humic acid, and Humin.

4.1.1.1 Fulvic Acid

Fulvic acid is a group of chemicals that form when plants and animals break down. It is found in the humus (organic matter) of soil, peat, streams, and lakes. Fulvic acid is characterized by high molecular weights and similar structures. Its colour typically ranges from light yellow to yellowish-brown, and it is soluble in water. The name 'fulvic acid' is derived from the Latin word 'fulvus,' meaning yellow, reflecting its colouration. Fulvic acid exhibits a high capacity for chelating minerals in the soil due to the presence of carboxylic acid groups. Ionic colloids of fulvic acid form stable complex compounds with polyvalent cations such as aluminium, copper, and iron.

4.1.1.2 Humic Acids

Humic acids (HA) are organic molecules that play vital roles in enhancing soil properties, promoting plant growth, and optimizing agronomic parameters. They can be sourced from various materials, including coal, lignite, soils, and organic matter. Representing most humus compounds in soil, Humic acids do not dissolve in water and are soluble in alkaline solutions but insoluble or only partially soluble in acidic solutions. Humic acids form fine granules that aggregate to create a dark brown spongy network. They possess a high capacity to retain water and carry strong negative charges, facilitating the exchange of cations and regulating oxidation and reduction processes, thus supplying oxygen to plant roots. Like fulvic acid, they form complex compounds with mineral ions, improving soil properties and facilitating the movement of essential nutrients, particularly nitrogen. In agriculture, Humic acids are often used as soil amendments or additives to enhance soil health and fertility. They are available in various forms, including liquid concentrates, granules, and powders, and are applied to soils to improve nutrient uptake, water retention, and overall plant health.

4.1.1.3 Humin

Humin is the most stable Humic compound found in soil, characterized by its high molecular weight. Unlike other Humic substances, it does not dissolve in water and forms strong bonds with colloidal minerals, particularly clay minerals. Humin derives its composition primarily from lignin, a complex organic polymer found in plant cell walls.

4.1.2 Soil as a Source of Nutrients

Fertile soil serves as the primary natural source of nutrients essential for plant growth. Acting as a natural storehouse, soil supplies plants with the necessary elements in the right proportions to support normal growth.

Plants require several essential elements to support their growth, tissue formation, and various vital processes necessary to complete their life cycle. Among these elements, 16 are considered fundamental. Three of these elements, i.e. carbon, hydrogen, and oxygen, are primarily sourced from water and carbon dioxide. Through photosynthesis, plants synthesize simple carbohydrates in their leaves in the presence of light, with these three elements constituting approximately 91 % of the plant's dry weight. The remaining 13 essential elements necessary for plant growth are obtained from the soil, underscoring the importance of soil in providing plants with these nutrients. These thirteen elements can be categorized as follows:

4.1.2.1 Macronutrients

Plants require macronutrients in larger quantities, typically ranging from 0.2 % to 4.0 % of their dry weight. These macronutrients can be categorized into two groups:

* Primary Nutrients

Primary nutrients are those essential elements required by plants in significant amounts. They include Nitrogen (N), Phosphorus (P) and Potassium (K). These elements are typically measured in milligrams per gram of soil or parts per million (PPM). Due to the high demand from plants during the growth period, primary nutrients are quickly depleted from the soil. On average, plant dry matter contains approximately 1.5 % nitrogen, 0.2 % phosphorus, and 1 % potassium.

* Secondary Nutrients

Secondary nutrients are required by plants in moderate quantities and are typically found in ample amounts in the soil. They include Calcium (Ca), Magnesium (Mg) and Sulfur (S). These elements are usually not continuously added to agricultural soil as they are often present in sufficient quantities. On average, plant dry matter contains approximately 0.5 % calcium and 0.1 % sulfur.

The importance of these elements, their sources, their impact on plant growth, as well as the symptoms of their deficiency in plants, are described below.

- **Nitrogen (N)**

Nitrogen is an essential element for plants, playing a crucial role in various physiological processes. It is involved in the synthesis of chlorophyll, the green pigment responsible for photosynthesis and the production of starches and sugars. Each chlorophyll molecule contains four nitrogen atoms. Additionally, nitrogen is a component of nucleic acids, vitamins, certain plant hormones, and enzymes. In the soil, nitrogen is typically found in the form of nitrate ions (NO_3^-) and ammonium ions (NH_4+). Plants acquire nitrogen primarily through three main sources:

» **Atmospheric Nitrogen Fixation:** Approximately 79% of the Earth's atmosphere is composed of nitrogen gas (N_2). Certain soil microorganisms, such as nitrogen-fixing bacteria, can convert atmospheric nitrogen into a usable form for plants. However, these microorganisms require specific conditions to thrive, such as adequate moisture, oxygen, and appropriate pH levels.

» **Biological Nitrogen Fixation:** Some plants form symbiotic relationships with nitrogen-fixing bacteria, such as those found in legume root nodules. These bacteria convert atmospheric nitrogen into ammonia, which can then be utilized by the host plant.

» **Mineral Nitrogen Fertilizers:** In agricultural settings, nitrogen fertilizers are commonly used to supplement soil nitrogen levels and promote plant growth. Examples of mineral nitrogen fertilizers include urea, ammonium sulfate, and ammonium nitrate.

By utilizing these various nitrogen sources, plants can fulfil their nitrogen requirements and support healthy growth and development.

In agricultural soil, nitrogen primarily originates from organic residues and atmospheric nitrogen fixed by both symbiotic and non-symbiotic nitrogen-fixing organisms, as well as from water or rainfall. Nitrogen in soil exists predominantly in organic form, with a smaller percentage present in mineral form, mainly as nitrate and ammonium ions, which are soluble in soil solution or held in exchangeable forms. Organic nitrogen constitutes the majority, ranging from 95 % to 99 %, and is primarily found in the form of proteins, Humic substances, and other complex organic compounds.

Various microorganisms present in the soil decompose organic compounds and proteins, leading to the formation of amino compounds and amino acids under aerobic conditions. During this process, known as mineralization, the amino compounds are further decomposed, releasing ammonia ions. Mineralization is a biological process through which soil microbes break down organic nitrogen from sources such as manure, organic matter, and crop residues into ammonium. The rate of decomposition in mineralization varies depending on soil temperature, humidity, and the level of oxygen present in the soil (aeration).

$$\underset{\textit{Nitrogen gas}}{N_2} \longrightarrow \underset{\textit{ammonia}}{NH_3} \longrightarrow \underset{\textit{organic N}}{R\text{-}NH_2}$$

$$\underset{\textit{organic N}}{R\text{-}NH_2} \longrightarrow \underset{\textit{ammonia}}{NH_3} \longrightarrow \underset{\textit{ammonium}}{NH_4^+}$$

Ammonium ions can undergo oxidation directly into nitrate through the process of Nitrification, during which microorganisms convert ammonium into nitrate to obtain energy. Nitrate ions are the predominant form of nitrogen available to plants, as they can be readily absorbed by both plants and microorganisms. However, nitrate ions are also susceptible to loss through leaching, where they can be washed away from the soil.

$$\underset{\textit{ammonium}}{2NH_4^+} \longrightarrow \underset{\textit{nitrite}}{NO_2^-} \longrightarrow \underset{\textit{nitrate}}{NO_3^-}$$

In organic agriculture, the loss of nitrate ions through leaching is generally lower compared to conventional agriculture. This is attributed to the presence of organic matter, which assists in binding nitrates. Additionally, nitrate ions can undergo reduction to gaseous forms, such as ammonia (NH_3) or nitrogen gas (N_2), through a process known as denitrification. Denitrification occurs under anaerobic conditions, where oxygen is limited.

$$\underset{\textit{nitrate}}{NO_3^-} \longrightarrow \underset{\textit{nitrite}}{NO_2^-} \longrightarrow \underset{\textit{nitric oxide}}{NO} \longrightarrow \underset{\textit{nitrous oxide}}{N_2O} \longrightarrow \underset{\textit{dinitrogen gas}}{N_2}$$

As previously mentioned, both ammonium ions and nitrates available for plant absorption can also be assimilated by living organisms in the soil, where they become incorporated into their biomass, thus transitioning into organic forms. This process is known as N-Immobilization. N-Immobilization occurs when the ratio of organic carbon to nitrogen in plant residues is high, typically at a ratio of 45:1 or higher. This process is temporary; as the percentage of carbon decreases over time, mineralization occurs, leading to the release of ammonium from the bodies of microorganisms.

It is important to note that inorganic nitrogen can be lost in various forms. In flood irrigation, especially in sandy soils, inorganic nitrogen may be lost in dissolved form with wastewater. Additionally, nitrogen can be lost in gaseous forms such as ammonia (NH3) and nitrogen oxides.

As previously mentioned, nitrogen plays a crucial role in various biochemical processes. It is involved in the synthesis of numerous enzymes and proteins. Furthermore, nitrogen is essential for producing chlorophyll, the green pigment responsible for photosynthesis, thereby contributing to the synthesis of plant biomass.

Symptoms of nitrogen deficiency manifest rapidly in older leaves, which exhibit weakening and a pale colouration. As the deficiency progresses, all leaves may turn yellow, become weak, and display stunted growth. Additionally, a greenish-yellow hue may be observed on the leaves due to the loss of chlorophyll. In the event of nitrogen deficiency, the available nitrogen is mobilized from older growth to support the development of new growth. Newer leaves tend to retain the nitrogen they acquire, supplemented by nitrogen transferred from older leaves.

Progressive nitrogen deficiencies can result in leaf shedding and thickening of plant branches due to the accumulation of carbohydrates. These carbohydrates, which are not utilized in the synthesis of amino acids and other nitrogenous compounds, contribute to the plant's structural changes. Furthermore, the excess carbohydrates may be used in the production of pigments such as anthocyanin. The accumulation of anthocyanin can lead to the discolouration of stems and leaves, causing them to turn purple in certain plant species.

In organic agriculture, the soil serves as the primary source of nutrients for plants. Therefore, it is crucial to focus on enhancing the natural, chemical, and biological properties of the soil. Soil acts as a reservoir, storing essential nutrients that plants require for their growth. By ensuring that the soil is enriched with these nutrients, plants can access them in a timely manner and in adequate quantities to meet their needs.

In organic agriculture, the cultivation of legumes plays a significant role in the agricultural cycle. Legumes have the unique ability to fix atmospheric nitrogen through a symbiotic relationship with the bacterium Rhizobia. This bacterium resides within the root nodules of legumes, where it forms a mutually beneficial partnership with the plant. Rhizobia receives carbon from the plant as an energy source, while in return, it fixes nitrogen from the atmosphere, providing it directly to the plant or releasing it into the soil upon decomposition of the root nodules.

Furthermore, the use of compost and green manure serves as another essential source of nitrogen in organic agriculture. These organic amendments enrich the soil with nutrients, including nitrogen, which becomes available to plants as it decomposes. Overall, integrating legumes into crop rotations and utilizing compost and green manure are key strategies in organic agriculture to enhance soil fertility and promote sustainable nutrient management.

Indeed, the addition of organic matter to the soil, such as organic fertilizers, stimulates the activity of various microorganisms, including heterotrophic bacteria and fungi. These microorganisms play a vital role in decomposing organic matter by oxidizing the carbon present within it. This process releases carbon dioxide, which combines with water in the soil to form carbonic acid, a weak acid that undergoes rapid decomposition.

As a result of this microbial activity and decomposition, the alkalinity of the soil decreases while the acidity (pH) increases due to the release of hydrogen ions from the decomposition of carbonic acid. Additionally, proteins present in organic matter are hydrolyzed by enzymes, leading to the conversion of proteins into amino acids and amino compounds, ultimately culminating in the production of ammonia (NH_3).

This natural process of decomposition and nutrient release is essential for soil health and fertility. It helps to replenish essential nutrients, improve soil structure, and create a favorable environment for plant growth. Therefore, the addition of organic matter is a fundamental practice in organic agriculture, contributing to sustainable soil management and enhanced agricultural productivity.

- **Phosphorus (P)**

Phosphorus (P) is an essential nutrient required by plants in significant quantities. Within a plant, phosphorus is a mobile element, translocating from older leaves located at the base of branches to younger leaves at the top. In the soil, phosphorus is predominantly absorbed by plant roots in the forms of H_2PO_{4-} and HPO_4^{2-} ions. Among these, H_2PO_{4-} is the initial form and is the most readily accessible and absorbable by plant roots.

After absorption, phosphorus does not undergo a reduction process like nitrates (NO_3) do; instead, it enters various biological processes within plant tissues in its oxidized form. Optimal availability of phosphorus in soils typically occurs within a pH range of 5.5 to 7.0. The highest concentrations of phosphorus are found in actively growing meristematic tissues, as well as in fruits and seeds during their growth and maturation stages.

This element is of utmost importance as it serves as a crucial component of protein substances. It binds with sugars within cells to form sugar-phosphate, which serves as an intermediate material during photosynthesis and respiration. Additionally, it combines with lipids to form phospholipids, integral components of plant membranes. Phosphorus is also involved in the synthesis of nucleotides and plays a role in the formation of energy-carrying compounds utilized in energy storage and transfer processes, such as ATP and ADP. Moreover, it serves as a cofactor for numerous enzymes, further highlighting its significance in various biochemical processes.

Phosphorus deficiency in plants impedes the synthesis of proteins, resulting in the accumulation of sugary substances within plant tissues. This accumulation triggers the formation of anthocyanin pigments, leading to a purple discolouration of affected tissues. Additionally, phosphorus deficiency causes dark green discolouration of leaves and necrotic spots on some tissues, ultimately resulting in the premature death of aged leaves and delayed fruit ripening.

Conversely, an excess of phosphorus in plants can lead to early fruit ripening, especially in fruit trees, as fruits, particularly seeds, are the richest parts of the plant in phosphorus content. Moreover, increased plant absorption of phosphorus, due to its abundance in the soil, can induce symptoms of zinc and iron deficiency, despite the availability of these elements in the soil.

As previously noted, symptoms of phosphorus deficiency typically manifest in older leaves due to its rapid mobility within the plant, translocating from older to newer foliage. The phosphorus content in soil is influenced by various factors, including the presence of organic matter, the geological composition of the soil, erosion levels, and the degree of phosphorus leaching from soil due to repeated washing.

In general, phosphorus exists in soil in two primary forms: mineral phosphorus and organic phosphorus. Mineral phosphorus is primarily found in poorly soluble compounds such as calcium, iron, and aluminium phosphate minerals. Soils in arid and semi-arid regions with minimal rainfall typically contain around 0.2 % phosphorus. Conversely, in desert lands characterized by low organic matter content, phosphorus levels in the soil may be as low as 0.02 %.

Indeed, the surface layer of soil typically harbours higher phosphorus content compared to the subsurface layers. This discrepancy arises because the surface layer tends to be richer in organic matter and fine-grained clay. However, the behaviour of phosphorus in soil varies depending on soil pH and composition.

In alkaline calcareous soils with a high pH, phosphorus often interacts with calcium carbonate, becoming adsorbed onto its surfaces or forming calcium phosphate compounds. Conversely, in acidic soils with a low pH, phosphorus tends to adsorb onto the surfaces of iron and aluminium oxides or precipitate as iron and aluminium phosphate compounds. These interactions influence the availability of phosphorus to plants and affect its mobility within the soil profile.

Organic phosphorus constitutes a significant portion of the phosphorus present in soil, originating from organic matter within the soil or added through organic fertilization practices. This organic matter contains phosphorus in various compounds, with phytin, nucleic acids, and phospholipids being among the most important.

The decomposition of organic matter, facilitated by enzymes secreted by soil microorganisms such as phosphatase, leads to the transformation of organic phosphorus into mineral phosphorus in a process known as P-Mineralization. This mineralized phosphorus becomes accessible for plant uptake. Microorganisms responsible for this process include certain species of *Penicillium* and *Aspergillus* fungi, as well as *Bacillus* bacteria.

The rate of organic phosphorus mineralization is influenced by the carbon-to-phosphorus ratio in the organic matter. When this ratio is less than 200:1, mineralization prevails, resulting in the conversion of organic phosphorus into plant-available forms. However, if the ratio exceeds 300:1, mineral phosphorus in the soil may be immobilized into organic phosphorus within the bodies of microorganisms through a process known as catabolism or P-Immobilization.

- **Potassium (K)**

Potassium is crucial for plant growth and development, primarily existing in plants as K^+ cations. It ranks among the most vital nutrients required by plants, often needed in larger quantities than any other element except nitrogen. In certain stages of growth, such as during fruit development, ripening, and colouration, the demand for potassium may even exceed that of nitrogen.

Unlike other essential nutrients like nitrogen, phosphorus, and calcium, potassium does not actively participate in the synthesis or building of organic compounds within plants. Instead, it remains primarily in its ionic form (K^+) within the cell sap of plant cells.

Potassium serves multiple crucial functions in plant physiology. It is instrumental in regulating osmotic pressure within plant cells, ensuring proper water balance. Additionally, potassium activates numerous enzymes involved in essential metabolic processes such as photosynthesis, respiration, oxidation, and protein synthesis in meristematic cells.

Furthermore, potassium plays a pivotal role in chlorophyll synthesis, contributing to healthy and vibrant plant foliage. Its presence helps prevent symptoms of toxicity caused by ammonia accumulation in plant tissues, a condition often associated with potassium deficiency. Moreover, potassium supports cell division processes, promoting overall plant growth and development.

Potassium exhibits mobility within plants, swiftly translocating from older leaves towards newly developing tissues. Consequently, symptoms of potassium deficiency typically manifest first in older leaves. These symptoms often include yellowing along the edges of the leaf blade, followed by desiccation and drying of affected foliage. Furthermore, plants deprived of an adequate potassium supply become more vulnerable to soil-borne fungal infections, heightening their susceptibility to various pathogens. Thus, ensuring sufficient potassium levels is essential for bolstering plant health and resilience against fungal diseases.

In fruit trees, potassium absorbed by the roots is stored in the woody tissues and bark during autumn and winter. Subsequently, as spring arrives, this stored potassium is mobilized and transferred to new tissues, particularly the developing fruits, followed by the leaves. Consequently, there is often a noticeable decrease in the potassium content of the leaves during years of abundant fruit bearing.

Different crops have varying requirements for potassium throughout their growth stages. For instance, tuberous crops like potatoes, as well as tomatoes and certain fruit trees such as citrus and mangoes, necessitate substantial amounts of potassium. Conversely, legume crops have the capacity to fulfil their potassium requirements from the soil during their growth cycle.

It has been observed that the level of potassium in soil tends to rise with increasing soil pH, indicating a correlation with soil alkalinity. In alkaline soils, the addition of gypsum (calcium sulfate) can aid in the conversion of non-exchangeable potassium into exchangeable potassium forms. This conversion renders the potassium more readily available for absorption by plants.

Adding organic fertilizers in organic farming has the added benefit of reducing potassium loss through leaching, as potassium tends to bind to Humus in exchangeable forms. While the use of potassium sulfate is not permitted in organic farming, it can serve as a transitional source of potassium during the shift from conventional to organic farming practices. The primary source of potassium in organic agriculture is through the incorporation of plant and animal waste into organic farms, typically in the form of compost, also known as manufactured organic fertilizer.

- **Calcium (Ca)**

Calcium is considered one of the major nutrients for plants, absorbed in the form of ions (Ca^{2+}). Its significance lies in its role as a component of the middle lamellae of plant cell walls, contributing to the hardening of plant tissues, particularly in fruits. For example, calcium deficiency in apple trees can result in bitter pits. Additionally, calcium plays a crucial role in cell elongation and division by influencing the spindle apparatus during cell division. It acts as a secondary messenger for hormonal and environmental stimuli by binding to a protein called Calmodulin, regulating various cellular processes. Furthermore, calcium facilitates the transportation of carbohydrates and amino acids and promotes root growth.

The presence of calcium counteracts the toxic effects of certain organic acids, such as oxalic acid, produced as a by-product during the breakdown of carbohydrates and proteins in food transformation processes. Oxalic acid can be toxic when present alone in plant tissues. However, calcium binds with oxalic acid to form non-toxic calcium oxalate crystals, which are then deposited in plant tissues. This mechanism helps neutralize the harmful effects of oxalic acid.

Calcium is typically abundant in older or mature tissues within plants. Calcium deficiency is rare under natural conditions. However, if a deficiency does occur, it typically manifests in young leaves since calcium is an immobile element within the plant. Symptoms of calcium deficiency include yellowing of the edges of young leaves, as well as their deformation and curling. Additionally, roots may exhibit abundant branching but appear short, and their colour tends to turn brown.

The deficiency of calcium can also result in severe stunting of growth or even death under conditions of severe deficiency. Increased absorption of certain elements such as potassium, sodium, or magnesium due to their availability in the soil can exacerbate symptoms of calcium deficiency.

It is noteworthy that the availability of calcium for plant uptake decreases as soil pH increases, particularly in alkaline soils where it forms insoluble mineral compounds. In such conditions, adding calcium sulfate (gypsum) can help by displacing sodium adsorbed on soil colloids. Conversely, in acidic soils where pH drops significantly, calcium mineral compounds become more soluble. Dolomitic limestone and gypsum are both excellent sources of calcium.

Organic materials present in the soil or added through organic fertilizers contribute significantly to the decomposition of mineral calcium compounds. This process involves the release of carbon dioxide gas from organic matter, which dissolves in irrigation water to form carbonic acid. Carbonic acid then acts on calcium carbonate, converting it into dissolved calcium bicarbonate in the soil solution. As a result, calcium is released in the form of ions (Ca^{2+}) in the soil solution, making it available for plant uptake.

- **Magnesium (Mg)**

Magnesium is absorbed by plants in the form of ions (Mg^{2+}), and its significance lies in its involvement in the synthesis of chlorophyll molecules in all green plants. Additionally, magnesium is crucial for the formation of nuclear proteins and for activating enzymes responsible for photosynthesis and respiration. Furthermore, magnesium plays a vital role in the synthesis and formation of oils and fats in certain fruits, including olives, avocados, and nuts such as walnuts, pecans, almonds, and hazelnuts.

Since magnesium readily moves from older leaves to younger ones, symptoms of magnesium deficiency typically manifest in aged leaves as confined yellowing of the leaf blade. This is because chlorophyll within the vascular bundles moves slower compared to chlorophyll outside the bundles. Severe deficiency of magnesium results in complete yellowing of the leaf blade followed by leaf fall. Soil minerals, organic matter, and dolomitic limestone are among the primary sources of magnesium. Dolomitic limestone, chemically known as calcium magnesium carbonate, is particularly rich in magnesium.

- **Sulfur (S)**

Sulfur is a crucial element for plant growth, with plant sulfur content equalling its phosphorus content. Plants absorb sulfur through their roots in the form of sulfate ions (SO_4^{2-}). Sulfur's importance lies in its involvement in the synthesis of certain vitamins and sulfur-containing amino acids essential for protein formation, such as cysteine and methionine. Some plants can have sulfur concentrations in these amino acids as high as 5.0-5.1 %. Plants can only absorb sulfur in the form of sulfates, which are then reduced to the active form after absorption. Although sulfur doesn't directly become part of the chlorophyll molecule, it plays a crucial role as a catalyst in chlorophyll synthesis. Additionally, sulfur promotes root growth, seed production, and enhances plant resistance to cold.

In soil, 50-70 % of sulfur exists in organic form. For this organic sulfur to become available for plant uptake, it needs to be converted from organic to mineral form. This conversion process is facilitated by enzymes secreted by soil microorganisms. The mineralization of sulfur increases as its concentration in organic matter rises. However, the degradation of sulfur in the soil also increases with higher ratios of carbon to sulfur and nitrogen to sulfur.

In alkaline soils, sulfur supplementation may be necessary for remediation. Specialized bacteria like *Thiobacillus* oxidize sulfur, resulting in the formation of sulfates. These sulfates then react with calcium to produce calcium sulfate. Additionally, natural deposits of gypsum ($CaSO_4 \cdot 2H_2O$) can be utilized to amend alkaline soils.

Symptoms of sulfur deficiency often mimic those of nitrogen deficiency, such as poor growth, yellowing of leaves, and anthocyanin pigment accumulation. However, a key difference is that the symptoms of sulfur deficiency typically manifest on young leaves first, unlike nitrogen deficiency where symptoms appear on older leaves initially. This discrepancy is due to the slower translocation rates of sulfur from old leaves to young leaves compared to nitrogen.

Soils rich in organic matter typically do not experience sulfur deficiency because organic matter serves as a sulfur reservoir. Sulfur is particularly vital for certain crops such as onions and plays a crucial role in the formation of fruits in crops like peppers, cherries, and plums.

4.1.2.2 Micronutrients

Micronutrients, also known as trace elements or minor elements, are vital for plant growth despite being required in small quantities. They are present in plant tissues in trace amounts and are estimated in soil in micrograms per gram of dry soil, typically measured in parts per billion (ppb). These micronutrients include iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), chloride (Cl), and molybdenum (Mo). These elements are essential for various metabolic processes within plants and are crucial for their overall health and development. The concentration of these essential micronutrients in plant dry matter typically ranges from 6 to 100 parts per million (ppm), although some may be present in even smaller amounts, such as molybdenum, which is found at an average concentration of 0.06 ppm.

Each micronutrient plays a specific role in plant physiology, affecting processes such as enzyme activation, photosynthesis, nutrient uptake, and cell division. Deficiencies in these micronutrients can lead to various symptoms and negatively impact plant growth and productivity. Understanding the importance of micronutrients, their sources, their effects on plant growth, and the symptoms of their deficiency is crucial for maintaining optimal plant health and maximizing crop yields.

- **Iron (Fe)**

Iron (Fe) is an essential micronutrient for plant growth, absorbed by plants primarily in the form of ferrous ions (Fe^{2+}) and occasionally as ferric ions (Fe^{3+}). However, upon absorption, plants typically reduce ferric ions to ferrous ions, which are more readily utilized. Iron is categorized as an immobile element within plants, meaning it does not translocate from older leaves to younger leaves.

The significance of iron lies in its incorporation into various enzymes that participate in electron transfer processes, such as cytochromes. Cytochromes are essential components of the electron transport chain, facilitating the transfer of electrons during cellular respiration and photosynthesis. In these reactions, iron ions undergo reversible oxidation and reduction reactions, transitioning between the ferrous (Fe^{2+}) and ferric (Fe^{3+}) states as they transport electrons.

Overall, iron plays a vital role in electron transport and energy metabolism within plant cells, contributing to fundamental processes like respiration and photosynthesis. Its availability and proper utilization are crucial for maintaining healthy plant growth and development. While iron is not directly involved in chlorophyll synthesis, its presence is crucial for the construction of chlorophyll molecules. Despite being required in only small amounts, iron is indispensable for plant growth.

Iron deficiency symptoms often arise not from a lack of iron in the soil, but rather from its limited solubility. In alkaline soils rich in calcium carbonate, iron salts tend to be less soluble, leading to symptoms of iron deficiency in plants grown in such conditions. To address this issue, soil conditioners can be added to increase iron availability. For instance, mineral sulfur or agricultural gypsum can be added to alkaline soils to enhance iron solubility and alleviate deficiency symptoms.

Organic matter also plays a role in improving iron availability to plants. Organic matter forms chelating compounds that bind with iron, making it more soluble and accessible to plant roots. Therefore, incorporating organic matter into the soil can help mitigate iron deficiency in plants by enhancing iron uptake.

Research has demonstrated that iron is biologically active in its reduced form (ferrous), and the conversion from its oxidized form (ferric) to the reduced form is influenced by the presence of manganese in plant tissues. Elevated levels of manganese in plant tissues can inhibit this reduction process, resulting in iron remaining in the ferric form, which is less usable by the plant even if it is present in sufficient quantities.

Symptoms of iron deficiency typically manifest as interveinal chlorosis, where the areas between leaf veins turn yellow while the veins themselves remain green. This is primarily observed in young leaves due to the slow translocation of iron ions from older leaves to newer ones. In severe cases of deficiency, leaves may become completely white. The inability of iron to migrate from older leaves to younger ones can be attributed to its deposition in the form of phosphate salts or insoluble oxides within the older leaves. Additionally, iron may form compounds with phytosiderophores, which are immobile protein compounds that impede the long-distance transport of iron within the plant's vascular system. These factors contribute to the restricted movement of iron within the plant, resulting in localized deficiencies in younger tissues.

- **Manganese (Mn)**

Manganese is absorbed by plants in the form of divalent ions Mn^{+2}, and these ions play a crucial role in activating numerous enzymes involved in oxidation processes and preventing reduction processes, such as dehydrogenases and decarboxylases. Additionally, manganese is essential for the synthesis of chlorophyll and is necessary for the release of oxygen gas during photosynthesis. However, due to the relatively slow movement of manganese ions within plant tissues, deficiency symptoms typically manifest in newly grown tissues. These symptoms often present as yellow spots between the veins on the leaf blade, which may eventually turn brown.

The high alkalinity of soil, indicated by a high pH level, promotes the formation of insoluble manganese oxide compounds when manganese interacts with organic matter in the soil. This reduces the availability of manganese for plant uptake, particularly in alkaline soils rich in organic matter. As a result, alkaline soils are among the most prone to manganese deficiency in plants.

- **Zinc (Zn)**

Zinc (Zn) is absorbed by plants in the form of divalent ions (Zn^{2+}), and it is considered a heavy and immobile element within plants. Zinc plays a crucial role in activating numerous redox enzymes. Additionally, it is essential for converting ammonia into amino acids, which is a critical step in protein synthesis in plants. Furthermore, zinc is necessary for chlorophyll formation in certain plant species.

Symptoms of zinc deficiency typically manifest in plants grown in calcareous soils. A lack of zinc can result in stunted growth of shoots, reduced leaf size, leaf deformation, and curling of leaf edges. Yellow spots may appear on older leaves, leading to tissue death in these areas. This deficiency adversely affects the plant's ability to synthesize chlorophyll and produce auxins.

As mentioned earlier, zinc deficiency can result in various symptoms such as the shortening and stunting of branch internodes, small leaf size, and leaf deformities. In specific fruit trees, these symptoms are known by different names, such as "Rosette" in apples and pears, "Mottle Leaf" in citrus trees, "Little Leaf" in grapes, and "Yellows" in walnuts.

Furthermore, zinc plays a critical role in pollen germination on fruit tree flowers, which is essential for successful pollination, fertilization, and fruit set. Therefore, adequate zinc levels are crucial for maximizing yield in fruit crops.

It is important to note that high soil pH levels in alkaline and calcareous soils can reduce the availability of dissolved zinc in the soil. In such conditions, dissolved zinc tends to precipitate and form insoluble compounds like zinc hydroxide $Zn(OH)_2$ in alkaline soils or zinc carbonate $ZnCO_3$ in calcareous soils. This reduced availability of zinc exacerbates the risk of zinc deficiency in plants grown in these types of soils.

- **Copper (Cu)**

Copper, like many other micronutrients, is absorbed by plants primarily in the form of divalent ions, Cu^{+2}. It is categorized as a heavy element and, like zinc, is immobile within plant tissues. Copper ions play crucial roles in various enzymatic systems required for the synthesis of plant hormones. Additionally, copper facilitates the reduction of nitrate ions to ammonia, which serves as the initial step in protein synthesis.

The availability of copper to plants is influenced by soil properties such as the percentage of organic matter, the presence of calcium carbonate, and the soil pH level. In soils with higher organic matter content, copper tends to bind with carboxyl or phenol groups present in organic matter, forming stable compounds. Consequently, plants grown in organic-rich soils may exhibit severe copper deficiency. Furthermore, elevated concentrations of other micronutrients like iron or zinc can interfere with the absorption of copper by plants.

The deficiency of copper in plants manifests through specific symptoms. Initially, affected leaves may exhibit a dark green discolouration, often accompanied by the appearance of necrotic spots on the tips of young leaves. As the deficiency progresses, the edges of the leaf blade may become dry and exhibit signs of drought stress. Severe copper deficiency can result in leaf loss.

Importantly, copper plays a vital role in enhancing plant resistance against fungal diseases. Therefore, inadequate levels of copper may render plants more susceptible to fungal infections, further emphasizing the significance of maintaining appropriate copper levels for plant health and disease resistance.

- **Boron (B)**

Boron is absorbed by plants in the form of boric acid (H_3BO_3) and is considered a non-mobile element, meaning that symptoms of boron deficiency primarily manifest in recent plant growth. Despite its immobility, boron plays a crucial role in various physiological processes within plants.

One of its key functions is regulating the rate of water absorption by plants, thereby enhancing their resilience to drought conditions. Boron is also implicated in processes such as nucleic acid synthesis, hormone activation, cell elongation, and division. Furthermore, it influences the functions of cell membranes and facilitates the efficient transfer of carbohydrates and proteins from their sites of synthesis to other parts of the plant. Consequently, a deficiency in boron can result in the accumulation of these compounds in specific areas of the plant.

There exists a significant interaction between boron and calcium within plants. Interestingly, symptoms of boron deficiency are often followed by signs of calcium deficiency, despite the ample presence of calcium in plant tissues. Boron deficiency typically manifests as the development of black spots on the bases of young leaf blades. Moreover, insufficient boron adversely affects apical dominance, leading to increased branching and inhibition of cell division. Despite its role in facilitating rapid substance transport within plants, boron exhibits slow movement in plant tissues.

Excessive boron levels, surpassing the plant's requirements, can result in symptoms of toxicity. Plant species sensitive to excessive boron include soybeans, peaches, and grapes. Therefore, maintaining an optimal balance of boron is crucial for proper plant growth and development.

- **Chlorine (Cl)**

Chlorine is essential for plants, existing in plant tissues in the form of chloride ions (Cl^-). It plays a crucial role in the photooxidation process of water during photosynthesis, facilitating the release of oxygen. Additionally, chlorine is involved in the reduction processes of certain energy-rich compounds and likely contributes to cell division processes in both leaves and roots. Furthermore, it is believed to enhance plants' resistance to certain diseases.

When plants experience a deficiency of chlorine, they exhibit specific symptoms. Initially, the tips of the leaves may wilt, followed by the appearance of yellow spots across the blade. These spots may progress to necrosis, causing affected areas of the leaf to turn bronze. Insufficient chlorine levels can also lead to stunted root growth and thickening of root tips. Therefore, ensuring an adequate supply of chlorine is vital for maintaining healthy plant growth and development.

- **Molybdenum (Mo)**

Molybdenum (Mo) is an essential micronutrient for plant growth, absorbed by plants in the form of molybdate ions (MoO_4^{2-}). Despite being required in minute quantities, molybdenum plays a critical role in various enzymatic processes within plants. It is considered a non-mobile element, meaning that symptoms of deficiency typically manifest in the recent growth of plants.

One of the key functions of molybdenum ions is their involvement in the formation of several enzymes. For instance, molybdenum is a component of nitrate reductase, an enzyme that catalyses the conversion of nitrates to nitrites. Additionally, molybdenum is essential for nitrogenase, an enzyme responsible for converting atmospheric nitrogen into ammonia during nitrogen fixation carried out by soil microorganisms. Given its pivotal role in these enzymatic processes, ensuring an adequate supply of molybdenum is crucial for promoting healthy plant growth and maximizing crop yields.

Symptoms of molybdenum deficiency typically manifest as yellowing of the areas between the veins of young leaves. As the deficiency worsens, the older leaves may begin to dry out. These symptoms are particularly evident in plants that primarily obtain nitrogen through the fixation of atmospheric nitrogen. Molybdenum deficiency is more pronounced in plants grown in highly acidic soils with low pH levels.

The absence of sufficient molybdenum can hinder the formation of flower buds and result in the premature shedding of flowers. In alkaline soils, deficiencies in micronutrients like molybdenum often occur due to their low concentration in ionic form. This is primarily attributed to their precipitation by hydroxyl ions in the soil.

In traditional agriculture, the supplementation of micronutrients like iron, zinc, manganese, and copper often involves the use of chelated forms of these elements. Chelation involves the binding of metal ions to organic molecules, forming stable complexes known as chelates. This chelated form enhances the solubility and stability of the micronutrients, preventing them from precipitating out of solution and remaining available for plant uptake.

One of the key advantages of chelated micronutrients is their ability to resist sedimentation, ensuring that the elements remain dissolved in a wide range of soil pH conditions. This promotes efficient absorption by plant roots, regardless of fluctuations in soil acidity or alkalinity. By utilizing chelated micronutrients, traditional agricultural practices can optimize the availability and uptake of essential elements by plants, thereby supporting healthy growth and productivity.

In organic agriculture, the use of industrial chelated compounds is prohibited due to their synthetic nature. Instead, organic farmers rely on organic fertilization methods to meet the plant's micronutrient requirements.

When organic fertilizers are added to the soil, various decomposition products of organic matter, amino acids, as well as compounds secreted by soil microorganisms, interact with micronutrients such as iron, zinc, manganese, and copper. This interaction results in the formation of natural chelating compounds within the soil. These natural chelates prevent micronutrients from precipitating or becoming unavailable to plants. As a result, the micronutrients remain in a soluble and bioavailable form in the soil solution, facilitating their uptake by plant roots.

Furthermore, compounds such as Fulvic acid and Humic acid, which are present in organic matter, also contribute to the chelation process, enhancing the availability of micronutrients to plants. By relying on organic fertilization and natural chelation processes, organic agriculture ensures sustainable nutrient management while adhering to organic farming principles.

4.1.3 Damage Caused by Using Chemical Fertilizers

As mentioned earlier, plants require various nutrients at different stages of their growth, including the vegetative phase, flowering stage, and fruit development period. A deficiency in any of these essential nutrients can lead to physiological and morphological symptoms in plants. These symptoms highlight the importance of ensuring that plants receive adequate nutrition throughout their growth cycle. Plants obtain their necessary nutrients directly from the soil. Therefore, it is crucial to replenish any lost elements and maintain soil fertility to sustain efficient cultivation practices and achieve high yields of crops with superior quantity and quality.

In the early twentieth century, following the conclusion of the First World War (1914-1918), the chemical fertilizer industry experienced significant growth. This was primarily due to the surplus of nitrogen resulting from its use in the manufacturing of bombs during the war. These nitrogen reserves were repurposed to produce nitrogen-based fertilizers, which were then utilized extensively in agriculture. It was discovered that these fertilizers not only accelerated plant growth but also increased crop yields, thereby catering to the growing nutritional demands of an expanding global population. Farmers across the world began favouring these chemical fertilizers over traditional organic ones, which were prepared and manufactured using primitive methods.

Chemical fertilizers encompass nitrogen, phosphate, calcium fertilizers, as well as formulations containing micronutrients and compound salts. These fertilizers are typically manufactured as granules and applied to agricultural soil in batches or doses tailored to the varying growth stages of plants. However, the excessive and indiscriminate use of chemical fertilizers poses significant risks to both the environment and human health.

The following points review some of the damages resulting from the intensive use of chemical fertilizers in traditional agriculture:

- **Soil Degradation:** Continuous use of chemical fertilizers can lead to a decline in soil health. Over time, the natural fertility of the soil is diminished due to the reduction in organic matter and microbial activity. This can result in soil compaction, erosion, and a decrease in soil's ability to retain water and nutrients.

- **Water Pollution:** Excessive application of chemical fertilizers can lead to runoff into nearby water bodies, causing nutrient pollution. This can result in the eutrophication of aquatic ecosystems, characterized by excessive growth of algae and depletion of oxygen levels, which can harm or kill aquatic life.

- **Groundwater Contamination:** Nitrates from chemical fertilizers can leach into the groundwater, posing a risk to human health. High levels of nitrates in drinking water are associated with health issues such as methemoglobinemia, or "blue baby syndrome," which affects infants.

- **Air Pollution:** The use of nitrogen-based fertilizers contributes to the release of nitrous oxide, a potent greenhouse gas, into the atmosphere. This exacerbates climate change and contributes to air pollution, which can have adverse effects on human health and the environment.

- **Loss of Soil Biodiversity:** Chemical fertilizers can negatively impact soil biodiversity by harming beneficial soil organisms such as earthworms and mycorrhizal fungi. This loss of biodiversity can reduce soil's resilience and its ability to support healthy plant growth.

- **Crop Quality:** While chemical fertilizers can boost crop yields, they can also affect the nutritional quality of the produce. Over-reliance on chemical fertilizers can lead to an imbalance of nutrients in the soil, resulting in crops with lower levels of essential nutrients and minerals.

- **Economic Costs:** The long-term use of chemical fertilizers can lead to increased costs for farmers. As soil health declines, farmers may need to use more fertilizers and other inputs to maintain crop yields, leading to higher production costs.

In addition to the general impacts of chemical fertilizers, each specific type of fertilizer commonly used in traditional agriculture has its unique set of environmental and health-related issues. Here is a closer look at the damage caused by different groups of chemical fertilizers:

4.1.3.1 Urea Fertilizer

Urea fertilizer($(NH_2)_2CO$) is a critical nitrogen fertilizer widely used in agriculture to meet the nitrogen demands of plants. It is also incorporated into the diets of certain ruminants as a protein source. This white granular compound contains approximately 46.4 % nitrogen, making it a highly concentrated source of nitrogen. Global production of urea exceeds one billion tons annually.

When applied to soil, urea undergoes decomposition mediated by soil microbes, resulting in the formation of ammonia (NH_3) and carbon dioxide (CO_2). Several types of bacteria are involved in this decomposition process, including *Micrococcus ureae*, *Sporosarcina ureae*, *Sporosarcina pasteurii* and *Pseudomonas* sp. These microbes play a crucial role in breaking down urea into its constituent components, facilitating its uptake by plants and contributing to soil fertility.

The synthesis of urea involves the reaction of ammonia gas with carbon dioxide under high pressure and temperature conditions. However, at lower temperatures during this process, a by-product known as "Biuret" can form. Biuret can be detrimental to plants if its concentration exceeds 0.3 % in the soil. Specifically, Biuret can: negatively impact seed germination, Hinder the development of plant tissues, and disrupt protein synthesis within the plant. Therefore, managing Biuret levels is essential to prevent adverse effects on plant growth and health.

The use of urea is generally not harmful to plants if the Biuret content does not exceed 1 kg per acre in a single application. This translates to a maximum recommended use of 100 kg of urea per acre per application, considering that commercially produced urea typically contains less than 1 % Biuret.

Additionally, allowing sufficient time between applications helps ensure the decomposition and dissipation of Biuret, preventing cumulative effects on plants or soil. As a result, careful adherence to recommended application rates and intervals helps mitigate any potential negative impacts of Biuret on plant health and soil fertility.

Improper application of urea, such as leaving it exposed on the soil surface for an extended period, can lead to the release of ammonia into the atmosphere. High concentrations of ammonia can cause irritation to the eyes and respiratory system, and ulcers in the eyes and respiratory system with prolonged exposure. Moreover, ammonia emissions contribute to environmental pollution and produce a pungent odour even at low concentrations. Therefore, it is crucial to follow proper application methods to minimize these risks and ensure the safe handling of urea fertilizer.

4.1.3.2 Ammonium nitrate – Ammonium Sulfate

Ammonium nitrate fertilizer contains 34 % nitrogen and is produced by reacting ammonia with atmospheric oxygen to form nitric acid, which then reacts with additional ammonia to produce ammonium nitrate. Similarly, ammonium sulfate fertilizer, which containing 21 % nitrogen, is produced by reacting aqueous ammonia with sulfuric acid.

Plants absorb nitrogen at intervals, leaving a portion of the ammonia in the soil continuously. Nitrifying microorganisms play a crucial role in converting ammonia into nitrite and then into nitrate. This process involves various microbes, including:

* **Fungi and Bacteria deriving nutrition from organic sources:** *Aspergillus niger* fungus and *Arthrobacter* bacteria.

* **Autotrophic Bacteria obtaining energy from inorganic compounds:** *Nitrosomonas*, *Nitrosococcus*, and *Nitrosospira* spp., which convert ammonia into nitrite, and *Nitrobacter*, *Nitrococcus*, and *Nitrospira* spp., which convert nitrite into nitrate.

During agricultural drainage operations, soil containing nitrites or nitrates can be washed into groundwater, often used for drinking. When nitrite or nitrate concentrations in water reach 45 ppm or more, it becomes unfit for consumption. Upon ingestion, nitrates convert to nitrites in the intestine and are absorbed into the bloodstream, where they react with

Haemoglobin to form Methemoglobin. This compound reduces the blood's oxygen-carrying capacity, leading to Methemoglobinemia, characterized by bluish discolouration of the skin, especially in infants and young children. To prevent this condition, human intake of nitrates in drinking water should not exceed 200 mg per day.

On the other hand, it is well-documented that certain plants, such as sorghum, maize, spinach, and lettuce, can accumulate significant amounts of nitrates when grown in nitrogen-rich soil. If animals or humans consume these plants, they may exhibit symptoms of nitrate poisoning, which can be severe and, in some cases, fatal. Furthermore, elevated nitrate concentrations in wastewater, lakes, and rivers promote excessive algae growth, altering water taste and odour. Decomposing algae increase organic matter in the water, leading to heightened microbial activity and oxygen depletion in aquatic ecosystems, adversely affecting fish populations and overall aquatic biodiversity.

In addition, the reaction between nitrite salts and substances produced from the decomposition of certain pesticides can occur, particularly in instances where these pesticides leach into groundwater. This contamination can lead to the formation of nitrosamine compounds. If individuals consume water contaminated with these compounds, they may accumulate in the cells of the body. Over time, when the concentration of nitrosamines exceeds a certain threshold, they can become carcinogenic, posing a significant risk to human health.

The reduction of nitrates and the release of nitrogen are accompanied by the formation of nitrogen oxides, including nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2). These gases ascend to the troposphere (extending approximately 17 kilometres above the Earth's surface), where increased concentrations of nitrogen oxides, particularly nitrous oxide, contribute to global warming. Inhalation of these gases can result in their conversion to nitric acid within the lungs. When nitrogen oxides react with atmospheric moisture, they form nitric acid, leading to acid rain. This phenomenon has numerous adverse environmental effects, including soil acidification, water body acidification, and damage to vegetation. Furthermore, nitrogen oxides may ascend to reach the stratosphere, which lies above the Earth's surface between 17 and 50 kilometres and contains the ozone layer. In the stratosphere, these oxides interact with oxygen, thereby depleting the ozone layer. This reduction in ozone thickness allows for higher doses of ultraviolet rays to penetrate the Earth's atmosphere, increasing the risk of skin cancer and other related health issues in humans.

4.1.3.3 Sulfur Fertilizers

Ammonium sulfate [$(NH_4)_2SO_4$] serves as a source of both nitrogen and sulfur and is commonly utilized in conventional agriculture. It is produced through the reaction of sulfuric acid with aqueous ammonia. When ammonium sulfate fertilizer is applied to the soil, particularly under anaerobic conditions such as waterlogged soil, certain soil microbes reduce sulfate to hydrogen sulfide gas. This gas then reacts with iron present in the soil, forming ferrous sulfide. Consequently, the soil experiences decreased oxygen levels, reduced fertility, and increased alkalinity, leading to the formation of what is known as Gleying Soil. When hydrogen sulfide gas is released into the atmosphere, exposure to high concentrations (ranging from 700 to 800 ppm) can result in sudden death in humans. Even at lower concentrations, it may cause headaches and inflammation of the mucous membranes and eyes.

In addition, hydrogen sulfide gas can also interact with other compounds in the soil, such as pyrite (FeS_2) and bornite ($CuFeS_2$). These compounds can oxidize into sulfate, while a portion of the hydrogen sulfide gas rises into the atmosphere. Additionally, another portion of hydrogen sulfide gas reacts with alcohols like methanol or ethanol to form thioalcohols, which are compounds known as Mercaptans.

Mercaptans and related compound gases can induce symptoms such as muscle weakness, tremors, and paralysis in the respiratory system, potentially leading to death. Even at lower concentrations, they can cause inflammation of the mucous membranes and the eyes, as well as affect the central nervous system. These effects underscore the importance of proper handling and management of sulfur-containing compounds in agricultural practices to mitigate potential risks to human health and the environment.

4.1.3.4 Phosphate Fertilizers

Phosphate fertilizers are essential for providing phosphorus, a key nutrient for plant growth. These fertilizers are produced from raw phosphates that are either minerals like Apatite (mainly calcium phosphate) with low cadmium content or former seabed sediments with a high cadmium content.

Phosphate fertilizers are produced through a chemical reaction between phosphate rock and sulfuric acid. This process, while effective in producing phosphorus fertilizers, is associated with significant environmental pollution due to the release of toxic gases. One of the by-products of this reaction is hydrogen fluoride gas, which poses serious health hazards. Additionally, when hydrogen fluoride gas reacts with silica present in phosphate rock, it forms silicon tetrafluoride gas (SiF_4). If these gases are released into the atmosphere during the manufacturing process, they can pollute the air. Exposure to these gases can lead to various health issues in humans, including skin and eye ulcers, pulmonary edema (blood pooling in the lungs), high body temperature, and even death at high concentrations. Therefore, strict precautions are necessary to control and mitigate the release of these toxic gases during the production of phosphate fertilizers to protect both human health and the environment.

4.1.3.5 Mineral Fertilizers and Heavy Metal Contamination

Mineral or chemical fertilizers, widely used in agriculture, often contain impurities of toxic heavy metals such as lead (Pb), mercury (Hg), arsenic (As), nickel (Ni), cadmium (Cd), and chromium (Cr). These impurities can accumulate in the soil over time and pose significant environmental and health risks. Continuous use of mineral fertilizers can lead to the gradual accumulation of toxic heavy metals in the soil. This accumulation can adversely affect soil health, microbial activity, and plant growth.

Moreover, certain soil microorganisms can convert heavy metals into more volatile and toxic forms through methylation. For example, mercury can be transformed into methylmercury, a highly toxic compound that can bioaccumulate in the food chain. Some heavy metals can be volatilized by microbial activity, leading to their release into the atmosphere and contributing to air pollution. The volatilization of heavy metals results in the presence of these toxic elements in the air. Inhalation of such pollutants can cause respiratory problems and other health issues in humans and animals. Breathing in air contaminated with heavy metals like lead, mercury, and arsenic can lead to serious respiratory issues, including chronic bronchitis, asthma, and lung cancer.

Additionally, some of these elements have the capability to accumulate in the tissues of plants, such as the accumulation of lead in pepper plants. Therefore, it is crucial to monitor and regulate the use of fertilizers containing these toxic elements to minimize environmental contamination and safeguard human and animal health.

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4.2 Fertilization Strategies in Organic Agriculture

4.2.1 Traditional Organic Fertilizers

Traditional organic fertilizers, such as farm manure and poultry manure, are produced by fermenting animal and agricultural waste. These fertilizers are then added to the soil in organic farms to enhance its natural and chemical properties. Al-Jalla (2002) mentioned that these fertilizers are widely used and contain a high percentage of organic matter and compost, as well as various essential nutrients needed for plant growth.

4.2.1.1 Farmyard Manure (FYM)

Farmyard manure is considered one of the best organic fertilizers for increasing soil fertility and improving its natural, chemical, and biological properties. It is typically produced from livestock waste, which is why it is sometimes referred to as "livestock manure." Generally, farmyard manure is derived from the waste of farm-raised animals along with bedding, as well as waste from transport animals.

The production method of farmyard manure involves placing bedding in the barns under the animals using plant residues available on the farm, such as straw or hay, and other materials. This bedding is then mixed with appropriate amounts of soil to absorb animal waste, including faces (solid waste) and urine. Subsequently, it becomes easier to transport. These waste materials are left on the bedding for a sufficient period to absorb the animal waste.

Farm animal waste is considered rich in its nutrient content, as approximately 80-95 % of the nutrients present in the animal feed are excreted in the manure and urine. Additionally, organic matter constitutes 40 % of the substances in the animal feed.

Animal manure is a rich source of various types of microorganisms that analyse different organic materials, mineralizing a significant portion of them and forming compost. This includes cellulose and protein-decomposing microorganisms, among others. Urea-digesting bacteria, such as *Sarcina ureae* and *Bacillus pasteurii*, are activated, leading to the formation of ammonia. Additionally, some organic acids and gases, such as carbon dioxide, methane, and hydrogen, are produced. As these gases are unpleasant for animals and can affect their health, these waste materials are continuously collected. The process of preparing, fermenting, and maturing farmyard manure is carried out away from the animals, typically in the rear part of the animal shelters, not facing the direction of the airflow. Below are the considerations to obtain good farmyard manure:

- » It is preferable for the floors of animal shelters to be made of concrete and non-permeable to liquids to prevent the loss of nutrient-rich urine from animals. Also, the areas where farmyard manure will be collected and prepared should have a layer of insulating material such as concrete or be well compacted.
- » The bedding in animal shelters should consist of a mixture of non-saline soil and plant residues from the farm (such as rice straw, hay, or chopped corn and cotton stalks). The bedding should be evenly distributed under the animals at a rate not exceeding 0.5 m3 of soil (approximately 75 kg of soil), in addition to at least 20 kg of plant residues per ten animals daily. For dairy farms and horse stables, it is preferable to use bedding containing a high proportion of plant residues (such as rice straw) and a small proportion of soil.
- » It is advisable to keep the manure in the shelters for as long as possible to minimize nutrient loss.
- » It is preferable to add agricultural gypsum or phosphate rock to the bedding at a rate of 2 kg per animal per week. Calcium sulfate helps reduce ammonia loss, and phosphorus becomes readily available in an easily accessible form for plants.
- » During the preparation and storage of farmyard manure, changes and analyses occur due to the activity of microorganisms. The biological activity and its results vary based on several factors, such as the type and quantity of bedding, the nature of the mixture (whether compacted or aerated), the duration of the manure's stay in the shelters, and the storage method.

Al-Jalla (2011) described three methods for storing farmyard manure, which can be summarized as follows:

- **Cold Manure**

In this method, farmyard manure is stored daily in a compacted pile to provide anaerobic conditions, maintaining the pile's temperature around 30°C. The benefit of this approach is the reduction of ammonia loss through volatilization. However, due to the prevailing anaerobic conditions, toxic substances may form in the pile. Therefore, after spreading the manure on the field, it is necessary to allow a period for these toxic substances to dissipate to prevent them from affecting root growth and the activity of soil organisms. This method also effectively disposes of weed seeds and harmful microbes.

- **Warm Manure**

This method combines the benefits of aerobic and anaerobic conditions during manure storage. Layers of farmyard manure are gradually added to the pile, with the first layer left for 2-4 days before adding the next layer. This allows the temperature to reach approximately 40-50°C. Consequently, the lower layers create anaerobic conditions, and the temperature drops to 30°C. This approach results in a high percentage of organic matter in the pile and eliminates most weed seeds and pathogens.

- **Composted Manure**

In this method, balanced conditions of air and moisture are provided for the decomposition process by microorganisms, raising the temperature to 60°C. After several weeks, the pile is turned to activate the decomposition process, resulting in compost. This process produces effective organic material, along with a 50 % reduction in organic matter density, making distribution easier. During the production stages, it is advisable to add phosphate rock, as phosphorus transforms from an inaccessible to an accessible form upon manure maturation. Additionally, many weed seeds and pathogenic microbes are eliminated during this process, and the compost contains important active substances such as antibiotics and hormones. Any pesticide residues present are broken down before adding the compost to the field.

In addition, the most significant drawbacks of using farmyard manure in organic farming include the following:

» **Emission of Unpleasant Odours:** During its production, farmyard manure emits foul odours due to the release of various gases such as methane, hydrogen sulfide, mercaptans, and nitrogen oxides. These gases can adversely affect humans and animals, leading to environmental pollution.

» **Imbalance in Nutrients:** This fertilizer is considered unbalanced as it lacks certain elements like phosphorus. Additionally, it contains only 10 % organic matter, including compost, which is insufficient for providing the necessary nutrients for plants.

» **Potential Presence of Harmful Microorganisms:** Farmyard manure may contain pathogenic microbes and intestinal parasites harmful to humans. Although the fermentation process and resulting heat eliminate a high percentage of these pathogens, necessary precautions should be taken, especially when using this fertilizer on vegetable crops, particularly leafy greens and crops with fruits close to or in contact with the soil.

» **Possible Contamination with Plant-Pathogenic Fungi and Nematodes:** Farmyard manure may contain germs of certain fungi and nematodes that are harmful to plants, which can be transmitted from agricultural and animal residues.

By addressing these drawbacks, organic farming can optimize the use of farmyard manure, ensuring that it provides maximum benefits while minimizing potential risks.

4.2.1.2 Poultry Manure (PM)

Poultry manure is a valuable source of nutrients, particularly for vegetables and other crops. According to Al-Jalla (2011), a single poultry farm can house between 5,000 and 45,000 birds in one cycle, whether for fattening or egg production. Typically, fattening farms raise more than one cycle of birds. On average, a bird excretes approximately 5 % of its live weight, meaning a bird weighing 2 kg would produce around 0.1 kg of waste daily, containing about 25 % dry matter. The poultry waste from fattening farms that use wheat straw, beans, or wood shavings as bedding absorbs liquids and secretions. The waste mixture, along with the bedding, is usually collected every two months, approximately at the end of each cycle, making this poultry manure suitable for use. Poultry manure from fattening farms is characterized by its dryness (with moisture content around 23-25 %) and its high content of nutrients and organic matter, ranging from 50-60 %.

Commercially, poultry manure is produced in several countries for use in organic farming. For instance, "Agroplus 2" is produced in the Sultanate of Oman. Similarly, the United Arab Emirates produces poultry manure under the trade name "Abu Deek," which is biologically prepared and heat-treated. It is free from weed and harmful herb seeds, bacteria, nematodes, and plant-pathogenic fungi. Abu Deek fertilizer contains major nutrients in the following proportions: 3.5 % nitrogen, 2.5 % phosphorus, and 2 % potassium. It also contains 55 % organic matter. Additionally, Abu Deek fertilizer includes various trace elements needed by plants, such as iron (600-800 parts per million), manganese (5-10 parts per million), zinc (300-600 parts per million), copper (5-15 parts per million), and boron (15-25 parts per million).

Usage Rates of Poultry Manure in Organic Farming:

» **Vegetables:** It is recommended to use poultry manure at a rate of 1.5 tons per 1000 square meters.

» **Fruit Trees:** The application rates for fruit trees vary:

  * **Fruit Trees:** Use at a rate of 4-8 kg per tree.
  * **Date Palm:** Apply at a rate of 10-15 kg per date palm.

» **Green Areas (Lawns, Turf, etc.):** For green areas, the suggested usage rate is 5 kg per square meter.

These rates provide general guidelines for the application of poultry manure in different agricultural contexts within organic farming. Adjustments can be made based on specific crop requirements, soil conditions, and other factors. It is essential to monitor the health of the plants and soil and make adjustments as needed.

It is worth mentioning that poultry feather meal can be used to increase the nitrogen content in compost. It contains 10 % nitrogen and can be added to compost before direct application to crops that require high levels of nitrogen, such as greenhouse vegetables, potatoes, and strawberries. This practice helps enhance the nitrogen content in the compost, providing an additional organic nitrogen source for plants.

4.2.2 Non-Traditional Organic Fertilizers

Non-traditional organic fertilizers are those used directly without fermentation. Among the most important non-traditional organic fertilizers that can be used in organic farming are:

4.2.2.1 Blood Meal Fertilizer

Blood meal fertilizer is prepared by collecting blood from slaughterhouses, where it is placed in containers. Lime is then added at a rate of approximately 2-3 % to eliminate the unpleasant odor. The mixture is left for some time, allowing all the proteins to settle. The liquid is separated from the sediment, which is then collected, air-dried, and ground. This fertilizer contains approximately 75-80 % organic matter, 10-12 % nitrogen, 1-2 % potassium, and 1 % phosphorus. The process of collecting and processing the blood ensures a high concentration of valuable nutrients, making blood meal an effective organic fertilizer.

4.2.2.2 Bone Meal Fertilizer

Bone meal or crushed bones is added to the soil in organic farming, and it contains approximately 25 % calcium phosphate, making it an important source of phosphorus. Additionally, bone meal contains 4 % nitrogen and 30 % organic matter. The inclusion of bone meal in organic agriculture provides a valuable combination of essential nutrients for plant growth. Phosphorus is crucial for root development, flowering, and fruiting in plants. The nitrogen content contributes to overall plant health and vigour, while the organic matter enhances soil structure and fertility. Bone meal, with its diverse nutrient profile, serves as a beneficial organic fertilizer in promoting plant growth and improving soil quality.

4.2.2.3 Fish Remnants Fertilizer

Fish waste, after removing fatty substances and grinding, is utilized as an organic fertilizer. Fish waste powder contains approximately 9 % total nitrogen and about 50 % organic matter. This makes it a valuable source of nutrients for plants in organic farming.

The nitrogen content in fish waste contributes to the fertility of the soil, supporting healthy plant growth. Additionally, the organic matter aids in improving soil structure and water retention. The use of fish waste powder as an organic fertilizer provides a sustainable and nutrient-rich option for enhancing the health and productivity of crops.

4.2.3 Green Manures and Cover Crops

4.2.3.1 Green Manures

Green manures refer to the cultivation of certain crops that are plowed and turned into the soil while still green, before flowering. This practice aims to increase the soil's content of organic matter and nutrients, thereby improving its physical, chemical, and biological properties. Plowing green manures can be carried out directly after their flowering. The benefit of plowing mature plants is greater compared to plowing younger plants because mature plants contain a higher percentage of cellulose and lignin. Consequently, they decompose slowly, producing a significant amount of organic matter. This slow decomposition provides a steady release of nutrients over time, preventing rapid nutrient loss, especially nitrogen. The use of green manures is a sustainable practice that enhances soil fertility, promotes nutrient cycling, and contributes to the overall health of the soil in organic farming.

Cultivating green manure is considered crucial in organic farming for enhancing soil properties. Green manure crops can be divided into two main categories: leguminous and non-leguminous crops, with each category further divided into winter and summer crops.

The following are the most important Green Manure crops:

- **Winter Leguminous Green Manure Crops:** Clover, Lupine, Beans, Lentils, Sweet Clover, Sour Clover and others.
- **Summer Leguminous Green Manure Crops:** Alfalfa, Cowpea, Bean, Peanuts, Soybeans, Chickpeas, Sesbania and others.
- **Winter Non-Leguminous Green Manure Crops:** Barley, Oat, Wheat (sometimes).
- **Summer Non-Leguminous Green Manure Crops:** Sorghum, Millet, Forage Sorghum, Sudan Grass, and others.

These green manure crops contribute to soil improvement, nutrient enrichment, and overall sustainable farming practices in both winter and summer seasons. Crops used as green manures should be characterized by deep roots, rapid growth, low fiber content, and low cultivation costs. It is essential to plow and turn over the plants used as green manure in the soil for a period of not less than 1.5 months before planting the main crop, referred to as the cash crop. If the seeds of the main crop are sown immediately after turning over the green manure in the soil, these seeds will not germinate well due to an increase in the carbon dioxide content in the soil. Additionally, it may cause damage to the seedling roots. Figure 4.1. illustrates the process of plowing green manures into the soil in a greenhouse before planting the main crop.

Figure 4.1. Plowing Green Manures into the Soil in a Greenhouse.

4.2.3.2 Cover Crops

Cover crops are planted primarily to cover the soil, regardless of whether they will later be incorporated into it. The main purposes of cover crops include:

» **Preventing Soil Erosion:** Cover crops protect the soil surface from erosion caused by wind or heavy rainfall. They help maintain soil structure and prevent nutrient loss.

» **Competing with Weeds:** Fast-growing forage crops serve as cover crops to outcompete weeds, reducing the need for chemical herbicides and promoting a healthier growing environment.

» **Pest Management:** Some cover crops act as trap crops or hosts for harmful pests, thereby protecting the main crops.

» **Intercropping:** Cover crops can be planted between rows of trees, vegetable lines, or alongside the main crop. This intercropping practice helps in better land utilization and can enhance biodiversity.

In addition to their primary purposes, cover crops can include vegetables, field crops, or medicinal and aromatic plants. These crops may be grown to harvest their produce while simultaneously serving the role of cover crops in intercropping practices. This approach integrates multiple benefits, including erosion control, weed suppression, and additional crop yield, contributing to the overall sustainability of crop production.

4.2.3.3 Important Characteristics of Green Manures and Cover Crops

The characteristics of green manures and cover crops used in organic farming are essential for enhancing soil health and crop productivity. These characteristics can be summarized as follows:

» **Plant Types:** Green manures and cover crops can be herbaceous annual, biennial, or perennial plants. They may be cultivated individually or in mixtures (more than one crop) to maximize benefits.

» **Nitrogen Fixation:** Leguminous crops are highly suitable for use as green manures due to their ability to fix nitrogen in the soil and enriching soil fertility.

» **Weed and Pest Suppression:** These crops provide cover for the soil surface, helping to resist weeds and suppress their growth. Additionally, they can reduce the susceptibility of the main crop to diseases and pests by disrupting pest life cycles and providing habitat for beneficial organisms.

» **Nutrient Retention:** When a cover crop is planted to reduce the leaching of nutrients from soil particles after harvesting the main crop, it is referred to as a "catch crop." For example, planting cereal rye after harvesting a corn crop helps capture residual nitrogen in the soil, reducing the risk of groundwater pollution. Cereal rye also functions as a winter cover crop, protecting the soil during the off-season.

» **Rotation and Gap Filling:** Short-term cover crops planted to fill gaps during crop rotation can also be considered catch crops. These crops help maintain soil cover and nutrient cycling between main crop cycles, preventing soil degradation and nutrient loss.

» **Forage Crops:** Forage crops in short crop rotations can serve dual purposes as cover crops or green manures. If forage crops are grown for use as dried or green forage, they are considered cover crops. If grown with the intention of plowing and incorporating them into the soil, they are considered green manure crops.

» **Crop Diversity:** It is essential to ensure that green manure crops or cover crops are not closely related botanically to the main crop to be planted. This helps avoid problems with the transmission of diseases or common pests from the cover crop to the main crop.

Incorporating these diverse and strategically selected crops into organic farming systems promotes soil health, improves nutrient availability, and supports sustainable agricultural practices.

4.2.3.4 Important Benefits of Green Manures and Cover Crops

As mentioned before, there are various types of green manures and cover crops that can be used in organic farming, each with numerous benefits. The most important of these benefits can be summarised in the following points:

- **Increasing Soil's Organic Matter Content**

The greatest benefit of cultivating green manures is the addition of organic matter to the soil. During the decomposition of organic matter by soil microorganisms, resistant materials such as gummy, waxy, and resinous substances are formed. These substances, along with the hyphae of soil fungi, mucous materials, and foamy substances secreted by microorganisms, help in the cohesion and bonding of soil particles, forming granules or aggregated blocks. Such well-structured soil is easy to plow, has good ventilation, and a high water leaching rate, meaning it has good drainage.

It is worth mentioning that increasing the levels of organic matter in the soil, and subsequently its decomposition, and ultimately the increase in humus content, positively affects the growth and productivity of the main crop. This impact extends to the availability and absorption of nutrients. Humus substances are mainly composed of organic acids such as humic acid, fulvic acid, and humins, which constitute 85 to 90 % of humus in the soil.

The properties of humic substances in the soil depend on the nature of the residues added to the soil, whether plant or animal, which decompose under appropriate conditions of moisture and temperature by soil microorganisms (bacteria, actinomycetes, and fungi). Initially, the materials added to the soil lose their cohesion and decrease in size, forming intermediate substances. New substances are then formed, and eventually, the added materials break down into simple substances such as carbon dioxide, water, oxygen, and ions like nitrates and ammonium. During this decomposition process, the residues turn brown, and after a certain time with sufficient moisture, a brown liquid containing humic substances is formed.

Green manures are important throughout crop rotation as they work to fill the deficiency and provide the soil with organic matter lost during annual crops in the rotation. It is important that the cultivation of green manure should not disturb the crop rotation system and should not incur significant expenses.

It should be noted that it may take several years to reconstitute the top layer of soil containing humic substances before a significant shift in their level occurs. In comparison, green manures grown annually may have an intangible or insignificant effect on the level of humic substances in the soil. This is due to the annual plowing and cultivation, where the organic matter supplied to the soil is quickly decomposed and consumed or mixed and disappears in the deep soil layers.

In general, Schmid and Klay (1984) mentioned that the organic matter added by a green manure crop to an acre of soil is equivalent to the organic matter added when applying 9-13 tons of farmyard manure per acre or when adding 1.8-2.2 tons of dry matter per acre.

- **Nitrogen Fixation in Leguminous Crops**

Nitrogen fixation when growing leguminous crops is one of the most important benefits, or the key benefit, of using leguminous crops as cover crops or green manures. One fundamental practice in organic agriculture is to plant a leguminous crop at least once every five years. In other words, to cover the surface of the organic farm with legume crops, it is necessary to plant 20 % of the farm area annually with one of the leguminous crops.

The accumulated nitrogen content in the soil from the cultivation of leguminous crops ranges from 40 to 200 nitrogen units per acre. The amount of nitrogen produced by leguminous crops depends on several factors, including the type of legume crop, the total amount of organic matter produced, the nitrogen content in plant tissues, and environmental and agricultural conditions that limit the growth of legume crops, such as delayed planting and drought. Factors that encourage an increase in the amount of nitrogen produced include the legume crop having good growth, the soil containing a good level of nutrients, having a suitable pH level, adequate soil moisture, and the presence of good bacterial nodules in the leguminous crop.

Sullivan (2003) mentioned that the amount of nitrogen added to the soil and available for the next main crop after planting the legume green manure crop usually ranges between 40-60% of the total amount of nitrogen in the leguminous crop. For example, when planting the legume crop "Hairy vetch", approximately 81.65 kg of nitrogen will accumulate in the plants per acre before tilling the legume crop into the soil. After tilling, this will contribute or provide around 49.90 kg of nitrogen per acre that can benefit the main crop, whether vegetables or grains, that will be planted.

Rasmussen *et al*. (1980) reported that some legume crops planted in the southern United States as winter cover crops produce approximately 2.2 tons per acre annually of crop residues (dry matter), which are sufficient to maintain soil organic matter at constant levels in soils grown continuously.

Table 4.1. illustrates the amount of organic matter and nitrogen added by some leguminous green manure crops to the soil. These numbers vary depending on the climate, region, and cultivation system.

Table 4.1. Average Amount of Organic Matter and Nitrogen Added by Some Leguminous Green Manures Crops to the Soil.

Leguminous Crop	Organic Matter (ton/acre)	Nitrogen (kg/acre)
Sweet clover	1.75	54.43
Berseem clover	1.1	31.75
Crimson clover	1.4	45.36
Hairy vetch	1.75	49.90

Source: Sarrantonio (1994).

- **Encouraging Soil Microbe Activity**

Green manures encourage the growth and reproduction of soil microorganisms that accelerate the decomposition of agricultural crop residues in the soil. It has been found that soil microbes multiply rapidly after plowing a green manure crop and incorporating it into the soil. These microbes attack and break down plant materials, releasing nutrients that become available for the targeted main crop to benefit from. Several factors can affect the ability of soil microbes to decompose organic matter, and the most important of these factors include:

» Soil Temperature: The activity of soil microbes increases with rising soil temperature, with the optimum temperature being 30°C.

» Soil Moisture: Adequate moisture must be provided to ensure the reproduction of soil microbes and their role in the decomposition of organic matter. Drought can lead to the death of many soil microbes.

» Carbon to Nitrogen (C: N) Ratio in Plant Material: The (C: N) ratio in the tissues of plant residues (for green manures or cover crops) indicates the type and age of the plants they originated from. As a plant ages, the proportion of fibers (carbon) increases in plant tissues, while the proportion of proteins (nitrogen) decreases. McLeod (1982) mentioned that the ideal (C: N) ratio for rapid organic matter decomposition should be between 15:1 and 25:1. The (C: N) ratio in plant materials is more correlated with the plant's nitrogen content than with its carbon content, as most plant materials have a carbon content of around 40 %. Therefore, to estimate the (C: N) ratio for any plant material, divide 40 % by its nitrogen content.

- **Weed Control**

Weeds are known to grow and flourish in exposed soil. Cover crops and green manure, by shading the soil and preventing sunlight from reaching it, limit or prevent the opportunity for weed growth. In general, living cover crops effectively resist weed growth, especially when the soil is not plowed. They compete with weeds for light, moisture, and nutrients. Additionally, soil loosening by the deep roots of green manure crops also limits the growth of weeds that thrive in compacted soil. The main purpose of cultivating non-leguminous green manure crops, such as barley, millet, or Sudan grass, is to provide a good opportunity to resist weed growth. These crops also contribute to adding organic matter to the soil and improving soil tillage.

In organic farming, cover crops can effectively resist weed growth by inhibiting their development. Such crops are referred to as "Allelopathic plants", meaning they inhibit or slow down the growth of nearby plants (such as weeds) by releasing natural toxins or Allelochemicals that inhibit the growth of nearby plants. Examples of these crops include small grains like barley and summer fodder crops like sorghum and Sudan grass.

- **Providing Nutrients and Preventing Soil Erosion**

In addition to providing nitrogen, cover crops and leguminous green manures also contribute to the supply and recycling of other nutrients. Nutrients such as phosphorus, potassium, calcium, magnesium, sulfur, and others accumulate in cover crops and green manures during their growing season. When these crops are plowed and mixed into the soil, these nutrients become available in the soil and are released slowly during the decomposition process.

Cover crops also maintain the soil by providing cover during the autumn and winter, when the soil is exposed to erosion. Planting a mixture of leguminous and other cover crops increases soil surface coverage while providing some nitrogen to the main crop. The benefits of cover crops go beyond protecting bare soil; these crops reduce water evaporation from the soil surface and act as a cover that reduces soil surface flaking and nutrient washing by heavy rain during rainy periods.

- **Strengthening Pest Management Programs**

Cover crops can strengthen many agricultural pest management programs. Sedentary natural systems are typically diverse, containing various types of plants, arthropods, mammals, birds, microorganisms, and more. Cover crop cultivation adds diversity to the agricultural system, and many scientists have observed that agricultural environments with high diversity rarely experience widespread agricultural pests. This diversity contributes to achieving a natural balance in the environment.

Cover crops contribute effectively to biological pest control by providing a habitat for beneficial insects, including predators and parasites. These cover crops offer a suitable environment for their hosts, protecting them from pests that they prey on or parasitize. Additionally, cover crops supply these beneficial insects with pollen and nectar, allowing them to reproduce, thrive, and maintain their populations in the agricultural environment. Therefore, when the main crop is planted and affected by pests, there will be a sufficient number of beneficial insects (predators and parasites) to actively combat and control agricultural pests.

Some green manure crops can control or inhibit nematode pests. For instance, Crotalaria juncea, Figure 4.2., also known as Brown hemp, Indian hemp, Madras hemp, or Sunn hemp, has this ability. After being plowed into the soil 10-12 weeks after cultivation, it acts as green manure, providing the next crop with nitrogen and controlling nematode pests in the following crop. Wang and McSorley (2009) mentioned that C. juncea produces allelopathic compounds that suppress and inhibit nematodes present in the soil, such as Root-Knot Nematodes (*Meloidogyne* sp.), Soybean Cyst Nematode (*Heterodera glycines*), and Reniform Nematodes (*Rotylenchulus reniformis*).

Figure 4.2. Crotalaria juncea, Which Used as Green Manure.

4.2.4 Compost

The word "Compost" originates from the Latin word "Compositum," meaning things mixed together. This definition indicates that compost refers to the mixing of plant and animal residues. Organic compost, or "compost," is a cornerstone for organic farmers, crucial for nourishing plants. The success of organic farming largely depends on producing high-quality compost, which improves soil properties and supplies plants with necessary nutrients for growth.

Compost serves as an alternative to the mineral fertilizers used in conventional agricultural systems. It is produced through the aerobic decomposition of a mixture of plant and animal residues on organic farms, facilitated by microorganisms. This natural biological process occurs under complete aerobic conditions, requiring the availability of air (oxygen) and moisture (water). Compost is rich in beneficial microorganisms and essential nutrients necessary for plant growth.

Producing compost on organic farms can be easily achieved when the necessary information and technical techniques for compost production are available. This also requires the availability of sufficient raw materials on the farm. Compost consists of plant residues, which must be untreated with pesticides, and animal residues such as livestock and poultry manure, fish residues, and slaughterhouse waste. Additionally, other permitted additives can be used, such as seaweeds, algae, phosphate rock, feldspar, dolomite, agricultural gypsum, and more.

There are two systems for compost production: the Static system and the Dynamic system. It is preferable to use the first system for compost production in small farms with an area ranging from 5 to 12 acres. The production and manufacturing process of compost in this system relies on manual labor. As for the second system, it is employed for compost production in larger farms. Here, specialized machinery is utilized in the production and manufacturing process of compost.

4.2.4.1 Raw Materials Used in Compost Production

- **Agricultural Residues**

There are two systems for compost production: the Static system and the Dynamic system. The Static system is preferable for small farms with an area ranging from 5 to 12 acres, relying on manual labour for the production and manufacturing process. The Dynamic system is used for larger farms, employing specialized machinery in the production and manufacturing process of compost.

Table 4.2. illustrates the nutrient content of various plant residues, including essential elements such as nitrogen, phosphorus, and potassium, as well as the carbon to nitrogen (C: N) ratio.

It is worth noting that the use of date palm residues in the compost production process may require up to 6 months to obtain mature compost suitable for use on organic farms. This extended period is due to the presence of lignin in palm fronds and date palm residues, which decomposes slowly because of the scarcity of microbes capable of breaking down lignin.

Table 4.2. The Nutrient Content of Some Plant Residues and The (C: N) Ratio.

Crop Waste	% (Dry Matter Basis)			
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	(C: N) Ratio
Wheat straw	0.54	0.15	0.80	105: 1
Rice straw (Japonica)	0.48	0.07	1.44	107: 1
Rice straw (Indica)	0.67	0.09	1.41	85: 1
Rice hull (Japonica)	0.48	0.05	0.31	116: 1
Rice hull (Indica)	0.50	0.07	0.68	151: 1
Barley straw	--	0.1-0.5	1.0	85: 1
Corn stalk	0.91	0.16	1.34	61: 1
Sorghum stalk	0.73	0.11	1.61	74: 1
Soybean stem	1.36	0.16	1.09	39: 1
Peanut stem	1.33	0.11	0.91	40: 1
Peanut hull	0.70	0.12	0.46	-
Tobacco leaves	3.50	0.14	2.54	11: 1
Tobacco factory waste	1.12	0.21	0.30	39: 1

Source: Hsieh and Hsu (1993).

- **Animal Residues**

Animal residues, such as manure from ruminant animals like cows, buffalo, sheep, and camels, as well as non-ruminant animals like horses, serve as a vital source of nitrogen necessary for the activity of microorganisms. Additionally, these residues provide cellulose-degrading bacteria. Poultry manure is also a valuable residue in compost production. Table 4.3. illustrates the nutrient content of various animal residues, including essential plant nutrients, organic matter percentage, and moisture content.

Table 4.3. Percentage of N-P-K, Organic Matter, and Moisture Content of Some Animals Manure.

Kind of Animal Manure	%				
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Organic Matter	Moisture
Cattle	0.6	0.2	0.5	17	83
Steer	0.7	0.3	0.4	17	83
Sheep	0.7	0.3	0.9	32 - 34	66 - 68
Horse	0.7	0.3	0.6	22 - 26	74 - 78
Camel *	1.03	--	--	69.6	2.60
Pig	0.5	0.3	0.5	14	86
Chicken	1.1	0.8	0.5	25 - 45	55 - 75
Rabbit	2.4	1.4	0.6	33	43

Source: Martin and Gershuny (1992).
***** Al-Turki (201

It should be noted that we should not use old dry residues from poultry manure, resulting from the cleaning process of poultry sheds, in the compost pile. As, these residues may contain some respiratory system disease pathogens for humans. It is also essential to emphasize that we should use plant and animal residues from organic farms in compost production. In case these primary materials are not available in sufficient quantities, they can be obtained from sources known to us, such as from a farm or farms where chemical inputs, especially chemical pesticides (whether insecticides, fungicides, herbicides, or nematicides), have not been used. This, of course, should be done after obtaining approval from the organic certification body.

It is worth noting that if we look around, we will find many non-traditional plant residues that can be used in preparing compost, whether at the level of large farms, small farms, or home gardens. Martin and Gershuny (1992) mentioned some of these residues that can be found near our farms and can be added to the compost pile, enriching it with the necessary nutrients for plant growth. It is crucial to ensure the primary sources of these residues are from organic farms or places that carry out organic production.

Table 4.4. illustrates a list of some of the unconventional plant and animal residues that can be used in the compost pile, indicating the presence ratio of essential nutrients (nitrogen, phosphorus, and potassium), as well as their effect on compost as materials rich in Nitrogenous (N) or Carbonaceous (C).

Table 4.4. Content of Essential Nutrients of Some Unconventional Plant and Animal Residues and its Effect on Compost as a Substance Rich in Nitrogenous or Carbonaceous Materials.

Crop / Animal Waste	% (Dry Matter Basis)			Rich in Nitrogenous (N) Rich in Carbonaceous (C)
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	
Apple Pomace	0.2	0.02	0.15	(N)
Bagasse	2.0	8.0	--	(C)
Banana Wastes	--	2.3 - 3.3	41 - 50	(N)
Beet Wastes	0.4	0.4	0.7 - 4.1	(N)
Bonemeal	3.3 - 4.1	21.0	0.2	(N)
Buckwheat Straw	--	--	2.0	(C)
Fish Scrap	6.5	3.8	--	(N)
Dried Blood	10 - 14	1 - 5	--	(N)
Olive Wastes	1.15	0.78	1.3	(N)
Oat Straw	--	--	1.5	(C)
Grass (Immature)	1.0	--	1.2	(N)
Barley Straw	--	--	1.0	(C)
Tobacco Wastes	2.5 - 3.7	0.6 - 0.9	4.5 - 7.0	(C)
Tomato Stalks	0.35	0.1	0.5	(C)
Rye Straw	--	--	1.0	(C)
Alfalfa Hay	2.45	0.5	2.1	(N)
Cocoa Shell Dust	1.0	1.5	1.7	(C)

Source: Martin and Gershuny (1992).

- **Residues That Should be Avoided in Compost Production**

In organic farming, the use of human feces and treated sewage water is prohibited to prevent soil contamination with heavy metals, which can be transferred to plants and fruits. Specifically, for fresh-consumed vegetable crops, particularly leafy greens that come into contact with the soil, there is a risk of microbial contamination from immature compost that contains sewage sludge. This compost might harbor food poisoning bacteria such as Escherichia coli, posing potential health risks to humans who consume contaminated plants.

One of the most important animal wastes to avoid when preparing compost, especially on small farms or gardens, is the waste from domesticated pets such as cats and dogs. These residues should not be used in the compost pile, despite being nutrient-rich, due to the challenges in collection, management, and the risk of harboring pathogenic microorganisms that can infect humans.

For example:

» Cat Waste: Hazardous especially for pregnant women and young children. Cat faeces contain Toxoplasma gondii, a single-celled parasite that can be transmitted to a pregnant woman and potentially affect the fetus, causing brain and eye diseases, and potentially leading to vision loss.

» Dog Waste: Like cats, dog faeces can contain Toxocara canis, a parasitic roundworm that can cause diseases in children.

» **Domestic Bird Waste:** Can carry various diseases transmissible to humans and may be mixed with unwanted weed seeds from bird cages.

Avoiding these types of residues in compost production ensures the safety and quality of the compost, reducing the risk of contaminating crops and the subsequent health risks to humans.

4.2.4.2 Equipment Used in Compost Production

Proper equipment and laboratory devices are essential at the compost production site for preparing raw materials, monitoring the composting process, managing compost maturation, and testing the quality of the produced compost. Below is a description of the necessary equipment and devices:

» Grinder and Shredder Machine

Plant residues must be finely chopped into very small pieces using a plant waste Grinder and Shredder Machine, Figure 4.3. The length of each piece should not exceed five centimeters, and its diameter should be around one centimeter. Chopping and grinding residues increases microbial decomposition due to the increased surface area exposed to these organisms. It also helps improve ventilation, retain moisture in the compost pile, and facilitates easy turning and handling.

» Windrow Turner Machine

The compost Windrow Turner Machine, shown in Figure 4.4., is used for stirring and rotating the compost pile or compost windrow. The temperature of the compost pile remains above 55°C for two weeks during the preparation of high-quality compost. The pile is turned five times during this period, approximately once every three days.

Turning the compost pile is crucial as it redistributes materials from the edges or top of the pile to the center, facilitating decomposition. It ensures heat reaches all parts of the pile, achieving lethal temperatures for harmful microbes, nematodes, and parasites. It also helps eliminate seeds and rhizomes of troublesome weeds that may be present in the residues. Compost turning aims to maintain the pile's temperature below 70°C, as exceeding this temperature can lead to the death of beneficial microorganisms.

Piles or windrows, as shown in Figure 4.5., are heaps used for open composting. The compost pile or windrow should be located on the farm, sufficiently distant from residential areas but close to a water source; alternatively, water tanks should be placed near the compost pile. The compost pile should be 2.3 to 2.5 meters wide and 1.2 to 1.5 meters high. The size should not exceed these dimensions, with the ideal pile being approximately 2 meters wide, 1.5 meters high, and the length determined by the available raw materials.

The production process of compost is achieved through biological decomposition by the predominant microorganisms in the compost pile. Therefore, it is essential to provide ideal conditions for these microorganisms to play their role effectively in decomposing the compost pile, which consists of plant and animal residues, into high-quality compost with elevated levels of organic matter and nutrients.

Generally, the microbiological components of the compost pile consist of bacteria and actinomycetes. The majority of microorganisms responsible for compost formation are aerobic, meaning they require or function better in the presence of oxygen. Many of the difficulties associated with the decomposition of composting pile materials can be traced back to insufficient oxygen levels to support the decomposition of these materials. Additionally, these microorganisms require a moist environment as they thrive in water films surrounding organic matter particles. The optimal moisture content for the activity of these microorganisms is 50-60 %.

Figure 4.3. Grinder and Shredder Machine.

Figure 4.4. Windrow Turner Machine.

It is worth noting that as a result of the decomposition processes occurring in the compost pile by microorganisms, carbon dioxide gas is released. This gas is heavy and therefore remains in the center of the compost pile. Hence, it is essential not to exceed the allowed size of the compost pile, as this would lead to a high concentration of carbon dioxide gas in the center of the pile. This, in turn, causes significant harm by killing many aerobic microorganisms, which are crucial for the decomposition of compost components. These microorganisms (microbes) play a vital role in converting various toxic and plant-unavailable forms of elements into accessible forms that plants can easily obtain and absorb from the compost.

Figure 4.5. Compost Piles or Windrows.

We start building the compost pile by placing a layer, 20 centimeters high, of carbon-rich plant residues such as leaves, straw, hay, wood shavings, small wood pieces, corn stalks, and cotton bush firewood. Afterward, a layer, 10 centimeters thick, of nitrogen-rich materials such as newly mowed grass, green weeds, garden residues, and animal manure (cows and buffaloes) is added. This process is repeated (20 centimeters of carbon-rich materials, then 10 centimeters of nitrogen-rich materials) until the pile reaches a height of 1.5 meters. It is essential to moisten with water each time a layer is added. Finally, the pile is covered with farm soil, followed by straw, banana leaves, or grass to preserve the heat within the compost pile.

This compost pile should be watered at least once a week in winter and twice a week in summer, along with regular turning or rotating as needed. The maturity of the compost pile is indicated by a decrease in the pile's temperature, the disappearance of ammonia odour, and the transformation of the compost into a brown colour. Additionally, the C/N ratio should reach a level of 15-20:1, indicating the maturity of the compost.

4.2.4.3 Phases of Compost Maturity

There are four phases that compost passes through until it reaches the maturity phase and becomes suitable for use in organic farms, as illustrated in Figure 4.6. These four phases take from 45 to 60 days, and they are as follows:

- **Mesophilic Phase**

In the beginning of preparing organic compost piles, the numbers of fungi, actinomycetes, and bacteria that thrive in moderate temperatures start multiplying. These microorganisms, known as Mesophilic Microorganisms, thrive in moderate temperatures, causing the temperature of the compost mass to rise to 40 – 44°C. During the composting process, these microorganisms work to integrate carbon with oxygen, producing carbon dioxide gas and energy. Part of this energy is consumed by the microorganisms for reproduction and growth, while the remaining energy is released in the form of heat. This occurs in the initial stage of compost preparation when the simple, easily decomposable organic waste begins to break down.

- **Thermophilic Phase**

Afterward, the second phase begins, where the temperature of the compost pile rises, and the activity of heat-loving microorganisms, known as Thermophilic Microorganisms, starts. Bacteria and actinomycetes that thrive in higher temperatures become active and grow. This stage progresses relatively quickly, and during this phase, large molecular weight materials such as starch, fats, and proteins break down. This results in an increase in pH due to the release of ammonia from the proteins. This phase may last only a few days or weeks, and the temperature during this phase can reach 60–70°C. It is essential to prevent the temperature of the compost pile from exceeding 70°C during this phase because temperatures higher than that can lead to the death of many beneficial microorganisms. Therefore, turning and moistening the compost pile during this process is crucial.

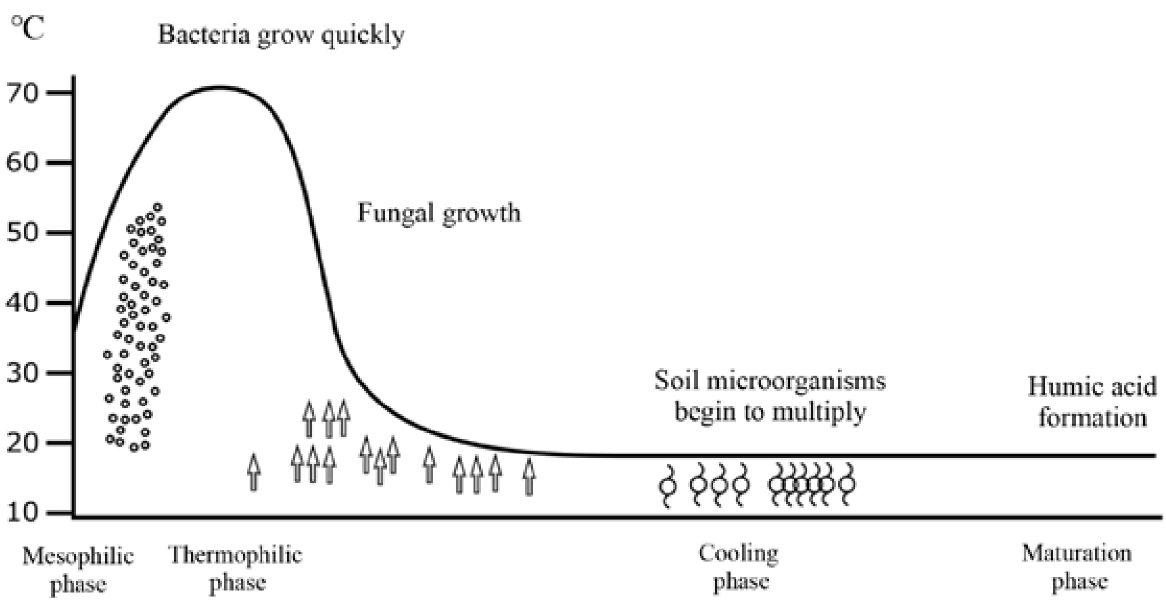
- **Cooling Phase**

After approximately three weeks of preparing the compost pile, the temperature of the pile begins to decrease until it reaches the ambient temperature of 20–30°C, and Mesophilic Microorganisms gradually increase until they remain constant. The activity of fungi that attack cellulosic substances begins, reactivating the Thermophilic Microorganisms. During this phase, the speed of decomposition decreases as difficult-to-decompose substances such as lignin begin to break down. This phase is called the cooling phase or the activity decline stage.

- **Maturation Phase**

This is the final phase in the composting process, known as the maturing phase or curing stage. During this stage, humus and Humic acids, such as Humic and Fulvic acids, are formed, and the microorganisms that produce antibiotics become active. To speed up this process of biological decomposition, a portion of fertile agricultural soil or Bentonite (clay) in the range of 4–10 % of the compost materials can be added. This encourages the growth and activity of microorganisms and speeds up the formation of Humic substances that form a complex compound with clay minerals. Additionally, 10 % of mature compost can be added to accelerate the decomposition process due to its content of active microbes. Rock phosphate can also be added as a phosphorus source. The addition of rock phosphate reduces ammonia loss by reacting with ammonium to form ammonium sulfate in the compost pile. Also, ground Feldspar rock as a source of potassium, and ground Dolomite as a source of calcium and magnesium can be added.

Figure 4.6. Phases of Compost Maturity.



4.2.4.4 Factors Affecting the Speed of Decomposition of Wastes

There are several factors that affect the speed of decomposition of the waste components in a compost pile. Below, we will discuss the most important of these factors and the devices used to monitor waste decomposition in compost pile:

- **Volume of Plant Residues**

As mentioned earlier, the size of plant residues should not exceed a length of five centimeters and a diameter of one centimeter. This is achieved by using a shredding machine to cut and chop the plant waste. The process of cutting and grinding the waste increases microbial decomposition due to the increased surfaces exposed to the activity of microorganisms in the compost pile. Additionally, it aids in enhancing ventilation rates and preserving moisture in the compost pile, as well as the ease of stirring and transporting.

- **Carbon Nitrogen Ratio (C: N)**

The ratio of Carbon to Nitrogen (C: N) in the residues used in the composition of the compost pile can range from 5:1 to 500:1, depending on the type of plant residues used. The Carbon to Nitrogen ratio plays a crucial role in the decomposition of organic matter by microorganisms, involving the conversion of organic nitrogen into mineral nitrogen, known as Nitrogen Mineralization. A wider carbon to nitrogen ratio, where organic matter contains a high proportion of carbon and a low proportion of nitrogen, results in microorganisms not finding sufficient nitrogen for their growth, leading to slow decomposition of organic matter. This also means most mineral nitrogen in organic matter converts to organic nitrogen within the microorganisms' bodies, causing a lack of ammonia (NH_3) release. When the carbon content in organic matter exceeds 33:1, whether present in the soil or added through organic fertilization, soil microorganisms may consume mineral nitrogen released from soil minerals or added to the soil through organic matter decomposition. As a result, plants growing under these conditions will suffer from a lack of absorbable nitrogen. Conversely, if the ratio of Carbon to Nitrogen in organic matter drops below 8.5:1, the decomposition of organic matter will stop.

For example, crop residues of grasses such as wheat and barley contain a high Carbon to Nitrogen ratio, reaching 100-200:1, indicating a wide Carbon to Nitrogen ratio. Consequently, microorganisms will not find sufficient nitrogen for their growth and tissue building, resulting in very slow decomposition of the residues in the compost pile. On the other hand, legume crop residues have a narrow Carbon to Nitrogen ratio, reaching 20:1. In this case, microorganisms will find adequate nitrogen for their growth, accelerating the decomposition of the residues and the preparation of compost. This, in turn, accelerates the process of organic nitrogen mineralization, converting it into mineral nitrogen suitable for plant absorption.

It has been found that the Carbon to Nitrogen ratio (C: N) in agricultural residues used in compost piles should range between 25:1 and 30:1. This provides a suitable environment for microorganisms to decompose complex organic matter into simpler substances efficiently and in a relatively short time. The activity of these microorganisms increases when the residues contain a high nitrogen ratio, as nitrogen is essential for their growth, while carbon serves as their energy source. Therefore, the Carbon to Nitrogen ratio is crucial in maintaining this balance.

The Carbon to Nitrogen ratio (C: N) in a compost pile decreases during the decomposition process, and it is essential to maintain this ratio throughout the process. For mature and high-quality compost, the Carbon to Nitrogen ratio should not exceed 18-20: 1. When using plant residues with a high carbon percentage, such as rice straw, wheat straw, or sawdust, it is preferable to add leguminous residues and animal pens wastes to elevate the nitrogen ratio in the compost pile. This helps balance the C: N ratio and enhances the composting process.

- **Temperature**

During the decomposition process of compost pile components, heat is released, leading to an increase in the pile's temperature. It has been found that the raw materials that make up the compost pile have a high ability to retain heat, and the appropriate temperature for the decomposition process of these components should range from 55 to 60°C. This temperature should be maintained throughout the pile during the active composting stage, which should last for two weeks. This temperature range leads to the activity of heat-loving bacteria, helps in killing weed seeds, and eliminates nematodes and plant diseases (whether bacterial or fungal). Consequently, the resulting compost is free from pathogenic microorganisms, parasites, and weed seeds.

The appropriate temperature can be achieved during the compost production process through regular turning of the compost pile every four days and ensuring the correct C: N ratio of 25:1. It is crucial to consistently measure the temperature of the compost pile using a Long Stem Dial Thermometer. This device features a long metal arm, approximately one meter in length, and should be used to measure the temperature along the length of the compost pile every 15 meters. This reflects the overall activity level throughout the entire compost pile. Temperature adjustments, if needed, can be made by moistening the compost pile through the addition of water as necessary.

Once the temperature of the compost pile begins to decrease, it is essential to take a random and representative sample of the compost pile to determine its elemental content. This allows for potential adjustments in phosphorus, potassium, pH levels, or magnesium. These adjustments can be made by incorporating certain natural materials, which are permitted for use in organic agriculture. These materials are added to the compost pile at fixed rates, then the pile is thoroughly turned. Afterward, the pile is watered, and it is left to mature for approximately a month. During this period, the microorganisms in the compost facilitate the added elements and make them suitable for absorption by plants.

- **Aeration**

Compost production takes place under aerobic conditions. Therefore, the availability of oxygen in the compost pile is a crucial factor influencing the activity of microorganisms involved in the decomposition process. It has been found that the oxygen level in the compost pile should not fall below 5 %. To ensure adequate aeration, it is necessary

to turn the compost pile approximately every four days. This turning process aerates the pile and provides the necessary oxygen for the decomposition process. An oxygen meter, as shown in the attached figure, should be used to measure the oxygen level in the compost pile. This ensures that the oxygen concentration remains at an optimal level to support the microbial activity essential for effective composting.

- **Moisture**

Maintaining appropriate moisture in the compost pile is crucial for the growth and activity of microorganisms responsible for waste decomposition. If moisture levels decrease, the growth of bacteria needed for decomposition is inhibited, leading to increased fungal growth on the surface rather than inside the pile. As a result, the decomposition process slows down, and valuable decomposition products are lost.

Figure 4.7. Field Test Demonstrating the Presence of Adequate Moisture in the Compost.

It is essential to use a moisture meter to maintain the optimal moisture level in the compost pile, which is critical for the waste decomposition process. The attached figure shows a moisture detection device for compost. The ideal moisture content in the pile should range between 40 % and 60 %. If the moisture level falls below 40 %, the activity of microorganisms in the pile decreases. Conversely, if it exceeds 65 %, the available oxygen in the pile diminishes, leading to reduced microbial activity.

To maintain proper moisture, it is recommended to sprinkle water on the waste pile while building it for composting. Afterward, the pile should be re-moistened by sprinkling water on it at least once a week. However, care must be taken not to overwater, as flooding the pile can reduce oxygen levels and create unfavorable conditions for decomposition. Excessive watering can also cause the dissolution and loss of nutrients formed in the pile.

A simple field test can be conducted to determine whether the moisture in the compost pile is at the optimum level. Take a handful of compost and press it in the palm of your hand. If your palm becomes wet with water, the moisture level is adequate for the decomposition process. If it does not get wet, the pile is too dry and lacks sufficient moisture, as shown in Figure 4.7. In this case, the pile should be moistened by sprinkling it with water to increase the humidity.

- **pH - Value**

The pH level (hydrogen ion concentration) is a critical factor influencing the decomposition process in the compost pile. While the microorganisms responsible for breaking down waste can function within a broad pH range of 5.5 to 9.0, it is preferable for the pH to be maintained between 6.5 and 8.0. If the pH falls below this range, adding calcium carbonate to the pile is recommended. Conversely, if the pH rises above this range, agricultural sulfur can be added to adjust the pH.

Typically, the pH level in the compost pile decreases during the initial days of composting and then rises as the temperature increases. As the compost matures, the pH level decreases again. This can be measured using a pH meter, as illustrated in the attached figure. Before use, the pH electrode should be rinsed in distilled water for 1-2 minutes and then calibrated.

- **Inoculation with Microorganisms**

To expedite the composting process, adding 2 % of well-decomposed old compost can be beneficial. This aged compost acts as a starter or inoculant, introducing essential microorganisms that accelerate the decomposition of the compost pile's components. These microorganisms play a crucial role in efficiently breaking down organic matter.

- **Percentage of Lignin in Components**

Wastes used in the compost pile that contain a high percentage of lignin, such as tree branch residues from pruning, require the addition of ligninolytic fungi to accelerate decomposition and ensure the breakdown of lignin. Additionally, adding a mixture of brown algae can further enhance the decomposition process. This algal material is rich in macro- and microelements, as well as vitamins and growth stimulants, which increase the nutritional value of the resulting compost.

Table 4.5 provides a summary of the importants factors required for the rapid completion of the compost maturation process.

Table 4.5. Important Factors for Accelerating Compost Ripening.

Item	Preferred Range	Reasonable Range
C: N Ratio	(25: 1) - (30: 1)	(20: 1) - (40: 1)
Moisture Content	50 - 60 %	40 - 60 %
Concentration O_2	>12	>5
pH	6.5 - 8.0	5.5 - 8.5
Temperature (°C)	55 - 60	45 - 65
Particle Size (cm.)	1 - 2.5	1 - 5
Compost Pile Density (kg/m³)	600 - 700	550 - 850

4.2.4.5 Maturity Criteria of Compost

Ensuring the maturity of compost is crucial, and specific criteria must be met to confirm the production of mature compost suitable for its intended use. According to Haga (1990), compost maturity can be assessed by evaluating several indicators, including the Biological Oxygen Demand (BOD) rate, Volatile Fatty Acids (VFA) levels, the percentage of nitrites, the percentage of reducing sugars, the Carbon to Nitrogen (C: N) ratio, and the results of germination tests.

It is important to consider the nutrient content of the mature compost and to be aware of any potential heavy metals or toxic substances that could impact plant health. The compost's organic matter content, particularly the humus, is also a significant criterion for determining compost maturity. Despite the considerable attention given to compost quality, there is still no universally accepted standard for evaluating compost properties.

Anthonis (1994) proposed several criteria for assessing compost maturity, which are outlined in Table 4.6. Additionally, Gaur (2006) suggested criteria for the rapid assessment of compost maturity and quality control, as detailed in Table 4.7. These criteria include regular monitoring of pH levels, temperature, humidity, and odour throughout the composting process. Furthermore, it is essential to measure the proportions of organic carbon, humus, and nitrogen, as well as to evaluate the impact of mature compost on plant growth.

Table 4.6. Proposed Criteria Indicating the Maturity of Compost.

Major Nutrient Content	Nitrogen (N)	1-3 %
	Phosphorus (P_2O_5)	1.5-3 %
	Potassium (k_2O)	1-5 %
Moisture Content	15-25 %	
Organic Carbon	20 % (at least)	
C: N Ratio	(10-20): 1	
pH	6.5-7.5	

Table 4.7. Some Rapid Criteria for Evaluating the Maturity and Quality Control of Compost.

Physical	Chemical	Biological
Particle size*	pH*#	Microbes*#
Colour*	EC*#	Annelids
Moisture*	C/N ratio*	Worms
Porosity	Nitrogen*#	Collembola
Bulk density	Sulfur*	Aerobes
Water holding capacity	Starch-iodine test* Plant nutrient content	Anaerobes
Temperature*	Heavy metals Pesticides residues	Thermophiles
Total solids	Cellulose Lignin	Pathogenic microbes#
Volatile solids	Protein	Verticillium test*
Total ash content	CEC*# (Cation Exchange Capacity)	Amoeba
	Humification index	Plant growth response test*
	Organic acids content	
	Infrared spectroscopy Analysis of water extract	

* Regular. # Quality control tests.

To effectively monitor the production and quality of compost, it is essential to have the following equipment available: a long stem dial thermometer, moisture detection equipment, a pH meter, an oxygen meter, and a nitrogen meter. These devices are crucial for assessing the efficiency and speed of the composting process.

Maintaining optimal environmental conditions is vital for producing mature, high-quality compost. This requires continuous monitoring throughout the compost preparation and maturation process to stabilize these conditions. Consequently, this highlights the importance of quality control in compost production.

4.2.4.6 Quality Control of Compost

The Quality control in compost production is essential for ensuring that the compost meets the standards required for its intended use, especially in organic farming. While there aren't fixed standards for nutrient content, certain indicators are widely recognized for assessing compost maturity and quality. These indicators can be classified into chemical, physical, and biological methods.

- **Chemical Methods for Assessin Compost Quality**

Chemical methods can often be conducted in a relatively short time and include the following:

» Carbon to Nitrogen (C: N) Ratio

The C: N ratio is a critical indicator of compost maturity. It reflects the balance between carbon, which provides energy for microorganisms, and nitrogen, which is essential for microbial growth and reproduction. A C: N ratio of around 20:1 is generally considered ideal for mature compost. At this ratio, the compost is stable and unlikely to cause nutrient imbalances when applied to soil. If the ratio is too high, it suggests that the compost is still immature, with excess carbon that may lead to nitrogen immobilization in the soil. If the ratio is too low, it might indicate excessive nitrogen, which could lead to nutrient leaching or volatilization.

» Nitrogen Content

Monitoring total nitrogen helps determine the overall nutrient content of the compost. The transformation of nitrogen into various forms (ammonia, nitrite, nitrate) is a key indicator of compost maturity. High levels of ammonia indicate incomplete composting and immaturity. Ammonia is typically produced during the early stages of composting and should decrease as the process progresses. The presence of nitrates is a positive indicator of maturity, as it suggests that the nitrogen cycle within the compost has stabilized, with most ammonia being converted into nitrate through nitrification.

» pH Level

The pH of compost evolves during the maturation process. Initially, compost tends to be acidic due to the production of organic acids during the breakdown of organic matter. Mature compost generally stabilizes within a pH range of 6.5 to 8. This range is suitable for most plant growth, indicating that the compost is mature and less likely to cause soil acidification. Compost that remains acidic might be immature or could result from the use of raw materials with high acidity. Continuous low pH values might also suggest anaerobic conditions during composting, which is undesirable. A pH meter is typically used to measure the acidity or alkalinity of compost, providing a quick and reliable indication of its maturity. By monitoring these chemical indicators, compost producers can assess the quality and maturity of their compost, ensuring it meets the necessary standards for its intended use.

- **Physical Methods for Assessing Compost Quality**

» Temperature

Monitoring temperature is crucial throughout the composting process, as it reflects the microbial activity and the stages of organic matter decomposition. When compost is mature, its temperature should stabilize and not exceed 5°C above the ambient air temperature. This stability indicates that the microbial activity has slowed, and the compost is nearing its final stage. A Long Stem Dial Thermometer is commonly used to measure temperature at different depths within the compost pile, providing accurate readings of the internal conditions.

» Colour and Odour

Mature compost typically has a dark brown to black colour, indicating the breakdown of organic material into humus. The colour consistency is an important visual cue for maturity. The scent of mature compost should be earthy and pleasant, akin to forest soil. This odour is largely due to the presence of geosmin and 2-methylisoborneol, produced by fungi and actinomycetes. A foul or sour odour may indicate incomplete decomposition or anaerobic conditions. Although specific gravity increases during composting, it is challenging to measure accurately. Mature compost typically has a specific gravity between 0.5-0.9 g/cm^3, but due to its broad range, it is not a reliable sole indicator of maturity. High-quality mature compost generally has particles ranging from 1-15 millimeters. Larger particles should be minimal, with those greater than 40 grams making up less than 5 % of the total compost.

- **Microbiological Tests**

» Microbial Activity

The activity and presence of various microorganisms, including fungi, actinomycetes, and bacteria, are important indicators of compost maturity. Enzymatic activity tests also help assess microbial processes. Mature compost should be free of harmful pathogens. Most pathogens die off when the compost is maintained at temperatures above 55°C for at least three days. However, heat-resistant microorganisms like *Clostridium perfringens*, *C. botulinum*, and certain parasitic worms may survive and require additional monitoring. Table 4.8. illustrates the temperatures required to eliminate many pathogenic microorganisms that may be present in a compost pile.

» Pathogen Limits

Faecal Coliform Bacteria: The acceptable level in mature compost is less than 1000 MPN (Most Probable Number) per gram of dry weight.

Salmonella sp.: The acceptable level is less than 3 MPN per 4 grams of dry weight.

- **Germination Tests for Assessing Compost Quality**

Germination tests are an effective method for assessing the maturity and quality of compost. As Gaur (1982) highlighted, these tests provide clear and definitive results. Here's a summary of the key points and steps involved in conducting these tests:

» Key Points on Germination Tests for Compost Quality

* Sensitive Plant Selection: Mustard plants are commonly used due to their quick response to compost conditions. However, other sensitive plants can also be employed based on availability and testing requirements.
* Test Duration: Results are typically obtained within five days, making germination tests a fast and efficient method compared to other compost maturity assessments.

» Steps for Conducting Germination Tests

* Sample Preparation: Collect a representative compost sample and sieve it to remove large particles. This ensures a uniform and consistent sample for testing.
* Seed Selection: Choose sensitive seeds like mustard, which are known for their rapid germination and high sensitivity to compost maturity.
* Planting: Sow the seeds in a mixture of the compost sample and a control medium, such as sand or soil. This comparison helps isolate the effect of the compost on seed germination.
* Observation Period: Monitor the germination and growth of seedlings over a five-day period. Pay attention to the rate of germination, seedling vigor, and root development.
* Evaluation: Compare the results between the compost-treated seeds and the control group. Calculate the germination index and other relevant metrics to assess compost maturity.

As previously mentioned, in addition to germination tests, other physical, chemical, and biological methods can be used to assess compost maturity. The selection of these methods is often based on the specific characteristics of the compost, the desired level of accuracy, and the resources available. Each method offers unique insights into different aspects of compost quality, and using a combination of these methods can provide a comprehensive evaluation.

Gaur (2006) provided standard specifications for evaluating compost quality and maturity, as detailed in Table 4.9. and Table 4.10. These standards help ensure consistent and accurate assessments across different compost samples. Additionally, these standards serve as benchmarks for determining whether the compost is mature and of high quality.

4.2.4.7 Storage of Mature Compost

Proper storage of mature compost is crucial for preserving its quality and nutrient content until it is ready for use. Mature compost should be stored in a shaded area to protect it from weather fluctuations such as rain and sunlight. This helps preserve the nutrients in the compost and prevents them from leaching out. If a shaded area is not available, covering the compost pile with plastic or straw can provide adequate protection, especially in dry areas. When using plastic, ensure proper ventilation by periodically lifting the cover to allow oxygen to enter the pile. This promotes aerobic conditions and prevents anaerobic conditions, which can lead to unpleasant odours and slow decomposition. Another option for storing mature compost is to cover it with a layer of soil. This helps maintain moisture levels and provides insulation, which can help regulate temperature fluctuations. During the storage period, keep the compost pile moist but not overly wet. Excessive moisture can lead to anaerobic conditions and nutrient loss through leaching.

It is advisable not to store compost for an extended period to avoid nutrient loss, particularly nitrogen. Prolonged storage can also attract pests and contribute to odour issues. Therefore, it is best to use mature compost as soon as it is ready or within a reasonable timeframe to maximize its benefits and effectiveness in soil improvement and plant growth.

Table 4.8. Temperature and Duration Required to Eliminate Pathogens in the Compost Pile.

Pathogens in Compost	Disease	Lethal Temperature
Salmonella typhosa	Typhus	Die within an hour at 55-60°C Die within 20 minutes at 60°C
***Escherichia* coli**	Gastroenteritis	Die within 15 minutes at 60°C
***Shigella* spp.**	Shigellosis	Die within 15 minutes at 60°C
Mycobacterium tuberculosis* var. *hominis	Tuberculosis	Die within 20 minutes at 60°C
Corynebacterium diphtheriae	Diphtheria	Die within 45 minutes at 55°C
Clostridium perfringens	Food poisoning Gangrene	----
Clostridium botulinum	Botulism	----
Listeria monocytogenes	Meningoencephalitis	----
Entamoeba histolytica	Amoebic dysentery	Die in a few minutes at 45°C Die in a few seconds at 55°C
Tapeworm, *Taenia saginata* & *Hymenolepsis nana*	Anemia	Die fast at 55°C
Hookworm *Ancylostoma* spp.	Ancylostomiasis (Anemia)	Die fast at 55°C
Ascaris worm eggs *Ascaris lumbricoides*	Larvae sucks blood (Anemia)	Die within an hour at a temp. more than 50°C

Table 4.9. Standards of Maturity and Quality of Compost.

Item	Good compost	Bad compost
Colour	Darkish brown	Diffrent
Odour	Earthy	Unacceptable smell
pH	6.5 - 8	< 6 or > 8
C: N	(10 - 20):1	(< 10 - > 20): 1
Temperature	30 - 45°C	> 45°C
Moisture content	25 - 30 %	> 30 %
Humus	> 4	< 4
Plant growth	Good growth	Growth inhibition
Total nitogen	> 1.25	< 1

Table 4.10. Standard Specifications Indicating the Maturity of Compost.

Item	Standard Specifications for Mature Compost
Colour	Darkish brown
Odour	Earthy
Textures	Sponge
Moisture content	25 – 30 %
pH	6.5 – 8 (Less than 8)
Temperature	No more than 5°C above the temperature of the atmosphere surrounding the compost pile
CO_2	Zero – 1 %
O_2	19 – 20 %
Total nitogen	0.8 – 1.2 %
Ammonium (NH_4)	0.5 ppm (Not more than 2 ppm)
Nitrate (NO_3)	In summer not more than 300 ppm In winter not more than 100 ppm
Nitrite (NO_2)	Absence
Organic matter	16 – 22 %
Organic carbon	10 – 15 %
Ash content	Not more than 70 %
Total phosphorus	Not less than 0.8 %
Total potassium	Not less than 1.0 %
Particle Size (cm.)	1 - 2.5
C: N	18:1 – 20:1
Bulk Density	600 -700 kg/m^3

4.2.4.8 Amendment of Nitrogen Percentage in Compost

The percentage of nitrogen in mature compost typically ranges from 1.2 % to 1.5 %. To increase the nitrogen content to meet the higher demands of certain crops, such as vegetable crops in greenhouses, potatoes, and strawberries, nitrogen-rich materials can be incorporated into the compost. Below are some nitrogen-rich materials that can be used to amend the nitrogen percentage in compost:

- » **Poultry Compost:** Poultry compost is a nitrogen-rich material containing approximately 2 % to 2.5 % nitrogen. Incorporating poultry compost into the mature compost at an appropriate ratio can increase the overall nitrogen content. Ensure thorough mixing to achieve uniform distribution.
- » **Poultry Feather Powder:** Poultry feather powder is exceptionally high in nitrogen, with around 10 % nitrogen content. Adding poultry feather powder to the compost can significantly boost the nitrogen content. Proper mixing is essential for even distribution.
- » **AgroBiosol:** AgroBiosol is an organic fertilizer with a nitrogen content of 6 % to 8 %. Adding AgroBiosol to the compost at a rate of 5 to 10 kg per cubic meter will contribute additional nitrogen to the mix. Ensure thorough mixing for uniform distribution throughout the compost.

When amending the nitrogen content of compost, it is crucial to monitor the overall nutrient balance to avoid excessive nitrogen levels, which can lead to nutrient imbalances and environmental issues. Conducting soil tests and adjusting nitrogen inputs accordingly will help optimize plant growth and minimize potential negative impacts.

4.2.4.9 Compost Utilization Rates in Organic Agriculture

Compost utilization rates in organic agriculture depend on various factors, including soil type, crop requirements, and compost quality. Proper application is crucial for maximizing the benefits of compost while minimizing potential issues like nutrient imbalances or environmental impact. The following factors influence compost utilization rates:

» **Soil Type and Condition:** The existing nutrient levels in the soil determine the amount of compost needed. Soils with low fertility may require higher application rates to achieve desired nutrient levels. Additionally, for soils with poor structure or high compaction, compost can be applied at higher rates to improve soil texture and water infiltration.

» **Crop Requirements:** Different crops have varying nutrient needs. High-yielding or nutrient-demanding crops may require more compost compared to crops with lower nutrient needs.

» **Compost Quality:** The nutrient content and maturity of the compost affect application rates. Well-matured compost with balanced nutrient levels can be used more effectively and at higher rates compared to immature or nutrient-imbalanced compost.

The recommended compost utilization rates for different crops in organic agriculture vary widely depending on soil fertility, crop type (including tree age and size for fruit trees), and the specific goals of the compost application (e.g., soil amendment, nutrient supply, organic matter addition). Below are general guidelines for compost application rates across various crop types:

» **Field Crops (e.g., Corn, Wheat, Soybeans):** Compost is typically applied to improve soil structure, increase organic matter, and provide a slow-release source of nutrients. It is applied before planting and incorporated into the soil during seedbed preparation. The application rate ranges from 10 to 20 tons per hectare (approximately 4 to 8 tons per acre), though this can vary based on the specific nutrient needs of the crop and existing soil conditions.

» **Vegetable Crops (e.g., Tomatoes, Peppers, Lettuce):** To enhance soil fertility, improve soil texture, and supply essential nutrients, compost should be applied and incorporated 2 to 3 weeks before planting to allow for decomposition and nutrient availability. The rate of application ranges from 20 to 40 tons per hectare (8 to 16 tons per acre).

» **Fruit Trees (e.g., Apples, Stone Fruits):** To improve soil organic matter, enhance moisture retention, and provide a steady nutrient supply, it is recommended to apply 2-4 inches (5-10 cm) of compost around the drip line of the tree in early spring or fall before new growth begins, avoiding direct contact with the trunk. The application rate ranges from 9 to 14 kg of compost per tree as a mulch or soil amendment.

» **Citrus Trees (e.g., Oranges, Lemons, Limes):** In organic citrus production, it is recommended to apply compost annually in early spring. Apply 2-3 inches (5-7.5 cm) of compost around the base of the tree, extending out to the drip line. This equals approximately 7 to 11 kg of compost per tree.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- **Vineyards (e.g., Grapes):** To improve soil structure, increase organic content, and provide nutrients over the growing season, it is recommended to apply compost in early spring or fall, working it into the soil between the rows or using it as a surface mulch. The application rate ranges from 5 to 15 tons per hectare (2 to 6 tons per acre).
- **Olive Trees:** For organic olive trees, apply 2-3 inches (5-7.5 cm) of compost around the base of the tree, extending out to the drip line. It is recommended to apply compost annually in early spring before the growing season begins. The application rate ranges from 4.5 to 9 kg of compost per tree.
- **Mango Trees:** For organic mango trees, apply 2-4 inches (5-10 cm) of compost around the base of the tree, covering the root zone but avoiding direct contact with the trunk. It is recommended to apply compost annually in late winter or early spring at an application rate of 9 to 14 kg of compost per tree.
- **Fig Trees:** For organic fig trees, apply 2-4 inches (5-10 cm) of compost around the base of the tree, extending out to the drip line. It is recommended to apply compost once or twice a year, preferably in early spring or fall, at an application rate of 9 to 14 kg of compost per tree.
- **Banana Trees:** For organic banana trees, apply 4-6 inches (10-15 cm) of compost around the base of the tree, extending 2-3 feet (60-90 cm) from the trunk. Apply 2-3 times a year, especially before the rainy season and during periods of active growth. The application rate ranges from 18 to 27 kg per tree.
- **Pastures and Forage Crops:** Apply compost before planting or overseeding and incorporate it into the soil to increase organic matter, improve soil structure, and enhance nutrient availability. The application rate ranges from 5 to 15 tons per hectare (2 to 6 tons per acre).
- **Greenhouses and Nursery Crops:** To improve soil fertility, enhance microbial activity, and provide a consistent nutrient supply, compost can be mixed with other media before planting. The rate of application ranges from 10 % to 30 % by volume in potting mixes or seed-starting media.

Applying compost in early spring is ideal for fruit trees, as it supplies them with nutrients during their most active growing phase. Fall application is also beneficial, allowing the compost to decompose over the winter and enhance soil fertility for the upcoming growing season. It is important to consider that young trees typically require less compost, while mature trees, particularly those with high fruit production, may benefit from higher compost application rates.

The aforementioned rates are general guidelines and should be adjusted based on factors like soil quality, specific crop requirements, and local agricultural practices. It is essential to monitor the condition of the soil and the health of the plants to determine the appropriate compost application rates. Additionally, avoid over-application of compost, as excessive compost application can lead to nutrient imbalances, particularly with nitrogen. It may also contribute to soil salinity or other issues. Adhere to recommended application rates and monitor soil and plant health regularly.

4.2.4.10 Mineral Additives Allowed in Compost for Organic Agriculture

The use of natural rocks and minerals in organic agriculture is a key practice for enhancing soil fertility and promoting sustainable plant growth. These materials are valued for their rich concentrations of essential nutrients and trace elements, which are crucial for plant health. When incorporated into compost or directly applied to the soil, these mineral additives help improve both the physical and chemical properties of the soil.

In organic systems, the additives are often ground into a fine powder to increase their surface area, making the nutrients more accessible to plants. The process of decomposition is facilitated by organic matter, microbial activity, moisture, and heat, all of which work together to break down these minerals and release nutrients in forms that plants can readily absorb.

Common mineral additives such as rock phosphate, feldspar, dolomite, agricultural sulfur and others are used not only to supply essential nutrients but also to improve soil structure, increase aeration, and support healthy root development. These materials are typically added to compost piles at a rate of around 5 %, which helps balance the nutrient profile of the compost.

Table 4.11. illustrates the percentage composition of various components in a compost pile, including plant residues, animal manures, and mineral additives.

By incorporating mineral additives into compost, organic farmers can maintain soil fertility, boost crop yields, and adhere to organic farming principles, which prioritize the use of natural, sustainable resources over synthetic fertilizers. This approach contributes to the long-term health of the soil and the broader agricultural ecosystem.

Table 4.11. Percentage Composition of Compost Pile Components.

Compost Pile Ingredients	%
Plant residues	65
Animal manures	30
Various additives	5

- Rock Phosphate

Rock phosphate, a naturally occurring mineral primarily composed of calcium phosphate, is a valuable additive in organic agriculture, serving as a key source of phosphorus, an essential nutrient for plant growth. It provides phosphorus in the form of tertiary phosphate compounds, which are less soluble than synthetic fertilizers. While its reduced solubility can limit effectiveness in alkaline soils, rock phosphate is particularly beneficial in soils with neutral to slightly acidic pH levels. In these conditions, it gradually releases phosphorus, supporting critical plant functions such as root development and flowering. To maximize phosphorus availability, rock phosphate can be combined with other practices, such as incorporating it into compost, to improve its solubility and effectiveness. The following points summarize the benefits of rock phosphate in organic agriculture:

» **Source of Phosphorus:** Phosphorus is crucial for energy transfer, photosynthesis, and root development. Rock phosphate provides a natural, slow-release source of phosphorus that supports these essential plant processes.

» **Improvement of Soil Fertility:** Rock phosphate enhances soil fertility by increasing phosphorus content, which is particularly beneficial in soils with low phosphorus levels that can limit plant growth and yield.

» **Enhancement of Soil Structure:** Rock phosphate contributes to the development of soil aggregates, improving soil structure, water infiltration, and root penetration.

» **Preserving Nitrogen in Compost:** While rock phosphate doesn't directly form ammonium sulfate, it can help reduce nitrogen loss in compost pile by:

  * Lowering the pH or creating conditions less favourable for ammonia volatilization, thereby reducing nitrogen loss.

* Binding with ammonia in compost, helping retain more nitrogen in the pile, making it available to plants as the compost matures.

This dual role of providing phosphorus and conserving nitrogen makes rock phosphate particularly valuable in organic farming systems. As a natural mineral, rock phosphate aligns with organic farming principles, emphasizing the use of natural materials and sustainable practices.

Rock phosphate can be applied directly to the soil in either powdered or granulated form, with application rates typically ranging from 500 to 1,500 kg per hectare. The exact amount depends on the existing phosphorus levels in the soil and the specific crop requirements. For optimal effectiveness, rock phosphate should be incorporated into the soil, allowing it to interact with soil particles and gradually release phosphorus to plants over time. Before applying rock phosphate, conducting a soil test is crucial to assess current phosphorus levels and soil pH. Rock phosphate is most effective in slightly acidic to neutral soils, with a pH range of 6.0 to 7.0. In very alkaline soils, combining rock phosphate with sulfur can enhance phosphorus availability.

Incorporating rock phosphate into compost is another effective method. Organic farmers often mix rock phosphate into compost because the microbial activity, organic acids, and moisture present during composting help make phosphorus more accessible to plants. Adding sulfur to the compost pile along with rock phosphate can create a more acidic environment, further improving the breakdown and availability of phosphorus. The recommended application rate for rock phosphate in compost is approximately 7-10 kg per cubic meter.

Rock phosphate can be used alongside other soil amendments, such as compost, manure, or lime, depending on soil conditions and crop needs. Its gradual release makes it suitable for long-term soil fertility management, though supplemental sources may be necessary for crops with immediate phosphorus requirements.

When considering the sustainability of rock phosphate use, responsible sourcing is paramount. It is essential to obtain rock phosphate from sources that adhere to sustainable mining practices, minimizing environmental degradation and ensuring long-term availability of this vital resource.

Another important aspect of sustainability is the heavy metal content in rock phosphate. It is crucial to ensure that the rock phosphate used is free from high levels of heavy metals, particularly cadmium. Acceptable levels of cadmium are typically below 90 mg per kilogram of phosphoric pentoxide (P_2O_5). This precaution is vital for maintaining soil health and ensuring compliance with organic farming standards, thereby safeguarding both the environment and human health.

In summary, rock phosphate is a valuable tool in organic agriculture for supplying phosphorus, improving soil fertility, and supporting sustainable farming practices. Its use should be guided by soil testing and integrated into a broader soil management strategy to optimize its benefits and effectiveness.

- **Feldspars**

Feldspar is one of the most abundant minerals in the earth's crust. The feldspars include a range of compositions with the general chemical formula $xAl(Al,Si)_3O_8$ where x can be potassium (K) and/or sodium (Na) and/or calcium (Ca). These minerals, primarily composed of aluminium silicates, are natural deposits rich in potassium and other essential elements. In organic agriculture, feldspars are primarily used as a slow-release source of potassium, an essential nutrient for plant growth. The following points summarize the benefits of Feldspars in Organic Agriculture:

» Source of Potassium: Potassium is vital for many physiological processes in plants, including photosynthesis, enzyme activation, water regulation, and stress resistance. Feldspars, particularly potassium feldspar (also known as K-feldspar or orthoclase), provide a natural and slow-releasing source of potassium for plants.

» Contribution to Soil Fertility: Feldspars gradually break down in the soil, releasing potassium and other minerals like sodium, calcium, and trace elements. This slow release helps maintain a steady supply of nutrients over time, which is beneficial for long-term soil fertility.

» Improvement of Soil Structure: The presence of feldspar minerals can improve soil structure by contributing to the formation of soil aggregates. Enhanced soil structure improves aeration, water infiltration, and root penetration, leading to healthier plant growth.

» **Support for Organic Farming Practices:** Feldspars are compatible with organic farming practices because they are natural minerals. Their use aligns with the principles of organic agriculture, which emphasize sustainability and the use of naturally derived materials.

In organic agriculture, feldspar minerals can be ground into a fine powder and applied directly to the soil as a soil amendment. The typical application rate varies based on the soil's potassium levels and the specific crop requirements, generally ranging from 500 to 2,000 kg per hectare.

Additionally, since feldspars decompose slowly in the soil, ground feldspar rock can be incorporated into compost piles to enhance the potassium content of the resulting compost. When added to compost, feldspar rocks improve the nutrient profile by increasing potassium levels, thereby enriching the compost with essential minerals vital for plant growth, soil fertility, and disease resistance. The recommended application rate for feldspar rocks in compost piles is approximately 7-10 kg per cubic meter of compost.

Feldspars can be used in combination with other soil amendments, such as organic matter, lime, or gypsum, depending on the specific needs of the soil and crops. Before applying feldspar, it is important to conduct a soil test to determine the existing levels of potassium and other nutrients. This ensures that the application is tailored to the specific needs of the soil and the crops being grown. While feldspars release nutrients slowly, their benefits may not be immediately apparent. However, over time, they contribute to sustained soil fertility and can reduce the need for more frequent fertilizer applications.

In summary, feldspars are a valuable and sustainable source of potassium in organic agriculture, contributing to long-term soil fertility and supporting healthy plant growth. Their application should be guided by soil testing and integrated into a comprehensive soil management plan to optimize their benefits.

- **Dolomite**

Dolomite, a naturally occurring mineral composed of calcium magnesium carbonate ($CaMg(CO_3)_2$), is widely used in organic agriculture due to its dual role as a source of both calcium and magnesium. These nutrients are essential for plant growth and play a critical role in soil fertility management. The following points summarize the benefits of Dolomite in Organic Agriculture:

» **Source of Calcium and Magnesium:** Calcium is vital for cell wall formation and stability in plants, influencing root development and overall plant structure. Magnesium is a key component of chlorophyll, necessary for photosynthesis. It also plays a role in enzyme activation and the transport of phosphorus within the plant.

» **Soil pH Adjustment:** Dolomite acts as a liming agent, helping to neutralize acidic soils. This adjustment in pH can improve nutrient availability, particularly in soils that are too acidic for optimal plant growth.

» **Enhanced Nutrient Availability:** By raising soil pH, dolomite can improve the availability of other essential nutrients, such as phosphorus, which tends to become less available in acidic soils.

» **Soil Structure Improvement:** The calcium in dolomite helps to improve soil structure by promoting the aggregation of soil particles, which enhances aeration, water infiltration, and root penetration.

Dolomite can be incorporated into compost piles to buffer pH levels, especially when composting acidic materials such as certain manures or food scraps. The recommended application rate for dolomite in composting typically ranges from 2 to 5 kg per cubic meter of compost material, depending on the initial pH and the desired outcome. Adding dolomite to compost helps ensure that both calcium and magnesium are present in balanced ratios. This balance is crucial for preventing nutrient imbalances in the soil when the compost is applied.

Before applying dolomite, it is important to conduct a soil test to determine the existing pH and calcium-magnesium levels. This ensures that dolomite is used appropriately and that the soil's nutrient balance is maintained. However, over-application of dolomite can lead to excessively high pH levels, which may lock out other essential nutrients, such as iron, manganese, and zinc. Careful management is necessary to avoid these issues.

In summary, dolomite is a valuable amendment in organic agriculture, contributing to soil health, nutrient availability, and overall plant growth. Its use should be guided by soil testing and integrated into a broader soil fertility management plan.

- **Gypsum**

Gypsum, or calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), is a highly beneficial soil amendment in organic agriculture, valued for its role in improving soil structure, enhancing fertility, and providing essential nutrients. Gypsum is soft, white, and completely dry, making it easy to apply to soils either as a powder or in granulated form. It is a naturally occurring mineral with a purity level often reaching up to 99 %, making it an excellent source of both calcium and sulfur. The benefits of using gypsum in organic agriculture can be outlined as follows:

» **Source of Calcium and Sulfur:** Gypsum is a readily available source of calcium, an essential nutrient that strengthens cell walls, plays a crucial role in root development, nutrient uptake, and overall plant health. Unlike lime, gypsum does not raise soil pH, making it suitable for use in soils where pH adjustment is not desired. Gypsum also provides sulfur in the sulfate form, which is immediately available for plant uptake. Sulfur is vital for the synthesis of amino acids, proteins, and enzymes, and is particularly important for crops with high sulfur demands, like canola, onions, garlic, and legumes.

» **Soil Structure Improvement:** Gypsum improves soil structure by promoting the aggregation of soil particles, enhancing water infiltration, and reducing soil compaction. This is particularly beneficial in heavy clay soils, where compaction and poor drainage are common issues.

» **Reduction of Soil Salinity:** Gypsum is effective in reducing soil salinity, especially in sodic soils with high sodium levels. It displaces sodium ions from the soil's cation exchange sites, allowing them to be leached out of the root zone by rainfall or irrigation, thus reducing soil salinity and preventing damage to crops.

» **Alleviation of Aluminium Toxicity:** In acidic soils, aluminium can become soluble and toxic to plants, inhibiting root growth. Gypsum helps reduce aluminium toxicity by increasing calcium levels in the soil, which mitigates the negative effects of aluminium.

» **Enhanced Phosphorus Availability:** In acidic or highly calcareous soils, phosphorus can become bound to iron, aluminium, or calcium, making it unavailable to plants. Gypsum helps keep calcium and phosphorus in more soluble forms, improving phosphorus availability.

Gypsum is commonly used to address deficiencies in calcium and sulfur, improve soil structure, and reduce soil salinity. Its application rate varies depending on soil type and the specific issues being addressed. For general soil enhancement, especially when calcium or sulfur supplementation is needed without altering the pH, the typical application rate ranges from 500 to 1,000 kg per hectare (approximately 200 to 400 kg per acre).

In alkaline or sodic soils, where the primary goals are to reduce salinity or sodicity and manage high sodium levels, the application rate is often higher, ranging from 1,000 to 2,500 kg per hectare (about 400 to 1,000 kg per acre). For crops with significant calcium or sulfur needs, such as canola or legumes, application rates are adjusted to meet the specific requirements of the crop, generally falling between 500 and 2,000 kg per hectare.

In addition to its use directly on soil, gypsum can be incorporated into compost piles to boost sulfur content and help balance the carbon-to-nitrogen ratio. This practice also prevents the formation of ammonia during composting, thereby reducing nitrogen loss and improving the overall quality of the compost. When added to compost piles, gypsum is typically applied at a rate of 3 to 5 kg per cubic meter of compost. Furthermore, agricultural gypsum can be applied through irrigation water to enhance its effectiveness.

Before applying gypsum, it is essential to conduct a soil test to determine the soil's existing calcium and sulfur levels, as well as its pH and salinity status. This ensures that gypsum is used appropriately and effectively. Gypsum can also be used in combination with other soil amendments, such as organic matter, lime, or rock phosphate, depending on the specific needs of the soil and the crop.

While gypsum is generally safe for use in organic agriculture, excessive application can lead to nutrient imbalances, particularly concerning magnesium and potassium. Therefore, it is crucial to apply gypsum at recommended rates and to monitor soil nutrient levels over time. As a natural mineral, gypsum contributes to sustainable soil management practices in agriculture. However, it is important to source gypsum responsibly, favouring natural deposits over industrial byproducts to maintain ecological balance.

Importantly, agricultural gypsum is free from harmful salts or toxic elements, making it safe for plant growth. It is required to contain a minimum of 70 % calcium sulfate by weight, with sodium chloride content not exceeding 2 %. Additionally, agricultural gypsum contains a significant amount of sulfur and trace amounts of beneficial microelements in organic form, which are beneficial for plant health.

In summary, gypsum is a versatile and effective soil amendment that supplies readily available calcium and sulfur, both of which are critical for plant health. Its ability to provide these nutrients without altering soil pH makes it an ideal choice for a wide range of agricultural applications, particularly in organic farming. By incorporating gypsum into agricultural practices, farmers can improve soil fertility, mitigate soil salinity, and promote healthy plant growth in a sustainable manner.

- **Agricultural Sulfur**

Agricultural sulfur is widely used in organic agriculture as both a soil amendment and a plant nutrient, playing several critical roles in promoting plant health and soil fertility. The benefits of using agricultural sulfur in organic agriculture include:

» **Source of Sulfur:**

* **Nutrient Supply:** Sulfur is an essential nutrient for plants, involved in the synthesis of amino acids, proteins, and enzymes. It also contributes to the formation of vitamins and overall plant metabolism.

* **Deficiency Correction:** Sulfur deficiency can cause symptoms like chlorosis (yellowing of leaves), stunted growth, and poor crop yields. Applying sulfur helps correct these deficiencies, supporting healthy plant growth.

» **Soil pH Adjustment:** Sulfur can lower soil pH by converting to sulfuric acid in the soil. This is particularly beneficial for reducing soil pH in alkaline soils, making nutrients more available to plants and improving soil conditions for certain crops.

» **Improvement of Soil Fertility:** By adjusting soil pH, sulfur increases the availability of other essential nutrients like phosphorus, iron, and manganese, which may become less available in alkaline soils. Additionally, sulfur contributes to the breakdown of organic matter in the soil, improving soil structure and fertility.

» **Pest and Disease Management:** Sulfur has natural fungicidal properties and can be used to control certain fungal diseases in crops. It is particularly effective against powdery mildew and other fungal pathogens.

In organic farming, agricultural sulfur is typically applied to the soil at rates ranging from 50 to 500 kg per hectare, depending on the soil's initial pH, sulfur deficiency, and crop needs. It is generally applied in the fall or early spring, allowing time for it to react with the soil before planting. To ensure even distribution and effective pH adjustment, sulfur should be incorporated into the soil using tillage or soil mixing equipment. Granulated sulfur can be used as a slow-release source of sulfur for plants and is often applied alongside other fertilizers to provide balanced nutrition.

For disease control, sulfur can be applied as a dust or in a liquid formulation. It is important to follow application guidelines carefully to avoid phytotoxicity and ensure effective disease management. Misuse or excessive application of sulfur can lead to several issues, including:

* **Burns on Vegetative Tissues:** Sulfur can cause burns on plant leaves, stems, and other vegetative tissues if applied at high concentrations or during hot weather conditions. To prevent damage, which often manifests as browning or yellowing of the affected tissues, sulfur should be applied when temperatures are below 32°C.

* **Toxicity:** Excessive sulfur levels in the soil can lead to sulfur toxicity in plants, resulting in stunted growth,

reduced vigour, and even plant death in severe cases. Sulfur toxicity interferes with nutrient uptake and disrupts various physiological processes in plants.

* Soil Acidification: As sulfur oxidizes, it produces sulfuric acid. Repeated sulfur applications can acidify the soil, lowering its pH level. Acidic soil conditions can negatively impact soil structure, microbial activity, and nutrient availability, ultimately harming plant health.

* Aluminium Mobilization: Acidic soil conditions resulting from sulfur applications can increase the solubility of aluminium in the soil. Elevated aluminium levels can be toxic to plant roots, impairing root growth, nutrient uptake, and overall plant health.

* Interference with Nutrient Uptake: Excessive sulfur levels can disrupt the uptake of other essential nutrients by plants, leading to deficiencies or toxicities of other elements, which further compromises plant growth and development.

Before application, it is essential to conduct soil tests to determine the existing soil pH and sulfur levels. This helps in determining the appropriate amount of sulfur needed and prevents over-application. Additionally, regularly monitoring soil pH after application ensures it reaches and maintains the desired level. Excessive sulfur application can lead to soil acidification beyond the optimal range, potentially harming plants. Therefore, it is crucial to adhere to recommended rates and monitor soil pH and plant health.

Sulfur can interact with other soil nutrients; for example, high sulfur levels can affect the availability of calcium and magnesium. It is important to consider these interactions when planning nutrient management. Although sulfur has a relatively low environmental impact compared to synthetic inputs, avoiding excessive application is necessary to minimize the risk of runoff and potential environmental harm.

In summary, agricultural sulfur is a valuable tool in organic agriculture, providing essential nutrients, adjusting soil pH, and supporting soil fertility and plant health. Its use should be guided by soil testing and integrated into a comprehensive soil and crop management strategy to maximize benefits and minimize potential issues.

- **Clay**

Clay plays a significant role in organic agriculture due to its unique properties that benefit soil structure, fertility, and water management. Below are the key advantages about the use of clay in organic agriculture:

» Soil Structure Improvement: Clay particles are much smaller than sand or silt and have a high surface area, which helps in binding soil particles together. This improves soil structure, making it more stable and reducing erosion. It also enhances the soil's ability to retain moisture, which is crucial in drought-prone areas.

» Nutrient Retention: Clay has a high cation exchange capacity (CEC), which means it can hold onto essential nutrients like potassium, calcium, magnesium, and ammonium. This prevents nutrients from leaching away and makes them more available to plants over time.

» Water Management: Clay's ability to hold water can be beneficial in organic agriculture, especially in sandy soils that drain quickly. However, in heavy clay soils, proper management is needed to prevent waterlogging, which can harm plant roots.

» Soil pH Buffering: Clay minerals can help buffer soil pH, making the soil less susceptible to rapid pH changes. This is important in organic farming, where maintaining a stable pH is crucial for nutrient availability and microbial activity.

» Microbial Habitat: The fine particles of clay provide a habitat for soil microorganisms, which are essential for organic matter decomposition and nutrient cycling. This supports the biological activity of the soil, which is a cornerstone of organic farming.

» Amendment in Compost: Adding clay to compost helps improve its quality by balancing the carbon-to-nitrogen ratio and enhancing microbial activity within the compost pile, leading to richer, more fertile compost.

» Erosion Control: In organic farming systems, clay can be used as part of erosion control strategies. Its ability to bind soil particles together can help prevent soil erosion on slopes and other vulnerable areas.

» Use with Other Amendments: Clay is often used in conjunction with other soil amendments like organic matter, lime, and rock minerals to improve overall soil health. The combination can help balance the physical, chemical, and biological properties of the soil, making it more fertile and productive.

» **Pest Control:** Some types of clay, like kaolin clay, are used as a natural pesticide. When sprayed on plants, it forms a protective layer that repels insects and reduces damage from pests without harming beneficial organisms.

In organic agriculture, the use of clay is valued for its ability to improve soil health and enhance plant resilience without relying on synthetic chemicals. This aligns with the principles of sustainability and environmental stewardship. While clay can provide many benefits, excessive clay content can lead to soil compaction and poor drainage, which can be detrimental to crop growth. Therefore, a balanced approach is essential, and managing the amount and type of clay in the soil is crucial.

- **Calcium Chloride**

Calcium chloride ($CaCl_2$) is a highly soluble salt used in agriculture for various purposes, although its application in organic agriculture is limited and regulated due to its synthetic origin. In organic farming, calcium chloride is primarily used to address calcium deficiencies in certain crops, especially during critical growth stages like fruit development.

Calcium chloride is commonly applied as a foliar spray to correct calcium deficiencies in crops such as tomatoes, apples, and peppers. It is particularly effective in preventing and treating physiological disorders like blossom end rot in tomatoes and bitter pit in apples, both of which are directly related to calcium deficiency. In these cases, organic farming practices may permit the application of calcium chloride solutions.

Additionally, calcium chloride can be used post-harvest to enhance the shelf life and firmness of fruits and vegetables. By strengthening cell walls, it helps reduce spoilage, making produce less susceptible to bruising and decay during storage and transportation. In some instances, calcium chloride is also applied as a soil amendment to address issues of soil salinity and sodicity. It can help displace sodium ions in the soil, thereby improving soil structure and promoting better water infiltration.

The use of calcium chloride in organic agriculture is regulated. In the United States, for example, it is permitted under the USDA **N**ational **O**rganic **P**rogram (**NOP**) only for specific purposes, such as treating physiological disorders related to calcium deficiency. Its use must comply with organic certification standards, which may vary by region.

However, excessive use of calcium chloride can lead to soil salinization, which can negatively impact soil structure and plant health. Therefore, it is important to apply it judiciously and only when necessary, adhering to recommended application rates.

Organic farmers typically prefer natural sources of calcium, such as gypsum (calcium sulfate) or limestone (calcium carbonate), which are more aligned with organic farming principles and less likely to contribute to salinity issues. However, in situations where a quick response is needed, calcium chloride remains a valuable tool when used in compliance with organic standards.

Before applying calcium chloride, it is essential to conduct soil and tissue tests to confirm calcium deficiency. This ensures that the treatment is necessary and prevents over-application. For foliar applications, calcium chloride is typically applied at a concentration of 0.5 % to 1 % in water, depending on the crop and the severity of the deficiency. Over-application can lead to leaf burn or other issues, so it is crucial to follow guidelines closely.

In summary, the use of calcium chloride in organic agriculture is often restricted and should be carefully considered within the context of organic certification standards. Its primary applications are in specific cases like treating physiological disorders such as blossom end rot in tomatoes and bitter pit in apples or as a post-harvest treatment. However, it is generally not the first choice for calcium supplementation in organic farming, where natural alternatives are typically preferred to align with organic principles.

- **Magnesium Sulfate**

Magnesium sulfate ($MgSO_4$), commonly known as Epsom salt, is widely used in organic agriculture primarily as a source of magnesium and sulfur, both essential nutrients for plant growth. The benefits of using magnesium sulfate in organic farming can be summarized as follows:

» **Source of Magnesium:** Magnesium is a central component of chlorophyll, the molecule responsible for photosynthesis. A deficiency in magnesium can lead to reduced chlorophyll production, causing symptoms like interveinal chlorosis (yellowing between leaf veins) and stunted plant growth. Magnesium sulfate provides magnesium in a readily available form, making it an effective treatment for these deficiencies.

» **Source of Sulfur:** Sulfur, also provided by magnesium sulfate, is essential for crops with high sulfur demands. It plays a key role in the synthesis of amino acids, proteins, and enzymes, as well as in the formation of vitamins and overall plant metabolism.

» **Improvement of Nutrient Uptake:** The application of magnesium sulfate can enhance the uptake of other essential nutrients, such as phosphorus. This is particularly important in soils where phosphorus availability is limited due to pH or other factors.

Magnesium sulfate is often applied as a foliar spray to correct magnesium deficiencies quickly. The typical concentration for foliar applications is 1-2 % magnesium sulfate in water. This method ensures rapid absorption of magnesium by the leaves, providing immediate relief to the plant.

Magnesium sulfate can also be applied directly to the soil to address magnesium and sulfur deficiencies. It is particularly useful in sandy soils, which often lack sufficient magnesium and sulfur due to leaching.

Additionally, adding magnesium sulfate to compost can help enrich the compost with magnesium and sulfur, making it a more balanced amendment when applied to soil. It can also help buffer the pH of the compost, preventing it from becoming too acidic.

Before applying magnesium sulfate, it is important to conduct a soil test to determine the existing levels of magnesium and sulfur. This helps in tailoring the application rate to the specific needs of the soil and the crops being grown. The application rate of magnesium sulfate varies depending on the severity of the deficiency and the crop being grown. For soil applications, rates typically range from 10 to 20 kg per hectare. For foliar sprays, 5-10 grams per liter of water is a common recommendation. Magnesium sulfate is generally allowed in organic agriculture, but it is important to check with local organic certification bodies to ensure its use complies with specific regulations. It is often preferred because it is a naturally occurring mineral and provides essential nutrients in a soluble form.

In summary, magnesium sulfate is a valuable tool in organic agriculture for addressing magnesium and sulfur deficiencies, improving nutrient uptake, and enhancing overall plant health. Its use should be guided by soil tests and aligned with organic farming practices.

- **Iron Slag**

Iron slag, a byproduct of steel manufacturing, is sometimes used in agriculture, including organic farming, as a soil amendment due to its potential to improve soil properties and provide essential nutrients. The benefits of incorporating iron slag into organic agriculture include:

» **Source of Micronutrients:** Iron slag contains several micronutrients, particularly iron, which is crucial for plant growth. Iron is a key component of enzymes involved in photosynthesis and respiration. A deficiency in iron can lead to chlorosis, a condition where leaves turn yellow while the veins remain green.

» **Soil pH Adjustment:** Depending on its composition, iron slag can be used to modify soil pH. It may help neutralize acidic soils, like lime, although the specific effect depends on the slag's chemical properties. This adjustment can enhance the availability of nutrients in the soil.

» **Improvement of Soil Structure:** Iron slag can improve soil structure by increasing the aggregate stability of the soil. This leads to better water infiltration, reduced erosion, and improved root growth.

» **Phosphorus Availability:** Some types of iron slag contain phosphorus, which can be slowly released into the soil, making it available for plant uptake over time. This slow-release characteristic can be particularly beneficial for crops requiring a steady supply of phosphorus.

Before applying iron slag, it is crucial to conduct a soil test to determine the soil's existing nutrient levels and pH. This helps in deciding the appropriate type and amount of slag to apply. One of the main concerns with using iron slag in agriculture is the potential presence of heavy metals, such as lead, cadmium, and arsenic, which can accumulate in the soil and pose risks to plant health and food safety. It is essential to ensure that the slag used is free from harmful levels of these contaminants.

Using iron slag in agriculture contributes to sustainability by recycling industrial byproducts. However, it is important to balance the benefits with the potential risks to soil and plant health. The use of iron slag in organic farming is regulated and may not be permitted under all organic certification standards. It is important to verify with local organic certification bodies whether its use is allowed in your region. The application rate of iron slag depends on soil conditions and the specific needs of the crop. It should be applied carefully, keeping in mind the potential risks of over-application, especially concerning heavy metal accumulation.

In summary, iron slag can be a useful amendment in organic agriculture for improving soil structure and providing essential micronutrients, particularly iron. However, careful consideration must be given to the source of the slag, potential heavy metal content, and compliance with organic standards. Soil testing and proper application rates are critical to ensuring safe and effective use.

4.2.4.11 Heavy Metals in Compost

The presence of heavy metals in compost is a significant concern in organic agriculture, as they can negatively impact soil health, plant growth, and ultimately, food safety. Heavy metals are metallic elements characterized by their high molecular weight and density, typically at least five times greater than that of water. More than 20 heavy metals are known to be toxic to humans, including lead, nickel, mercury, chromium, arsenic, cobalt, and cadmium. Among these, four heavy metals, (lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As), are particularly hazardous. They can accumulate in the soil, enter the food chain, and cause severe health effects in humans even at low concentrations.

Sources of heavy metals in compost can arise from various feedstock materials and agricultural inputs. Compost made from municipal solid waste, sewage sludge, or contaminated yard waste often contains elevated levels of heavy metals. Additionally, compost that includes byproducts from industrial processes, such as fly ash or certain manures, may introduce heavy metals. Plants grown in contaminated soils can also contribute to heavy metal accumulation in compost. Agricultural inputs are another potential source, as some synthetic pesticides and fertilizers may contain heavy metals as impurities. When these materials are used in compost feedstocks, they can introduce heavy metals into the final product. Furthermore, manure from animals fed with contaminated feed or supplements may also carry heavy metals, contributing to their presence in compost.

Heavy metals in compost pose several significant risks, which can be summarized as follows:

- **Soil Contamination:** Heavy metals in compost can accumulate in the soil over time, especially with repeated applications. This accumulation can lead to long-term soil contamination, rendering the soil unsuitable for growing food crops.
- **Plant Uptake:** Some plants can absorb heavy metals from the soil, which may then be translocated to the edible parts of the plant. This poses a direct risk to human health if contaminated produce is consumed.
- **Impact on Soil Microbiology:** Heavy metals can disrupt microbial activity in the soil, which is essential for nutrient cycling. This disruption can reduce soil fertility, making it harder for plants to thrive.
- **Bioaccumulation and Biomagnification:** Heavy metals can accumulate in plants and animals, leading to higher concentrations in organisms higher up the food chain. This can have serious ecological consequences, affecting not just individual species but entire ecosystems.

To manage and prevent heavy metal contamination in compost, it is crucial to implement several key practices. First, carefully select feedstock materials, using only clean and uncontaminated inputs for composting. Avoid municipal waste, industrial byproducts, or manure from animals exposed to contaminated feed, and regularly test feedstock materials for heavy metal content before adding them to the compost pile. Regular testing of the compost itself is also essential to monitor heavy metal concentrations and ensure the final product is safe for use in organic farming. Adhering to national or regional guidelines and standards for acceptable levels of heavy metals in compost is critical.

If heavy metals are detected, phytoremediation techniques, which involve using plants to absorb and concentrate heavy metals, can be employed to clean up contaminated soil. However, it is important to ensure that the contaminated plant material is not used for composting. Lastly, compliance with organic standards is vital, as organic certification bodies often impose strict limits on permissible heavy metal levels in compost. Ensuring that your composting process meets these standards is essential for maintaining organic certification.

Acceptable levels of heavy metals in compost are crucial due to the potential for these metals to accumulate in both soft tissues, such as kidneys, and hard tissues, like bones. Since compost is typically applied to agricultural soil before planting, it is essential to monitor its heavy metal content to prevent soil contamination. Contaminated soil can lead to agricultural products that contain harmful elements, posing serious health risks to humans who consume them, even at low concentrations.

Different countries and certification bodies have established varying standards for acceptable levels of heavy metals in compost. For example, the United States Environmental Protection Agency (EPA) and the European Union have set specific limits for metals like lead, cadmium, and mercury in compost products. These maximum permissible limits are designed to ensure the safety of compost. Table 4.12. provides an overview of these limits across different countries. Familiarity with and adherence to these standards are critical for maintaining the safety and quality of compost.

In summary, while compost is a valuable resource in organic agriculture, the presence of heavy metals can significantly undermine its benefits. By carefully selecting feedstock, regularly testing compost, and adhering to established organic standards, the risk of heavy metal contamination can be minimized, ensuring that compost remains a safe and effective soil amendment.

Table 4.12. Maximum Permissible Limits of Heavy Elements in Compost in Different Countries.

Country	Permissible Limits of Heavy Elements in Compost (ppm) (Milligrams per kilogram)							
	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Nickel (Ni)	Zinc (Zn)	Copper (Cu)	Chrome (Cr)	Arsenic (As)
Austria	150	1	1	60	400	100	70	-
Belgium	120	1.5	1	20	300	90	70	-
Denmark	120	0.8	0.8	30	4000	1000	100	-
Finland	150	3	2	100	1500	600	-	50
France	800	8	8	200	-	-	-	-
Germany	150	1.5	1	50	400	100	100	-
Italy	500	10	10	200	2500	600	10 (Cr+3) 500 (Cr+6)	-
Netherlands	65	0.7	0.2	10	75	25	50	5
Norway	60	0.8	0.6	30	400	150	60	-
Spain	1200	40	25	400	4000	1750	750	-
Switzerland	120	1	1	30	400	100	100	-
Canada	500	20	5	180	1850	-	50	10 -20
USA	300	10	8	50-200	400-2500	750	100	10
Colombia	150	2.5	0.8	50	315	600	210	13
New Zealand	600	15	10	200	2000	1000	1000	-
Korea	150	5	2	-	-	-	5	50
Taiwan	150	5	2	25	500	150	5	50

Source: Barth, J. *et al.*, (2012).

4.2.4.12 Potential Damages Caused by Compost to Plants

Although mature compost is generally beneficial for plant growth, it is important to recognize that compost can sometimes cause harm. Improper production or application methods, as well as excessive use, especially with sensitive plants or young seedlings, can increase these risks. The potential damage from compost can be categorized into acute and chronic effects, which are explored further below.

- **Factors with Acute Effects**

» High Salinity

High salinity is often a significant issue associated with compost. Plants typically obtain nutrients from the soil in the form of dissolved salts. When compost contains high levels of soluble salts, it can contribute to salt buildup in the soil over time. Excessive salt levels can hinder water uptake by plant roots, leading to dehydration or salt stress. Symptoms of salt-induced damage include rapid wilting and leaf yellowing.

High salinity weakens plants and makes them more susceptible to root rot, particularly from soil-borne fungi such as *Pythium* and *Phytophthora*. Ideally, salinity levels in compost should range between 3 and 4 mmhos/cm. If salts are not adequately washed out, excessive salinity can be toxic to plants.

To mitigate salinity in compost, it can be rinsed with water to reduce the salt content. Alternatively, high-salinity compost can be mixed with low-salinity compost, such as compost made from tree bark, to balance salinity levels.

It is important to emphasize that salinity percentage is a critical factor in compost quality control. Salinity levels can be measured using a conductivity meter as part of routine compost quality assessments.

» Ammonia Toxicity

While ammonia provides a valuable nitrogen source for plants, elevated concentrations in compost can lead to phytotoxicity, potentially causing rapid plant death. Even at lower levels, ammonia can cause leaf edge burns in sensitive plants, while less sensitive species may show browning at the tips of their roots. Azaleas, which are particularly sensitive to ammonia, are often used as indicators of ammonia toxicity.

The risk of ammonia toxicity is especially high in compost with a high nitrogen content, which typically corresponds to a low carbon-to-nitrogen (C: N) ratio, particularly when nitrogen is in a readily absorbable form. To mitigate this risk, compost should be applied at rates that match or fall below the nitrogen requirements of cultivated plants, ensuring that the nitrogen levels do not exceed what the plants can absorb.

» Organic Acids

Organic acids are commonly present in immature compost that has not fully decomposed or in compost stored under anaerobic conditions, even for short periods. Many organic acids are toxic to plants, causing symptoms such as leaf bleaching or paleness as the leaves lose their green color. In compost with a high carbon-to-nitrogen ratio (greater than 40:1), acetic acid and some alcohols are primarily produced. On the other hand, compost with a low carbon-to-nitrogen ratio tends to produce ammonium compounds (ammonia), often accompanied by foul odours.

Generally, compost that is either immature or improperly processed may contain high levels of organic acids, ammonia, or other harmful substances. This can lead to phytotoxicity, causing stunted growth, leaf burn, or even plant death. Changes in pH, while indicative of compost acidity or alkalinity, should not be solely relied upon to assess toxicity issues, as organic acids and other harmful compounds typically degrade within 24-48 hours after causing plant damage.

Ensuring the use of fully matured compost is the primary defense against these problems. Many organic acids emit strong odours, which can serve as indicators of their presence. Compost maturity tests, along with biological tests, can be employed to detect organic acids.

In relatively mature compost, organic acids break down or dissipate when exposed to air. As a precaution, compost that has been stored in airtight conditions, such as in sealed piles or trucks, should be aerated for several days before use or sale to consumers.

- **Factors with Chronic Effects**

Symptoms here appear and develop slowly, and are often complicated due to their interaction with other factors.

» C/N Ratio

Compost with a high carbon-to-nitrogen ratio (C: N) of 70:1 can lead to nitrogen immobilization, resulting in nitrogen deficiency in plants. This occurs because microorganisms decompose the excess carbon, which depletes the available nitrogen, leaving insufficient nitrogen for plant uptake.

The symptoms of nitrogen deficiency typically manifest as yellowing of the leaves, especially in new growth, and stunted plant development.

To mitigate nitrogen deficiency caused by immobilization, compost with a lower carbon-to-nitrogen ratio (C: N) or compost with a balanced potassium-to-nitrogen ratio (K: N) can be applied as a surface mulch. This helps address the deficiency by gradually releasing nitrogen into the soil.

While nitrogen is often the limiting factor, it is important to note that high levels of available carbon can also affect the availability of other nutrients, especially when they are present in limited quantities.

» Plant Toxicity

Plant toxicity can occur when certain elements are present in compost at excessively high concentrations. While these elements may not be harmful in moderate amounts, their abundance can lead to interactions that affect the availability of other nutrients, ultimately causing toxicity. For example, elevated levels of boron can result in significant crop damage. Increased boron concentrations may arise from the use of specific additives in compost, such as coal ash or cellulose derivatives.

To reduce the risk of plant toxicity, it is important to establish benchmarks or quality standards for compost. Additionally, compost should be tested if it contains substances known to potentially elevate certain elements to toxic levels.

» pH Ratio

High pH levels in compost, especially in calcium-rich compost derived from solid sewage waste or treated with certain additives, can present a persistent challenge. While calcium is beneficial for many crops, most garden and orchard plants prefer soil with a pH of 5 to 6. Excessive calcium in compost can raise the soil pH to levels that are unsuitable for many plants.

Lowering the pH of soil affected by high-pH compost can be difficult and may lead to poor crop growth. Therefore, it is essential to use compost that provides detailed information about its composition, including pH level, quality, and nutrient content. This ensures that the compost is applied correctly and does not negatively impact plant health or soil pH levels.

4.2.5 Compost Tea

Compost tea, also known as compost solution, is an aqueous extract of compost fermented under aerobic conditions. This fermentation process encourages the growth of aerobic microbes by providing ample oxygen, which in turn inhibits the growth of anaerobic microorganisms that offer fewer benefits. Compost tea typically contains three primary components:

- Abundant Nutrients: Compost tea is rich in essential macro- and micronutrients required for plant growth and development.
- Beneficial Microorganisms: Compost tea contains various beneficial microorganisms, such as bacteria, fungi, protozoa, and nematodes. These microbes play crucial roles in soil health and plant growth, including the biological control of plant diseases. Some microorganisms in compost tea actively inhibit the growth of pathogenic fungi and bacteria, enhancing plant health and disease resistance.
- Growth Regulators: Compost tea may also contain organic compounds that act as growth regulators, influencing important physiological processes in plants.

Overall, compost tea is a valuable organic amendment that promotes soil fertility, enhances plant growth, and supports sustainable agricultural practices.

4.2.5.1 How to Prepare Compost Tea

Preparing compost tea using a plastic container is a simple and efficient method, particularly suitable for small farms or greenhouse operations. Taha (2007) outlined the following steps for preparing compost tea:

- Equipment Setup: Begin by using a 20-liter plastic container. Install an air pump with a distributor attached to the edge of the container. Extend hoses from the distributor to the bottom of the container.
- Water Preparation: If using tap water, allow it to sit for an hour to eliminate chlorine. Fill the container with water, leaving about 8 cm from the top edge.
- Compost Addition: Add approximately 5-8 kg of high-quality compost to the container without compacting it.
- Mixing: Stir the compost and water thoroughly using a long stick to ensure even distribution.
- Molasses Addition: Add about 30 grams of unsulfured molasses to the mixture. Stir well to ensure even distribution.

- **Aeration:** Turn on the air pump to introduce a steady stream of air into the container. This will create air bubbles that rise from the bottom to the top, effectively stirring the contents of the container. Continue aeration for 3 days to ensure thorough oxygenation of the compost tea.
- **Optional Additions:** Additional nutrients or beneficial microorganisms can be added to enhance the compost tea. For example, dry fodder yeast can be included as a source of vitamins and amino acids. Approximately 10 % of the volume of molasses added can be used for this purpose, equivalent to around 3 grams. Alternatively, specific beneficial microorganisms such as *Azospirillum*, *Arthrobacter*, *Bacillus*, *Paenibacillus polymyxa*, *Saccharomyces cerevisiae*, *Serratia marcescens*, *Pasteuria penetrans*, and *Pseudomonas putida* may be added to secrete growth regulators, inhibit pathogens, and aid in nutrient absorption.

After the aeration period, it is crucial to ensure there are no unpleasant odours in the compost tea. Such odours indicate poor aeration, which can lead to the growth of anaerobic microorganisms. These microorganisms produce alcohols and gases toxic to plant roots, even at concentrations higher than one part per million. If unpleasant odours are detected, ventilate the compost tea for several more hours until the odours dissipate. Once properly aerated, the compost solution should be filtered through gauze to obtain the compost tea. It is important to use the compost tea immediately, ideally within an hour of production. The compost tea can be applied by spraying it onto the plant's vegetative system, watering the soil around the plants, or through irrigation systems.

For larger-scale operations, commercial compost tea brewers are available. These systems come in various sizes and use aerobic technology to produce compost tea, typically featuring outlets for the finished tea. Various sizes of commercial brewers are available, as depicted in Figure 4.8., and can be purchased from www.growingsolutions.com

The method of preparing compost tea in commercial brewers is not significantly different from the previously described process. However, these brewers may also use a compost tea catalyst. This catalyst is a powder composed of a unique blend of soluble seaweed powder, natural rock powder, and a mixture of plant ingredients. The compost tea catalyst is used to stimulate the growth of diverse aerobic microorganisms during compost tea production.

These substances are authorized for use in organic farming and serve as food for the living microorganisms. As a result, their populations increase, enriching the natural biodiversity of microorganisms in the compost used to produce the tea.

4.2.5.2 Factors Affecting the Production and Quality of Compost Tea

The quality of compost tea, or compost solution, is significantly influenced by several factors, with the type and maturity of the compost being among the most critical. Mature compost yields higher-quality compost tea due to its reduced presence of plant pathogens. Therefore, using mature compost ensures a more effective and safer compost tea extraction process. The production and quality of compost tea depend on several crucial factors, which are outlined below:

Figure 4.8. Commercially Compost Tea Brewers.

- **The Quality of Compost Used in Compost Tea Production**

The quality of the compost used in compost tea production directly influences the effectiveness and benefits of the final product. Various organic materials, such as animal waste, plant residues, and others, are used in the composting process. Each type of material has specific properties that affect the quality of the resulting compost.

Ideally, the compost used for producing compost tea should meet certain criteria: it should be of high quality, well-matured, moist, and slightly coarse. The optimal moisture content for compost is typically around 45-50 %. These conditions promote the growth of beneficial microorganisms and facilitate the decomposition of organic matter.

Research suggests that the type of microorganisms present in mature compost can vary depending on the source of the compost materials. For example, compost derived from carbon-rich residues, such as dry leaves and wood, typically contains higher fungal content. On the other hand, compost made from nitrogen-rich residues, such as animal waste and poultry manure, tends to be richer in bacteria.

By using high-quality compost that meets these criteria, growers can ensure that their compost tea is rich in beneficial microorganisms and nutrients. This promotes soil fertility and plant health, leading to improved crop yields and overall agricultural productivity. Regular monitoring and management of compost parameters are essential to maintain the quality and effectiveness of compost tea production.

The choice of compost type for extracting and producing compost tea depends on its intended purpose, as follows:

» Compost rich in bacteria is typically used for foliar fertilization, where the tea is sprayed directly onto plant leaves.

» Compost rich in fungi is preferred for soil applications, particularly around fruit trees or in strawberry fields.

Understanding the role of each type of microorganism is crucial when working to increase their populations in compost tea. By selecting the appropriate compost type based on its microbial composition, growers can maximize the benefits of compost tea for their specific agricultural needs.

When preparing compost, it is possible to favour the proliferation of bacteria over fungi by carefully selecting the raw materials. A recommended mixture to achieve this balance is: 45 % green waste, 25 % nitrogen-rich waste, such as organic fertilizers (e.g., animal waste) and legumes (e.g., alfalfa, beans, cowpeas), and 30 % wood waste.

Additionally, frequent turning or stirring of the compost pile can enhance bacterial dominance, as regular agitation disrupts fungal growth and promotes bacterial proliferation, resulting in compost rich in bacteria.

- **The Quality and Temperature of the Water Used to Produce Compost Tea**

The quality and temperature of the water used in compost tea production are crucial factors that impact the effectiveness of the final product. Chlorine, commonly found in tap water, can inhibit the growth of beneficial microorganisms. Therefore, it is essential to aerate the water in compost tea containers for at least an hour before adding compost to eliminate chlorine.

Additionally, maintaining an optimal temperature during the extraction process is important. Ideally, the temperature should range between 21-24°C. Lower temperatures can slow down the growth of beneficial microbes, while higher temperatures reduce the level of dissolved oxygen in the solution, adversely affecting microbial activity. Therefore, controlling water quality and temperature is critical for producing high-quality compost tea.

- **Compost Tea Catalysts**

Certain nutrients and growth stimulants, known as “Compost Tea Catalysts”, are added to promote biological activity during compost tea preparation. These catalysts include molasses, humic and fulvic acids, sugary substances, and fish extracts. However, caution is necessary when adding these nutrients, particularly if the compost contains harmful microorganisms or pathogens such as *Salmonella* or *Escherichia coli*. Adding these stimulants may inadvertently increase the numbers of these pathogens, posing risks to plants and users.

Therefore, it is important to carefully assess the compost's microbial content and apply additives judiciously to ensure the safety and efficacy of the compost tea.

- **Aeration**

Aeration and oxygen availability are vital during the compost tea production process, as they facilitate the growth of beneficial aerobic microorganisms. Proper aeration ensures the oxygenation of the compost tea, promoting the proliferation of beneficial microbes while suppressing anaerobic pathogens. Inadequate ventilation, on the other hand, can lead to the growth of harmful microorganisms, which can be detrimental to both plants and humans.

Therefore, maintaining adequate aeration throughout the compost tea production process is essential to preserve microbial balance and produce a high-quality, beneficial compost tea.

4.2.5.3 Important Guidelines to Follow When Using Compost Tea

When using compost tea, consider the following important guidelines:

» **Frequency of Application:** Compost tea can be applied every 10-30 days, or even twice a week during the growing season. However, it is advisable to discontinue its use at least one week before harvesting crops, especially when spraying directly onto the plant foliage.

» **Freshness:** Use compost tea immediately after extraction and within 24 hours at most. Avoid storing it for longer periods, as the population of beneficial microorganisms may decline significantly over time.

» **Spraying Compost Tea:** Apply compost tea in the early morning or late afternoon to reduce exposure to high temperatures and UV radiation, which can harm beneficial microorganisms. Avoid application during rainy or windy conditions to prevent runoff or dilution. Ensure thorough coverage of all vegetative parts when spraying onto plant foliage.

» **Salinity:** Monitor the salinity level of the compost tea solution to prevent leaf burn and other negative effects on plants. Properly applied compost tea can enhance plant immunity against adverse environmental conditions.

» **Irrigation Systems:** Compost tea can be used with drip irrigation systems but ensure proper filtration to prevent clogging of the drip lines.

» **Water Quality:** Ventilate the water used for compost tea preparation to remove chlorine. When using undiluted compost tea from high-quality compost, dilute it with water at a 1:1 ratio for proper distribution.

» **Soil Drenching:** For soil drenching, ensure that enough water is used to carry the compost tea deep into the root zone. The optimal dilution ratio is 1 part compost tea to 5 parts of water.

» **Sediment Removal:** Before spraying compost tea, ensure no sediment is present. If detected, filter the tea again to remove any remaining particles.

» **Clean Equipment:** Always use clean spraying equipment that has not been previously used for chemical pesticides. Residual pesticides can negatively affect the beneficial microorganisms in compost tea and harm plant health.

» **Brewing Time:** Compost tea should be brewed for a sufficient duration to allow ample time for microbial proliferation. Brewing times typically range from 12 to 48 hours, depending on the specific recipe and the desired level of microbial diversity.

» **Compatibility and Record Keeping:** Test compost tea on a small area or a few plants before applying it widely to ensure compatibility and avoid any adverse effects. Keep detailed records of brewing times, application rates, dates, and plant responses to optimize future applications.

4.2.5.4 Benefits of Using Compost Tea in Organic Agriculture

The following are the key benefits of using compost tea in organic agriculture:

» **Enhanced Soil Bio-Properties:** Compost tea increases the population of beneficial microorganisms in the soil. These microorganisms convert nutrients into forms that are easily absorbable by plants, improving soil fertility and reducing production costs.

» **Nutrient Supply:** Compost tea provides essential nutrients such as nitrogen, phosphorus, potassium, magnesium, sulfur, and trace elements like iron, zinc, manganese, and copper. The nutrient composition varies based on the type of compost used and the age of the compost tea.

- **Organic Nutrients:** In addition to minerals, compost tea contains organic nutrients like sugars, amino acids, and growth regulators, all of which promote healthy plant growth and development.
- **Disease and Pest Suppression:** Compost tea enhances plant resistance to diseases and pests by introducing beneficial microorganisms that inhibit the growth of pathogenic fungi and bacteria. For example, spraying compost tea on tomato and potato plants can help inhibit *phytophthora* infections, while adding it to soil enhances resistance to damping-off diseases caused by soil-borne pathogens.
- **Enhanced Plant Resilience:** Compost tea contains natural hormones and antioxidants that strengthen plants' resilience to adverse climatic conditions such as drought, high temperatures, frost, salinity, and other environmental stressors, resulting in healthier, more robust plants.
- **Stimulates Root Growth:** The growth-promoting compounds in compost tea, such as enzymes and growth regulators, enhance root development and improve nutrient absorption.
- **Improved Soil Structure:** Compost tea helps improve soil aggregation, leading to better water retention, aeration, and root penetration.
- **Increased Crop Yields:** Regular use of compost tea results in healthier plants and higher crop productivity by boosting soil fertility and plant vitality.

4.2.6 Patentkali Granular Fertilizer

Patentkali Granular fertilizer is a potassium sulfate-based fertilizer primarily used as a source of potassium. Its composition includes 30 % Potassium Oxide (K_2O) (equivalent to 24.9 % potassium), 10 % Magnesium Oxide (MgO) (equivalent to 6 % magnesium), and 44 % Sulfur Trioxide (SO_3) (equivalent to 17.6 % sulfur). This granulated fertilizer ensures that each granule contains a balanced distribution of these essential nutrients, facilitating uniform soil application.

Since the nutrients in Patentkali are in sulfate form, they are water-soluble, allowing easy absorption by plants. Additionally, its composition makes it unaffected by soil acidity, making it suitable for a wide range of soil types.

As a raw salt fertilizer, Patentkali is approved for use in organic agriculture, in compliance with EU Regulation 834/2007 and EC 889/2008, which govern organic agriculture practices.

Produced by K+S KALI GmbH in Kassel, Germany, Patentkali is particularly beneficial for crops requiring high sulfur levels, such as oilseeds, sunflowers, onions, cabbage, potatoes, leeks, and grapes.

Application of Patentkali involves mixing it with the soil during spring to ensure optimal nutrient retention and to prevent nutrient loss during winter. By using Patentkali Granular Fertilizer, organic farmers can provide essential nutrients to their crops, enhancing growth and productivity while maintaining compliance with organic agriculture standards. The recommended application rate for Patentkali fertilizer is 300 kg/ha.

4.2.7 Fish Manure

To increase the nitrogen content in organic agricultural soil, fish meal can be effectively used at a rate of 300 kg per hectare, combined with compost application. This process can be repeated two to three times during the growing season. A commercial product available for this purpose is Agrofish Manure, produced by Emirates Biologica Fertilizer WLL in the UAE. Certified for organic farming, Agrofish Manure contains the following nutrients: total nitrogen (3.5 - 4.5 %), phosphorus (2 - 2.5 %), potassium (1.5 - 2.0 %), sulfur (0.9 %), and calcium (1.5 - 2.0 %). It also includes essential microelements (800 - 1200 ppm), such as iron, manganese, zinc, copper, and boron.

Application rates of fish manure vary depending on the crop. For citrus trees, it is recommended to use 2 kg per tree, while for mango, grape, and palm trees, the rates range from 3 to 5 kg per tree. For ornamental plants and flats, the application rate is 500 kg per 1000 m^2. Agrofish Manure also contains significant organic matter, ranging from 50 % to 65 %.

Another product, Agrofish Liquid Organic Fertilizer, is formulated with a balanced ratio of nitrogen, phosphorus, and potassium (8:2:2), along with 2% calcium and organic matter content ranging from 25% to 30%. This liquid fertilizer is applied by watering the soil, with a recommended rate of 3.8 liters per 1000 m^2 every two weeks throughout the season. For fruit trees, the application involves watering the soil around each tree with 100-120 ml of the solution per tree.

4.2.8 Humic Acids Fertilizers

Humic acid fertilizers have long been recognized for their ability to improve soil fertility and promote plant growth. These substances are naturally formed in the soil through the decomposition of organic matter, a process driven by microbial activity. Humic substances, including humic acid and fulvic acid, provide a rich source of organic nutrients, macro- and microelements, and essential minerals, all of which are crucial for plant nutrition and soil fertility.

Soil fertility can often decline due to low levels of humic substances and organic matter. Humic acid fertilizers stand out for their excellent ion exchange capacity, high oxygen and nutrient content, and exceptional water retention capabilities. These properties make them invaluable for enhancing soil fertility and supporting plant growth over long periods. Additionally, humic acid fertilizers have the unique ability to bind undissolved metal ions, oxides, and hydroxides, releasing them gradually to plants as needed.

As a result, humic fertilizers provide triple benefits, improving soil and plant health through physical, chemical, and biological enhancements.

4.2.8.1 Benefits of Using Humic Acid Fertilizers in Organic Agriculture

- **Physical Benefits**

Humic acid fertilizers play a crucial role in improving soil structure and fertility. In light and sandy soils, they help retain water and nutrients, effectively transforming these soils into fertile grounds. They also enhance soil aeration, promoting better root growth and overall plant health. In heavy and compact soils, humic acid fertilizers improve water retention, reducing the risk of water runoff and soil erosion. Additionally, they make tillage and other agricultural operations easier by enhancing soil structure and reducing compaction. By preventing soil cracking, humic acid fertilizers maintain soil integrity and help prevent surface water erosion.

- **Chemical Benefits**

Humic acid fertilizers contribute to balancing soil pH, ensuring optimal conditions for plant growth. They improve the absorption of water, organic matter, and mineral nutrients, supporting robust plant development. Acting as natural suspensions for mineral ions, particularly in alkaline soils, they enhance the root uptake of essential nutrients. With their high nutrient content and ion exchange capabilities, humic acid fertilizers convert nutrients into forms readily accessible to plants. Additionally, they release carbon dioxide from soil calcium carbonate, aiding photosynthesis. Humic acid fertilizers also promote nitrogen absorption, preventing nitrogen deficiency-induced yellowing and iron deficiency-induced chlorosis in plants.

- **Biological Benefits**

Humic fertilizers stimulate plant vitality and activate beneficial soil microorganisms. Acting as organic catalysts, they enhance vital processes that promote plant growth. They activate plant enzymes, improve enzyme productivity, and encourage the growth of beneficial microorganisms, boosting plant disease resistance and overall vitality.

Humic fertilizers promote vertical root growth, improving water and nutrient absorption, root respiration, and root hair formation. They also enhance chlorophyll production, sugar and amino acid synthesis, supporting photosynthesis. Additionally, humic fertilizers stimulate cell division, enhance root system development, and increase vitamin and mineral content in plants and their produce, such as fruits and grains. They also contribute to thicker fruit cell walls, extending storage life.

In addition to these benefits, humic acid-enriched soils help prevent nitrate leaching into groundwater, reducing the risk of nitrogen deficiency in plants and groundwater contamination. This leads to cost savings by reducing the need for added nitrogen. Humic acid fertilizers also absorb excess soil and irrigation water salinity, mitigating toxicity from ammonium cations, which can harm young plants. Furthermore, they help reduce root burn caused by salt buildup in the soil.

Commercially produced organic acid fertilizers, which contain a high concentration of Humic acid, are widely available and can be effectively used in both organic and conventional agricultural practices. These fertilizers typically offered in two forms: solid and liquid.

4.2.8.2 Examples of Commercial Organic Acid Fertilizers

- **Disper Humic 85 % GS**

Disper Humic 85 % GS is a fertilizer derived from organic humic matter, containing 85 % Humic extracts, including 68 % Humic acid and 17 % Fulvic acid. It is sourced from American Leonardite, a leading global exporter of organic acid fertilizers. Leonardite, an oxidation product of natural coal found in the mines of the American Leonardite Company in North Dakota, is renowned for its rich humic substance content. The region is recognized for its vast reserves of this valuable material. Leonardite is highly soluble in alkaline solutions and is prized for its high level of oxidation, making it an optimal source of Humic substances. It has a soft, shiny, waxy texture with a dark black or brown colour, resembling metallic material with minimal crystallization. Leonardite is named after A.G. Leonard, the first director of the Geological Survey of North Dakota.

Disper Humic fertilizer is available in Granule Soluble (GS) form and is applied to soils with low organic matter content. It provides numerous benefits, including improvements in the physical, chemical, and microbiological properties of the soil.

The key benefits of Disper Humic fertilizer are attributed to its high Humic acid content, which offers the following advantages:

» Activation of Beneficial Microbial Life: Humic acid promotes the activation of beneficial microorganisms in the soil, enhancing seed germination and overall soil health.

» Conversion of Nutrients for Plant Uptake: Humic acid helps convert soil nutrients into forms that are more readily accessible to plants. It enhances phosphorus availability and chelates microelements, particularly iron, making them more biologically available to plants.

» Stimulation of Plant Growth: Humic acid provides an additional source of phenolic compounds, which play a crucial role in plant respiration, accelerating cell proliferation and supporting the development of root networks. This leads to improved plant health and growth.

» Enhancement of Soil Water Retention: The colloidal nature of Humic acid allows it to absorb and store significant amounts of water for plant use, increasing crop drought tolerance.

» Improved Nutrient Absorption: Even in small amounts, Humic acid and its derivatives enhance the permeability of plant cell membranes, allowing faster uptake of both major and minor nutrients by root cells.

» Increased Soil Aeration and Ease of Tillage: When mixed with the soil, Humic acid promotes the formation of soil aggregates, improving permeability, aeration, and water movement. This reduces the presence of large soil clumps that can hinder root growth, making tillage easier.

The application rate of Disper Humic 85 % GS fertilizer ranges from 5 to 15 kg/ha, depending on the irrigation system used. It is applied at a rate of 5-10 kg/ha with drip irrigation, 8-12 kg/ha with sprinkler irrigation, and 10-15 kg/ha with surface irrigation.

- **Humax fertilizer**

Humax fertilizer, produced by JH Biotech, is a premium, concentrated Humic acid product extracted from Leonardite, an organic material formed over years from the decomposition of plant matter. It is available in two forms: Humax Liquid and Humax 95 Granular, both containing Humic acid, Fulvic acid, and potassium. Humax Liquid contains at least 12 % Humic acid, 3 % Fulvic acid, and 3 % potassium (K_2O), while Humax 95 Granular contains a minimum of 80 % Humic acid, 15 % Fulvic acid, and 12 % potassium (K2O). The application rate of Humax liquid is 6-12 l/ha, while Humax 95 granular is used at 1-2 kg/ha. It is essential to add water just before use.

Humax fertilizer is primarily used for soil applications, where the solution can be sprayed onto the soil surface and immediately plowed or irrigated. It can also be applied using modern irrigation systems or as a foliar spray when necessary.

- **Blackjak SC Fertilizer**

Blackjak fertilizer is a concentrated aqueous blend of organic acids, including Humic, Fulvic, and Ulmic acids, as well as Humins, suitable for both soil application and foliar spray. It contains a minimum of 25 % organic matter and at least 18 % organic acids. Blackjak can be used alone or mixed with fertilizers and plant protection products, though prior testing for compatibility is recommended. As a natural organic acid, Blackjak can be combined with acidic fertilizers or used to lower the pH of alkaline solutions. It enhances the absorption rate of foliar fertilizers and promotes strong root growth.

Blackjak has been successfully used on a wide range of crops, including fruit trees, vegetables, and cereals, such as grapes, potatoes, onions, corn, sugar beet, sunflower, strawberries, and more. In heavy clay soils, Blackjak helps break clay bonds, improving soil structure, microbial activity, air and water circulation, and water retention. The recommended application rate for Blackjak fertilizer is 1 liter per hectare.

- **Codahumus Fertilizer**

Codahumus fertilizer, produced by Coda, is available in two forms: e-codahumus, a liquid extract derived from Leonardite, and Codahumus S80, a granular form.

» e-codahumus Fertilizer: This liquid extract consists of 20.2 % humic extracts, including 10 % Humic acid, 10.2 % Fulvic acid, and 3.2 % potassium (K_2O) in a water-soluble solution. It is recommended to apply e-codahumus at a rate of 30-50 liters per hectare per cycle, distributed in 4-8 batches. For fruit trees, 4-5 batches are recommended, while for vegetables and ornamental crops, treatments should be performed every 7-10 days.

» Codahumus S80: This granular form of Leonardite extract contains 80 % humic extracts, including 76 % Humic acid, 4 % Fulvic acid, and 12 % potassium (K_2O). Although this fertilizer is water-soluble, it should be added slowly while stirring to prevent clumping. Codahumus S80 is applied at a rate of 8-15 kg per hectare per crop cycle, with water added just before use. When distributed in 4-5 batches, the rate is 1-2 kg per hectare per treatment.

- **Zelsius Fertilizer**

Zelsius fertilizer is a water-soluble product manufactured in Spain, containing nitrogen (8 %) and potassium (15 %), along with chelated micro-fertilizer elements such as iron and manganese. It also includes Leonardite, a rich source of organic matter and Humic acids, which enhance the plant's ability to absorb nutrients, promoting growth and improving crop quantity and quality. The Leonardite in Zelsius fertilizer contains 29 % Fulvic acid, which is vital for improving soil structure, moisture retention, nutrient retention, and pH stability.

Zelsius fertilizer is a stable and soluble compound, where iron and manganese are chelated in a homogeneous mixture, making it compatible with dissolved nitrogen, potassium, and Leonardite. Modern manufacturing technology ensures double protection of the microelements iron, manganese, potassium, and Leonardite in a chelated compound with two protective layers:

» Inner Layer: Composed of highly stable chelates, such as Fe-EDDHMA for iron and Mn-EDTA for manganese, ensuring they remain soluble in the soil solution, readily accessible to plant roots, and easily absorbable without precipitation or leaching.

» Outer Layer: Formed from organic molecules found in Leonardite, including Fulvic acid and humic substances, treated with potassium ions to create a protective three-dimensional network. This outer layer shields the iron from precipitation or leaching, even in highly acidic fertilizer solutions.

These innovative formulations make Zelsius fertilizer highly effective in enhancing nutrient availability and uptake in various crops.

- **Biosol or AgroBiosol**

Biosol, also known as AgroBiosol, is a by-product of the penicillin fermentation process and serves as a natural slow-release organic fertilizer, ideal for various types of planting. Produced by the Sandoz company, it is tailored for use in organic farming and complies with EU regulations for organic agriculture. Biosol consists of 100 % pure granules of fungal biomass, with sizes ranging from 2 to 6 mm.

The production of Biosol involves converting proteins, sugars, juices, trace minerals, and vitamins into fungal biomass using fungi such as *Penicillium* chrysogenum. The raw materials used in this process are sourced directly from agricultural products like soybean flour, corn juice, cotton grain flour, and beet sugar, which provide nutrients for the fungi and bacteria during fermentation. Biosol is prepared through a bio-fermentation process lasting several days, followed by drying at high temperatures (3-4 hours) with the addition of 3 % calcium sulfate. The final product contains approximately 6-7 % organic nitrogen, 1-2 % phosphorus, 3-4 % potassium, and a significant amount of organic matter. The key advantages of using Biosol fertilizer include:

» Slow-release organic nutrients, which provide continuous benefits to plants as they grow, enhancing both crop yields and quality.

» Improvement of soil fertility with regular applications over time.

- **Enhanced plant resistance and vitality,** promoting healthier and more strong growth.
- **Increased soil organic matter,** which stimulates the formation of root hairs and overall root development.
- **Low salinity,** making it ideal for use in greenhouses and arid regions.
- **Boosts microbial activity,** improving overall soil fertility and ecosystem health.

Typically, a single application of Biosol fertilizer during the growing season is sufficient for most crops. It should be applied to the surface layer of agricultural soil or lightly mixed into the soil approximately two weeks before sowing or planting. However, for intensive crops like vegetables and ornamental plants, additional applications of Biosol fertilizer may be necessary, though in smaller quantities. Biosol fertilizer granules can be applied manually, mechanically, or even by helicopter.

When applying, Biosol should be added to the soil surface or lightly mixed into the top 1-3 cm of soil. The fertilizer has a distinct fungal odour, which usually dissipates soon after application, depending on temperature and humidity.

- **For fruit trees,** Biosol is typically applied at a rate of 900 kg/ha. During replanting, the fertilizer can be topically applied to the planting rows. Fertilizer application for trees is usually done in late autumn or early spring. The rate of fertilizer use for older trees can be adjusted based on crop needs and nutrient uptake.
- **For vegetable crops,** the application rate ranges from 800 to 2500 kg/ha, depending on the specific crop and soil conditions.

4.2.9 Foliar Fertilizers and Fertigation

Plants generally obtain essential nutrients from the soil, often supplemented by fertilizers tailored to their specific needs. However, in certain situations, foliar fertilization or fertigation (the application of fertilizers through irrigation systems) becomes necessary, particularly for addressing deficiencies in microelements such as iron, manganese, zinc, and copper. This is especially true in alkaline soils, where these elements may exist in insoluble forms, rendering them inaccessible to plants.

In some cases, natural minerals containing microelements can be added to compost piles. During decomposition, organic acids are released, interacting with the compost and forming chelating compounds that enhance the availability of these microelements to plants. This process improves the effectiveness of compost fertilizers by providing microelements in a form that plants can readily absorb.

Foliar fertilization plays a crucial role in organic farming by ensuring that plants receive essential nutrients during various stages of their physiological growth, such as flowering, fruit development, and maturation. This method is particularly useful when root activity decreases, limiting nutrient uptake from the soil. One major advantage of foliar fertilization is the high percentage of nutrient absorption when applied directly to the vegetative parts of plants. This bypasses the limitations of alkaline soils, which can restrict the availability of microelements for plant uptake. Additionally, foliar fertilization enables rapid nutrient delivery during critical growth stages, meeting the plant's immediate nutrient needs.

A key example of the importance of foliar fertilization is the need to supplement calcium in fruits, particularly in apple trees, to prevent diseases like bitter pit. Bitter pit occurs when there is insufficient calcium transfer to the woody tissues of apple trees, leading to fruit deformities. To prevent this, apple trees require foliar sprays of calcium, applied directly to the fruits and vegetative parts, ideally before any symptoms of the disease appear. Typically, apple trees should undergo 6-8 foliar calcium applications throughout the fruiting season to ensure adequate calcium levels.

When applying foliar fertilization, several key considerations should be kept in mind:

- **Timing:** Foliar spraying should be done early in the morning or during cooler periods of the day to minimize plant stress and optimize nutrient absorption.
- **Use of Spreaders and Adhesives:** Adding spreaders and adhesives to the foliar fertilizer solution is recommended to ensure proper adhesion to leaf surfaces, enhancing the efficiency of nutrient uptake.
- **Thorough Coverage:** It is essential to ensure thorough coverage of both sides of the leaves, particularly the lower surface, which contains more stomata. This promotes the efficient absorption of nutrients from the spray solution.

In addition to foliar fertilization, modern irrigation systems can utilize a method known as **fertigation**, which involves the application of fertilizers through irrigation water. This technique can be used for a wide range of crops, including fruit trees and vegetables. Fertilizers containing various nutrients are added to the irrigation water in controlled concentrations to prevent salinity levels from exceeding acceptable limits.

A key advantage of fertigation is the continuous supply of nutrients to the root zone throughout the plant's growth stages. Fertilizers are tailored to meet the specific nutritional needs of plants during different growth phases, including vegetative growth, flowering, fruit development, and maturation. Furthermore, fertigation improves fertilizer efficiency by minimizing nutrient losses, particularly in deeper soil layers that are beyond the reach of the plant's root system.

Numerous commercially prepared fertilizers are available for fertigation, which can be applied directly to the vegetative system of plants or mixed with irrigation water. It is essential that these commercial fertilizers are organically certified, allowing their use in organic farming practices. Table 4.13. provides examples of some of these fertilizers, detailing the nutrients they contain and their recommended application rates in organic agriculture.

Table 4.13. Examples of Commercial Fertilizers Used for Foliar Nutrients or Fertigation in Organic Farming.

Nutrients	Commercial Fertilizers	Rate of Application	
		Foliar Nutrients Per 100 Liters of Water	Fertigation Per Hectare
Calcium	Disper Ca 14 % GS	300 - 400 g	---
	e-CODASAL	---	4 -6 Liters
Zinc	Disper Zn 14 % GS	50 - 100 g	3 - 10 kg
	CODA-Zn-L	200 - 300 ml	3 -5 Liters
Manganize	Disper Mn 13 % GS	200 - 400 g	100 – 200 g/m^3
	CODA-Mn-L	200 - 300 ml	3 - 5 Liters
Iron	Disper Fer 6 % GS	100 - 300 g	40 - 60 kg
	CODA-Fe-L	250 - 400 ml	3 -5 Liters
Magnesium, Boron, Copper, Iron Zinc, Manganese, Molybdenum	e-CODAHORT	---	30 -60 Liters/ha (per season)
Iron, Manganese, Zinc, Copper Magnesium, Boron, Molybdenum	Disper Complex	300 - 400 g	4 - 8 kg
Copper	CODA-Cu-L	200 - 300 ml	3 -5 Liters
Boron	CODABOR	100 - 200 ml	1 -3 Liters
Copper - Iron - Manganese -Zinc	CODA-VIT	200 - 400 ml	---
Iron - Manganese -Zinc - Copper - Boron - Molybdenum	CODAMIX	200 - 300 ml	3 -5 Liters
Zinc - Manganese	codaquel	200 - 300 ml	3 -5 Liters

4.2.10 Vermicompost

Earthworms belong to the animal kingdom (Kingdom: Animalia), specifically to the division of segmented worms (Phylum: Annelida) and the class (Class: Oligochaeta), further categorized into the order (Order: Megadrilacea). They exhibit a range of body colours, from pink to dark brown. Earthworms are elongated and cylindrical, with their bodies divided into segments known as rings, which range from 100 to 250 in number. While most earthworms are just a few millimeters in length, some species, such as the Giant Gippsland Earthworm, can grow up to three meters. Earthworms are found worldwide in a variety of environments, except in polar regions. Globally, more than 4,400 species of earthworms have been identified, with over 350 species in India and around 180 documented in America.

Earthworms are hermaphrodites, meaning they possess both male and female reproductive organs within a single individual. Each earthworm has a pair of ovaries and two pairs of testes. Despite having both reproductive organs, self-fertilization rarely occurs. Instead, cross-fertilization happens through the exchange of sperm between two earthworms. The sperm from one worm is transferred to another and stored in specialized structures called sperm reservoirs. After fertilization, the female worm deposits eggs in lemon-shaped cocoons coated with a nutrient-rich substance that nourishes the developing young after hatching. Juvenile earthworms resemble adults, except they lack sex organs, which develop after 2-3 months, marking sexual maturity.

Earthworms offer numerous benefits to soil health and plant growth. They play a critical role in aerating the soil by creating tunnels, allowing oxygen to penetrate the soil and reach plant roots. They also facilitate water movement from the soil surface to deeper layers, aiding moisture distribution. As earthworms consume organic matter, they produce waste, known as worm casts, which they deposit in their tunnels. These casts increase soil porosity and prevent compaction, thereby improving soil structure. Earthworms also assist in nutrient cycling by breaking down organic residues and making nutrients more available to plants. When they die, their decomposing bodies further enrich the soil with nutrients.

Worm casts are especially valuable because they are rich in essential nutrients such as calcium, potassium, nitrogen, and phosphorus, all of which are vital for plant

growth and development. Studies have shown that earthworm activity can significantly increase the levels of these nutrients in the soil. For example, earthworms can increase soil nitrogen content by up to five times, phosphorus by seven times, potassium by eleven times, magnesium by three times, and calcium by one and a half times. Overall, earthworms contribute significantly to soil fertility and ecosystem health through their beneficial activities.

The study by Garg *et al.* (2007) underscores the significant role of earthworms in nutrient cycling and soil enrichment. Their research found that earthworm activity contributes notably to nitrogen addition in the soil, with rates varying by ecosystem type. In grasslands, earthworms contribute approximately 230 kg of nitrogen per hectare per year, while in forest ecosystems, they add around 165 kg of nitrogen per hectare per year. This nitrogen addition is primarily due to the decomposition of organic matter by earthworms, releasing nitrogen in forms that plants can readily absorb. Additionally, earthworms stimulate bacterial activity, leading to increased nitrate production in the soil.

Moreover, worm casts, the waste produced by earthworms, are found to contain higher nutrient levels compared to the surrounding soil. These casts are rich in essential cations such as calcium, magnesium, sodium, potassium, and phosphorus, all vital for plant growth and development. This nutrient enrichment makes worm casts valuable as organic soil amendments, improving soil fertility and enhancing plant productivity.

While vermicompost may not always surpass other organic fertilizers in terms of nutrient content, it provides a sustainable and effective approach to composting organic waste materials. Table 4.14. presents an overview of the chemical composition of worm casts, highlighting their nutrient content and potential benefits for soil health and plant nutrition.

Ronald and Donald (1977) described six species of earthworms found in Europe:

- The native night crawler, *Lumbricus terrestris*
- The common field worm, *Helodrilus caliginosus*
- The green worm, *Helodrilus chloroticus*
- The manure worm, *Eisenia foetida*
- The slim earthworm, *Diplocardia verrucusa*
- The redworm, *Lumbricus rubellus*

Table 4.14. Chemical Composition of Earthworm Waste (Worm Casts).

Element	%	Element	ppm
Organic Carbon	9.15 - 17.88	**Calcium & Magnesium**	22.67 - 47.60
Total Nitrogen	0.5 - 0.9	**copper**	2.0 - 9.5
Phosphorus	0.10 - 0.26	**Iron**	2.0 - 9.3
Potassium	0.15 - 0.26	**Zinc**	- 9.3

Source: Garg *et al.*, (2006).

Vermicomposting is a process that utilizes specific species of earthworms to transform organic matter, typically waste materials, into nutrient-rich compost known as vermicompost, Figure 4.9. Earthworms play a crucial role in this process by consuming organic waste. The waste enters their body through the mouth, located on the first segment of the worm. It then passes through their digestive system, starting with the muscular pharynx, continuing through the esophagus, gizzard, stomach, intestine, and finally reaching the rectum. The digested material is excreted as worm castings, which form the basis of vermicompost fertilizer.

Vermicompost is rich in essential nutrients such as nitrogen, phosphorus, potassium, and calcium, all of which are available in forms that plants can readily absorb. Additionally, vermicompost contains bioactive substances, including plant growth regulators, which further promote plant growth and health.

Overall, vermicomposting is an efficient and rapid method for converting organic waste into a valuable resource, using earthworms and microorganisms to facilitate the breakdown of organic material.

4.2.10.1 Benefits of Using Vermicompost in Organic Agriculture

Using vermicompost in organic agriculture offers several benefits, contributing to soil health, plant growth, and overall agricultural productivity. The following points illustrate the general benefits when using vermicompost in organic agriculture:

» **Restoration and Enhancement of Soil Microbial Activity:** Vermicompost enriches the soil with beneficial microbes, including nitrogen-fixing bacteria and microorganisms that aid in the breakdown of organic matter, leading to improved soil fertility and nutrient availability.

» **Increase in Soil Organic Matter:** Vermicompost adds organic matter to the soil, enhancing its structure, moisture retention capacity, and nutrient-holding capacity. This promotes healthier plant growth and resilience to environmental stressors.

» **Improvement of Nutrient Availability:** Vermicompost enhances the exchange of positive ions in the soil, facilitating the availability of essential macro and micronutrients in forms readily accessible to plants.

» **Regulation of Soil pH:** Vermicompost helps maintain optimal soil pH levels, creating a favourable environment for plant nutrient uptake and microbial activity.

» **Reduction of Soil Salinity:** Vermicompost aids in reducing excess sodium levels in the soil, mitigating soil salinity issues and promoting healthier plant growth.

» **Enhancement of Soil Texture and Water Retention:** Vermicompost improves soil structure, leading to better soil aeration, drainage, and water retention capacity. This fosters root development and improves overall plant vigour.

» **Promotion of Beneficial Microorganisms:** Vermicompost fosters the proliferation of beneficial microorganisms in the soil, which contribute to nutrient cycling, disease suppression, and overall soil health.

» **Pest and Disease Suppression:** Vermicompost helps in maintaining low populations of insect pests and nematodes in the soil, reducing the risk of crop damage and enhancing plant resilience to diseases.

» **Soil Erosion Prevention:** Vermicompost improves soil structural stability, reducing soil erosion and runoff, thus preserving soil quality and preventing nutrient loss.

» **Enhancement of Crop Quality:** Vermicompost enriches the soil with essential nutrients, leading to improved crop quality, including increased sugar content in grains and fruits, resulting in better flavour, texture, and nutritional value.

» **Contribution to Mitigating Global Warming:** Agriculture is a major contributor to greenhouse gas (GHG) emissions, accounting for approximately 33 % of global emissions. One key factor is the loss of soil organic carbon as CO_2, primarily due to aggressive plowing and tillage practices associated with chemical agriculture. These practices compact the soil, accelerating the release of carbon into the atmosphere. Additionally, the use of chemical nitrogen fertilizers, such as urea, leads to the emission of nitrous oxide (N_2O), a powerful greenhouse gas approximately 312 times more effective at trapping heat than CO_2. Nitrous oxide emissions occur due to the oxidation of nitrogen compounds in the soil, especially under sunlight exposure.

Figure 4.9. Vermicompost Preparation.

Vermicompost offers a promising solution to help reduce these emissions and mitigate agriculture's impact on global warming. Vermicompost contains organic matter that sequesters atmospheric carbon dioxide (CO_2) and stores it in the soil. This process not only improves soil fertility but also reduces GHG emissions by trapping carbon in the soil, contributing to the mitigation of global warming.

Overall, the use of vermicompost in organic farming promotes sustainable soil management, enhances plant health and productivity, and contributes to the production of high-quality, nutritious crops.

4.2.10.2 The Role of Vermicompost in Controlling Pests and Diseases

The ability of vermicompost to suppress and resist various pests and diseases has been well-documented by numerous scientists. Vermicompost has proven effective in reducing plant infections caused by pests and diseases, especially those present in the soil. Several studies, including those by Arancon *et al*. (2002, 2005), Chaoui *et al*. (2002), Compant *et al*. (2005), Yardim *et al*. (2006), Wang *et al*. (2007), Elmer (2009), and Jack (2010), have highlighted vermicompost's role in plant protection against pests and diseases.

These studies suggest that vermicompost aids in pest control through several mechanisms, including:

- Presence of Beneficial Organisms

Vermicompost contains beneficial organisms that contribute to pest control, such as fungivorous and bacterivorous organisms that feed on harmful fungi and bacteria. Additionally, the presence of entomopathogenic nematodes, which parasitize insects, helps regulate pest populations in the soil. As a result, vermicompost serves as a valuable tool in integrated pest management, offering environmentally friendly and sustainable pest control solutions for agriculture. Its ability to suppress pests, enhance plant resistance, and promote beneficial microbial activity makes it an essential component of organic farming practices.

- Induced Plant Resistance

Vermicompost enhances the plant's natural defense mechanisms, boosting its resistance to pests and diseases. This is achieved through the bioactive compounds and natural antibiotics found in vermicompost, which strengthen the plant's biological defenses. The ability of vermicompost to induce resistance in plants against pests and diseases can be attributed to several factors:

» **Enhancement of Plant Immune Responses:** Vermicompost stimulates the plant's natural defence mechanisms, activating biochemical pathways that produce phytochemicals and secondary metabolites, which deter pests and pathogens.

» **Promotion of Beneficial Microorganisms:** Vermicompost harbours beneficial microorganisms, including bacteria, fungi, and nematodes, which play a crucial role in maintaining plant health. These microorganisms help suppress the growth of pathogenic organisms and enhance plant immunity through mechanisms like competition for nutrients and space.

» **Improved Nutrient Uptake:** Vermicompost supplies essential nutrients to plants in forms that are easily absorbed. This proper nutrition strengthens plant vigour and resilience, making them less susceptible to pest attacks and diseases.

» **Balanced Soil Microbial Communities:** Vermicompost promotes the growth of beneficial soil microbes, fostering a balanced soil ecosystem. A diverse microbial community helps regulate soil pathogens and supports plant health through symbiotic relationships.

Studies by Chaoui *et al*. (2002), Arancon *et al*. (2002, 2005, 2007), and Edwards *et al*. (2009) have demonstrated

vermicompost's effectiveness in increasing plant resistance to various pests and diseases, including Jassids (*Empoasca kerri*), Aphids (*Myzus persicae* & *Aphis craccivora*), spider mites (*Tetranychus urticae*), mealybugs (*Planococcus citri*), and caterpillars (*Pieris rapae*). However, it is important to note that vermicompost achieves these effects through natural, biological mechanisms rather than synthetic antibiotics or radioactive drugs. It enhances the "biological resistance" of plants, making them stronger and more resilient against pests and diseases.

- **Suppression or Repellent Effect**

Vermicompost may exhibit pest-suppressive or repellent properties, deterring pests from attacking plants or suppressing their populations. The observed reduction in aphid infestations in crops treated with vermicompost, compared to those treated with chemical fertilizers, can be attributed to several factors:

» Enhanced Plant Defence Mechanisms: Vermicompost stimulates the production of secondary metabolites and phytochemicals in plants, which act as natural repellents against aphids and other pests. These compounds strengthen the plant's immune system, making it less attractive to pests.

» Improved Plant Health: Vermicompost improves soil structure and fertility, leading to healthier, more vigorous plant growth. Healthier plants are better equipped to resist pest attacks and are less susceptible to aphid infestations.

» Changes in Plant Physiology: The application of vermicompost can alter plant physiology, such as changes in cell wall composition and water content. Firmer plant cell walls and reduced water content make it more difficult for aphids to feed on plant tissues, reducing their attraction to the plant.

Research by Edwards and Arancon (2004) supports the idea that vermicompost can effectively reduce populations of various insect pests, including aphids, mealybugs, and spider mites. The presence of chitinase enzymes in vermicompost is especially significant, as these enzymes break down the chitin in the exoskeletons of insects, making them more susceptible to environmental stressors and predators.

Additionally, vermicompost contains cellulose-degrading enzymes that can break down cellulosic pathogens like Pythium and Phytophthora, which are responsible for causing fungal diseases in various crops. By suppressing the growth of these pathogens, vermicompost indirectly contributes to pest management and reduces the risk of secondary infestations. Studies have also shown that vermicompost inhibits parasitic nematodes in crops such as pepper, tomato, strawberry, and grape.

Overall, the use of vermicompost in organic farming helps create a more balanced and resilient ecosystem, where plants are better equipped to defend themselves against pest pressures. Furthermore, by promoting soil health and enhancing microbial activity, vermicompost supports sustainable agricultural practices that benefit both crops and the environment.

4.2.10.3 Characteristics of Worms Best Suited for Vermicomposting

The selection of worms with specific characteristics is essential for ensuring efficient and effective vermicomposting. Below are some key traits that are desirable in composting worms:

» Efficiency in Organic Residue Consumption: The worms should exhibit high efficiency in consuming organic residues, which leads to rapid decomposition and conversion into vermicompost. This trait is crucial for optimal waste management and nutrient recycling.

» Adaptability to Various Environmental Conditions: Worms should have a wide tolerance for environmental factors, including temperature fluctuations and variations in organic waste composition. This adaptability allows them to thrive in diverse settings and feed on a variety of organic materials.

» High Reproductive Rate: Worms with a high reproductive rate produce large numbers of offspring in a short period. Rapid reproduction facilitates population growth and accelerates vermicompost production.

» Short Life Cycle: A shorter life cycle is advantageous because it enables worms to reach maturity quickly, contributing to efficient vermicomposting operations. This ensures continuous population turnover and maintains high composting rates.

» Species Diversity: Utilizing a mixture of worm species promotes biodiversity within the vermicomposting system. Different species may have varying feeding habits and preferences, which enhances the breakdown of organic residues and improves compost quality.

» Disease Resistance: Worms should be resistant to common diseases and pathogens to maintain healthy populations and prevent disruptions in the vermicomposting process. Disease-resistant worms are more likely to thrive and ensure consistent compost production.

By selecting worms with these desirable characteristics, vermicomposting operations can optimize waste management, produce high-quality vermicompost, and contribute to sustainable organic agricultural systems.

4.2.10.4 Species of Earthworms Used in the Production of Vermicompost

Several species of earthworms are commonly utilized in vermicomposting, each offering unique characteristics and benefits. Some of the most widely used species include *Eisenia fetida* (Red Worm), *Eudrilus eugeniae* (African Nightcrawler), *Perionyx excavatus* (Blue Worm), *Megascolex mauritii*, *Lampito mauritii*, *Lampito rubellus*, *Eisenia andrei*, and *Drawida willis*. Below are descriptions of the life cycles of three commonly used species in vermicomposting:

- **Red Worm (*Eisenia fetida*)**

Also known as the red worm or red wiggler, *Eisenia fetida* is one of the most popular species used in vermicomposting. It thrives in organic waste environments and is highly efficient in converting organic matter into nutrient-rich vermicompost. Formerly known as *Eisenia foetida*, this species is commonly referred to by various names, including red worm, red wiggler worm, spotted worm, trout worm, tiger worm, Californian red worm, or manure worm.

Eisenia fetida is widely used in vermicomposting due to its excellent adaptation to feeding on decaying organic matter. Unlike some earthworm species, it is rarely found in soil, but it thrives and reproduces prolifically in environments rich in rotting plant material and manure. It is typically found in horse stable manure, farm manure, or can be sourced from specialized companies producing vermicomposting worms.

When disturbed, *Eisenia fetida* worms secrete a foul-smelling, irritating liquid, which is the origin of their species name foetida, meaning "stinky." This secretion likely evolved as a defense mechanism to ward off predators.

The reproductive cycle of *Eisenia fetida* is relatively fast, with worms producing cocoons approximately every three days, resulting in 2-3 cocoons per week. Each cocoon typically hatches 1-3 offspring after a gestation period of around 23 days. Newly hatched worms are white and about 1.5 cm long. They grow quickly by consuming organic residues and reach maturity within 40-60 days. Adult *Eisenia fetida* worms can weigh up to 1500 milligrams.

- **African Nightcrawler (*Eudrilus eugeniae*)**

Eudrilus eugeniae, commonly known as the African nightcrawler, is native to tropical West Africa but is now widespread in tropical and subtropical regions around the world. This species is prized for its larger size and robustness, making it particularly well-suited for processing large quantities of organic waste. Known for its rapid reproduction and high-quality vermicompost production, the African nightcrawler is highly valued in vermicomposting and is considered the second most widely used earthworm species for this purpose.

One of the distinguishing characteristics of *Eudrilus eugeniae* is its rapid growth rate compared to other earthworm species. These worms can gain approximately 12 milligrams of weight per day, with mature individuals reaching an average of about 4.3 grams per worm. They typically reach maturity within 40 days of hatching. Once mature, adult worms begin laying egg cocoons about one week after reaching maturity, producing an average of one cocoon per day.

Under laboratory conditions, the lifespan of *Eudrilus eugeniae* ranges from 1 to 3 years. This species' ability to rapidly process organic matter and reproduce makes it highly effective in vermicomposting systems.

- **Blue Worm (*Perionyx excavatus*)**

Also known as the blue worm or Indian blue worm, *Perionyx excavatus* is highly valued for its ability to quickly process organic waste. It thrives in warmer climates, making it an ideal choice for vermicomposting operations in tropical and subtropical regions. Blue worms are efficient decomposers, contributing to the production of fine-textured vermicompost. This species is extensively used in regions such as the eastern and western Himalayas, Bengal, and the Lesser Andaman Islands for vermicomposting.

Perionyx excavatus is highly adaptable, thriving in diverse environmental conditions, including varying moisture levels and different types of organic matter. This species exhibits an average growth rate of approximately 3.5 milligrams of body weight per day, with mature individuals reaching a maximum weight of about 600 milligrams per worm. The worms typically reach maturity within 21 days of hatching and begin laying egg cocoons by day 24. Each cocoon yields 1-3 offspring.

Due to its adaptability, rapid growth rate, and high reproductive capacity, *Perionyx excavatus* is considered one of the most suitable earthworm species for vermicomposting in tropical regions. Its efficient processing of organic matter makes it a valuable asset in composting operations.

Other species used in vermicomposting include *Megascolex mauritii*, *Lampito mauritii*, *Eisenia andrei*, *Lampito rubellus*, and *Drawida willis*. Each species has its unique characteristics, such as specific feeding habits, reproductive rates, and environmental tolerances, making them suitable for different vermicomposting systems and conditions. Understanding the life cycles of these earthworm species is crucial for optimizing vermicomposting processes and ensuring successful vermicompost production.

4.2.10.5 Vermicomposting Production

Vermicomposting is an aerobic and non-thermal process that relies on the biological oxidation of organic waste, facilitated by specific species of earthworms. These earthworms consume and decompose organic residues, which enhances microbial activity. The process begins with the acquisition or propagation of earthworms, known as vermiculture. The goal of vermiculture is to cultivate a sufficient population of worms for vermicomposting. Any surplus worms can be sold for similar purposes or other applications.

Vermicompost can be produced on a small scale for home gardens or small farms using specialized containers called vermireactors, Figure 4.10. Alternatively, larger-scale production can be achieved using methods like the windrow system, where organic compost piles are prepared on the ground's surface.

The vermicomposting process yields two primary products: earthworms, which are cultivated through vermiculture, and vermicompost (also known as vermicast). Additionally, a liquid fertilizer called vermiwash is produced during this process. Vermicompost and vermiwash are valuable biofertilizers widely used in organic farming. Vermiwash, in particular, is rich in essential and trace nutrients and can be applied by spraying it on the vegetative parts of plants.

According to Siddique *et al*. (2005), earthworms exhibit rapid growth rates, with mature worms reaching weights of up to 1500 milligrams. They can reproduce approximately 50-55 days after hatching from their cocoons. Red worms, for example, consume organic matter equivalent to their body weight each day. On average, one million worms weigh about one ton, and their population doubles every two months. As a result, around 64 million worms can be obtained within a year, capable of consuming approximately 64,000 tons of organic waste daily and producing around 32 tons of vermicompost per day. To achieve this level of production using the windrow system, approximately two acres of land are required.

4.2.10.6 Essential Requirements for Vermicompost Production

Garg *et al*. (2006) outlined the fundamental needs and requirements for successful vermicompost production, which can be summarized as follows:

- **Bedding**

A key requirement for vermicompost production is providing suitable bedding for the earthworms. This bedding serves as a stable habitat for the earthworms, ensuring they have an optimal environment for growth and reproduction. The bedding material should possess the following qualities:

» **Absorbency:** The bedding should absorb and retain excess moisture produced by the earthworms' respiration.

» **Oxygen Permeability:** It should allow adequate oxygen flow to the earthworms, meeting their respiratory needs.

» **Slow Decomposition:** While the earthworms will consume the bedding material, it is important that it decomposes gradually. Rapid decomposition can cause overheating, which is harmful to the worms.

Various materials can be used as bedding, including horse manure, household compost, corn silage, oat and wheat straw, newspaper, sawdust, shredded tree bark, corn stalks, cobs, and kitchen waste (excluding oils, meat, and fish). These materials provide a diverse and nutritious substrate for the earthworms, supporting the vermicomposting process.

- **Food Sources**

Another critical aspect of vermicompost production is providing suitable food sources for the earthworms. This step sustains the earthworm population and facilitates the vermicomposting process. Earthworms can efficiently consume a wide range of organic matter, including cow dung, poultry manure, sheep and goat waste, agricultural residues (such as crop stalks and husks), horse manure, aquatic weeds, plant residues (leaves and stems), paper waste, and municipal solid waste (excluding oils, meat, and fish).

Earthworms should ideally have access to a variety of nutrient-rich food sources to support their growth and reproduction. On average, earthworms can consume organic matter equivalent to about half of their body weight daily. Providing an ample and diverse supply of organic materials ensures optimal conditions for vermicompost production and the health of the earthworm population.

- **Humidity**

Maintaining Maintaining proper humidity levels is crucial for successful vermicompost production, as it directly impacts the well-being of earthworms. Earthworms thrive in environments with humidity levels between 60-70 %. However, it's essential to avoid excessive moisture in the organic materials used, as too much moisture can create anaerobic conditions, which are harmful to both the earthworms and the overall vermicomposting process. Striking the right balance and carefully monitoring humidity levels are key to creating optimal conditions for earthworm activity and efficient vermicompost production.

- **Ventilation**

Proper ventilation is essential in the vermicomposting process to prevent the development of anaerobic conditions, which can be harmful to earthworms. High levels of fatty or oily substances in the waste, combined with excess moisture and poor ventilation, can create anaerobic environments. In such conditions, earthworms may suffer from oxygen deprivation and the accumulation of toxic substances like ammonia, which can be fatal. To avoid this, it is important to exclude fatty meats and other oily waste from the organic materials used for vermicomposting. Adequate ventilation ensures the circulation of fresh air, maintaining the aerobic conditions necessary for the health of earthworms and the efficient decomposition of organic matter into vermicompost.

- **Temperature**

Temperature plays a critical role in the vermicomposting process, influencing various essential functions in earthworms, including their activity, metabolism, growth, respiration, and reproduction. Most earthworm species used in vermicomposting thrive in moderate temperatures ranging from 10°C to 35°C, though temperature tolerance can vary between species. Earthworms generally tolerate cold and humid conditions better than hot and dry environments. Temperatures exceeding 35°C can significantly increase mortality rates among earthworms. Therefore, maintaining the appropriate temperature range is essential for the health and productivity of earthworms in the vermicomposting system.

- **pH**

Earthworms can tolerate a pH range between 5 and 9, but they thrive best in a pH range of 7.5 to 8.0. During the vermicomposting process, the pH tends to gradually decrease as organic matter decomposes through

Figure 4.10. Vermireactor Used for Small-Scale Vermicompost Production.

various chemical reactions. If the organic residues are alkaline, the pH will move closer to neutral or become slightly acidic. However, when the residues are acidic, the pH may drop below 7. Acidic conditions can attract pests such as butterflies and spiders. To mitigate acidity and raise the pH, calcium carbonate can be added to the vermicomposting system. This adjustment helps create a more favorable environment for earthworms and promotes efficient vermicomposting.

- **Secondary Factors**

In addition to the primary factors affecting earthworms during vermicompost production, there are other secondary factors that can also impact their well-being, such as:

» **Salt Content:** Earthworms are highly sensitive to salt and prefer organic residues with a salt content below 0.5 %. If seaweed is used in vermicomposting, it should be thoroughly rinsed with water to reduce its salt content. It's important to note that not all types of seaweed are suitable for earthworms.

» **Urine Content:** Cow manure used in vermicomposting may contain a high percentage of urine, particularly if the cows are raised in areas with concrete floors. This can lead to the accumulation of toxic gases, such as ammonia, in the earthworm environment. To mitigate this, cow manure should be washed with water to remove excess urine before being used in the vermicomposting process.

4.2.11 Biofertilizers

At the end of the 19th century, the scientist Beijerinck discovered that nodules on the roots of leguminous plants harbour bacteria capable of fixing atmospheric nitrogen, providing essential nitrogen to plants. Throughout the 20th century, significant advancements were made in soil microbiology, particularly in understanding the biological and chemical processes occurring in soils rich in organic matter. It became evident that beneficial microorganisms, including bacteria and fungi, rely heavily on the presence of organic matter in the soil. These microorganisms depend on organic carbon as an energy source and play crucial roles in nitrogen stabilization. For example, bacteria like *Azotobacter* spp. stabilize atmospheric nitrogen under aerobic conditions, while others, like *Clostridium pasteurianum*, do so under anaerobic conditions. Additionally, certain bacterial strains, such as *Rhizobium* spp., form symbiotic relationships with leguminous plants, fixing atmospheric nitrogen. Other microbial strains also form symbiotic associations with non-leguminous plants, further contributing to nitrogen fixation in soils.

There are also groups of microorganisms dedicated to solubilizing and facilitating the uptake of nutrients from various compounds and minerals, including essential elements like phosphorus, potassium, and micronutrients. This group includes bacteria such as *Bacillus* and *Streptomyces*, as well as mycorrhizal fungi. The effectiveness of these organisms depends on the presence of organic matter, which serves as a substrate and energy source for their metabolic activities. Through their enzymatic actions, these microorganisms play a critical role in enhancing nutrient availability to plants, thereby promoting plant growth and development.

The term "biofertilizers" refers to preparations or biomass containing beneficial microbial strains, also known as microbial inoculants. These microorganisms are added to the soil to provide plants with essential nutrients through their biological activities. Biofertilizers are defined as formulations containing cells of highly efficient microbial strains capable of fixing nitrogen, or solubilizing phosphates and potassium. They are typically applied with seeds or directly to the soil to increase the population of beneficial microorganisms and enhance specific microbial processes that improve nutrient availability for plants.

Biofertilizers play a crucial role in reducing the environmental damage caused by chemical fertilizers and help meet the nutrient needs of crops. Many leguminous crops form symbiotic associations with nitrogen-fixing bacteria, such as rhizobia, which enhance soil fertility and increase the protein content of crops. This symbiotic relationship provides balanced nutrition at lower costs and without contributing to environmental pollution. Overall, biofertilizers are an essential component of sustainable agriculture practices, promoting soil health, boosting crop productivity, and minimizing the ecological footprint of farming activities.

The general benefits of biofertilizers in organic agriculture can be summarized as follows:

» **Nutrient Retention:** Biofertilizers enhance nutrient availability and retention in the soil by activating specialized microbes. These microbes break down organic matter, release nutrients, and make them more accessible to plants.

» Enhanced Nutrient Absorption: Biofertilizers facilitate the absorption of essential nutrients by plant roots, leading to improved nutrient uptake and utilization. This results in healthier plants with better growth and development.

» Disease Resistance: Certain biofertilizers contain beneficial microorganisms that produce antibiotics, helping plants resist diseases caused by pathogens. This natural defense mechanism promotes overall plant health and reduces the need for chemical pesticides.

» Growth Promotion: Biofertilizers contain growth-promoting substances, such as hormones and enzymes, that stimulate root development and vegetative growth. This leads to increased yields and improved crop quality.

» Environmental Sustainability: By reducing reliance on chemical fertilizers and pesticides, biofertilizers help decrease environmental pollution. They promote soil health and biodiversity while supporting sustainable agricultural practices.

In summary, the use of biofertilizers in organic farming offers numerous benefits, from improved nutrient management to enhanced environmental sustainability and crop productivity. Incorporating biofertilizers into agricultural practices can create a more resilient and ecologically balanced farming system. Biofertilizers can also be classified based on their biological activity and the type of nutrients they provide to plants.

4.2.11.1 Biofertilizers for the Mineralization of Organic Matter

Organic matter in the soil, or that which is added to it, undergoes decomposition through the action of various microorganisms. If these microorganisms are present in low abundance, the decomposition process occurs slowly. To accelerate this process, specific microorganisms are cultured in laboratories and introduced into the soil. These microorganisms primarily target the breakdown of cellulose, hemicellulose, and lignin, which are components of organic matter that decompose more slowly. Key microorganisms used for this purpose include fungi such as *Trichoderma* viride, *Aspergillus* niger, and *Paecilomyces fusisporu*, as well as bacteria like *Cellulomonas* and *Cytophaga*.

4.2.11.2 Nitrogen-Fixing Biofertilizers

Various microorganisms, including bacteria, fungi, and algae, have the ability to fix atmospheric nitrogen either through symbiotic relationships with certain plants or via free-living nitrogen fixation in the soil. These nitrogen-fixing microorganisms are used in the production of biofertilizers for organic agriculture. They convert atmospheric nitrogen (N_2) into forms that plants can utilize, such as ammonia (NH_3) or nitrate (NO_3). Examples include nitrogen-fixing bacteria like *Rhizobium* spp. and *Azotobacter* spp., cyanobacteria, as well as nitrogen-fixing fungi and algae. Nitrogen-fixing biofertilizers are classified into two categories: symbiotic and non-symbiotic biofertilizers.

- **Symbiotic Nitrogen-Fixing Biofertilizers**

Symbiotic biofertilizers involve a mutually beneficial relationship between nitrogen-fixing microorganisms and certain plants, particularly leguminous plants. In this relationship, the microorganisms colonize the plant roots and form specialized structures called nodules, where nitrogen fixation occurs. In this mutually beneficial interaction, the microorganisms provide essential nutrients, such as nitrogen, to the plant, while obtaining carbon and other nutritional requirements from the host. This cooperative arrangement ensures the well-being of both organisms, and thus, these microorganisms are referred to as symbionts.

» ***Rhizobium* spp.**

Rhizobium is a genus of nitrogen-fixing bacteria that forms symbiotic relationships with the roots of leguminous plants. The presence of *Rhizobium* colonies in root nodules is essential for the growth and productivity of legumes, as they convert atmospheric nitrogen (N_2) into ammonia (NH_3), which plants can readily absorb and use for growth. *Rhizobium* species play a vital role in agriculture by enhancing the nitrogen nutrition of leguminous crops such as soybeans, peas, beans, and alfalfa, Figure 4.11.

It is estimated that around 80,000 tonnes of atmospheric nitrogen are available above each hectare of land. Through the rhizobium-legume association, up to 20-25 kg of nitrogen per hectare can be fixed, providing a significant amount of nitrogen for subsequent crops. This symbiotic relationship improves soil fertility and agricultural productivity, reducing the need for external nitrogen fertilizers and promoting sustainable farming practices.

Figure 4.11. Rhizobium Colonies in Root Nodules of Soybean.

Since ancient times, the significance of leguminous crops in enhancing soil fertility has been recognized, primarily due to the symbiotic relationship between legumes and nitrogen-fixing bacteria residing in root nodules. Genera such as *Rhizobium*, *Bradyrhizobium*, *Azorhizobium*, and *Sinorhizobium* spp. are among the root nodule bacteria that engage in this mutualistic association with leguminous plants. These bacteria, housed in the root nodules of legumes, can fix atmospheric nitrogen, converting it into a form that plants can use. These microorganisms fix approximately 50-100 kg of nitrogen per hectare and transfer it to the plant in exchange for essential nutrients required for their own growth and reproduction, which are obtained from the host plant.

By propagating specific strains of root nodule bacteria to inoculate leguminous crops, both the current and subsequent crops can benefit, reducing or even eliminating the need for nitrogen fertilizers. This practice contributes to more sustainable agricultural systems. The selection of bacterial species for inoculation depends on the particular leguminous plants being cultivated. Below are examples of root nodule bacteria species and the plants they are associated with:

* ***Rhizobium meliloti:*** Used for alfalfa and fenugreek plants.
* ***Rhizobium trifolii:*** Utilized for common clover plants.
* ***Rhizobium leguminosarum:*** Applied to peas, lentils, and beans.
* ***Rhizobium phaseoli:*** Employed for bean plants.
* ***Bradyrhizobium japonicum:*** Specifically used for soybean plants.
* ***Sinorhizobium*** spp.: Used for Sesbania rostrata plants.

» ***Frankia***

The genus *Frankia* consists of actinomycete bacteria capable of fixing atmospheric nitrogen within root nodules formed on the roots of various non-leguminous trees and shrubs. Approximately 120 plant species, including trees and shrubs such as *Alnus*, *Casuarina*, *Ceanothus*, *Elaeagnus*, *Myrica*, *Hippophae*, and *Purshia*, form symbiotic relationships with *Frankia* bacteria. Certain *Frankia* strains are used to inoculate forest trees, like *Frankia casuarina*, which is employed in seeding *Casuarina* trees commonly used as windbreaks.

Non-leguminous nitrogen fixation systems have moderate agricultural significance, with nitrogen fixation rates varying based on factors such as soil type, climate, and plant age. For instance, nitrogen fixation rates reported by Gaur (2006) range from 12-200 kg/ha/year for species of the genus *Alnus*, 27-179 kg/ha/year for species of *Hippophae*, approximately 58 kg/ha/year for species of *Casuarina*, 60 kg/ha/year for species of *Ceanothus*, and 10 kg/ha/year for species of *Myrica*.

» ***Azolla***

Azolla, an aquatic fern belonging to the family Azollaceae, is commonly found in temperate and tropical regions, especially in lowland rice-growing areas. It forms a symbiotic relationship with the algae *Anabaena azollae*, which uses energy from photosynthesis to fix atmospheric nitrogen, contributing up to 100-150 kg of nitrogen per hectare annually. *Azolla* can be used as a green manure before rice transplanting or as a dual crop after rice transplanting. Its growth and nitrogen-fixing efficiency are generally higher in hilly, humid, and coastal regions compared to high-temperature areas.

In cultivation, *Azolla* is typically grown in ponds and later incorporated into rice paddies to provide nitrogen to rice plants. This agricultural practice is widely used in regions of India and Southeast Asia.

- **Non-Symbiotic Nitrogen-Fixing Biofertilizers**

Non-symbiotic nitrogen-fixing biofertilizers consist of free-living microorganisms in the soil that are capable of fixing atmospheric nitrogen and accumulating organic nitrogen within their cells. These microorganisms grow, activate, and multiply in the soil environment. As they fix atmospheric nitrogen, they produce cells rich in organic nitrogen, increasing the biomass of these organisms. Upon their death and decomposition, organic nitrogen is mineralized by other soil organisms, releasing ammonia, which benefits plants. Key examples of non-symbiotic nitrogen-fixing microorganisms include bacteria from genera such as *Azotobacter*, *Azospirillum*, *Clostridium*, and *Beijerinckia* sp. Additionally, certain species of cyanobacteria, commonly known as blue-green algae, also contribute significantly to non-symbiotic nitrogen fixation. These microorganisms play a crucial role in enhancing soil fertility and promoting plant growth across various agricultural ecosystems.

» *Azotobacter*

Azotobacter, belonging to the family Azotobacteriaceae, is an aerobic, free-living bacterium in soil. As a non-symbiotic bacterium, *Azotobacter* plays a crucial role in nitrogen fixation, converting atmospheric nitrogen into forms usable by plants. This makes it particularly valuable for non-leguminous crops such as cereals and millets, significantly contributing to their nitrogen requirements.

Azotobacter thrives in neutral to alkaline soils and effectively promotes the growth of various crops, including rice, wheat, barley, sorghum, maize, and vegetables like tomato and potato, as well as mustard and cotton. When used in agricultural practices, *Azotobacter* can contribute approximately 10 to 20 kilograms of nitrogen per hectare, reducing the need for synthetic fertilizers and promoting sustainable farming methods.

Furthermore, *Azotobacter* secretes polysaccharides that play a vital role in soil aggregation. These polysaccharides help bind soil particles together, improving soil structure and increasing water retention capacity. By enhancing soil aggregation, *Azotobacter* indirectly supports plant growth by creating a more favorable soil environment for root development and nutrient uptake.

Treating seeds and seedlings with *Azotobacter* cultures is a simple and effective method. In addition to its nitrogen-fixing capability, *Azotobacter* produces growth-promoting substances that improve seed germination and promote robust root development. This enhances nutrient uptake by the plant, contributing to overall plant growth and vigour. Additionally, *Azotobacter* produces antifungal antibiotics, which help inhibit the growth of root pathogens, resulting in healthier plants and better stand establishment in the field.

Studies conducted in India by Gaur (2006) demonstrated the effectiveness of *Azotobacter* in enhancing crop yields for sorghum, corn, mustard, cotton, and various vegetable crops. These studies reported yield increases of 15 % to 30 % with the use of *Azotobacter*, highlighting its significant potential in improving crop productivity and yield in agricultural systems. Overall, *Azotobacter* serves as a beneficial microorganism in agriculture, offering nitrogen-fixing capabilities and soil improvement properties that contribute to increased crop yields and soil fertility.

» *Azospirillum*

Azospirillum is an aerobic nitrogen-fixing bacterium commonly associated with the roots of cereals and grasses. Its high nitrogen-fixation capacity, low energy requirement, and ability to establish abundantly in cereal roots make it especially suitable for cultivation in tropical conditions. *Azospirillum* is used in crops such as sorghum, pearl millet, little millets, barley, and forage legumes, contributing significantly to nitrogen fixation in these plants at rates of 15-30 kg of nitrogen per hectare.

In addition to nitrogen fixation, *Azospirillum* secretes growth-promoting substances such as indole acetic acid (IAA) and gibberellic acid. These substances stimulate plant growth and development, enhancing root elongation, shoot growth, and overall plant vigour. By improving nutrient uptake and supporting physiological processes, *Azospirillum* helps boost crop yields and productivity in agricultural systems.

» Blue-Green Algae (BGA)

Blue-green algae, also known as cyanobacteria, are characterized by the formation of non-fibrous slimy growths on soil surfaces and water bodies. They are distributed globally and thrive in diverse climatic conditions, including harsh environments. Cyanobacteria primarily reproduce vegetatively through cell division, and unlike some other organisms, they do not engage in sexual reproduction. Instead, cyanobacteria form various types of spores, such as exospores, endospores, and akinetes, during their reproductive cycle.

Atmospheric nitrogen fixation in cyanobacteria occurs in specialized cells called heterocysts, which are large, thick-walled cells located within the algal filaments, surrounded by vegetative cells. Nitrogen fixation is a mutual process where heterocysts and adjacent vegetative cells work together to convert atmospheric nitrogen into a form usable by plants. Some of the most significant genera of blue-green algae used in biofertilizer production include *Nostoc*, *Anabaena*, *Calothrix*, *Tolypothrix*, *Plectonema*, *Oscillatoria*, *Cylindrospermum*, *Aulosira*, and *Scytonema*. These cyanobacteria play a vital role in enhancing soil fertility and promoting plant growth through nitrogen fixation and other biochemical processes.

Cyanobacteria that fix atmospheric nitrogen are classified into three groups:

* Aerobic heterocystous forms: These cyanobacteria form specialized cells called heterocysts, where nitrogen fixation occurs in an oxygen-free environment. Examples include *Nostoc* and *Anabaena*.
* Aerobic unicellular forms: These are single-celled cyanobacteria that fix nitrogen in aerobic conditions without forming heterocysts. An example includes *Gloeocapsa*.
* Non-filamentous microaerophilic forms: These cyanobacteria thrive in low-oxygen (microaerophilic) environments and fix nitrogen in such conditions. An example is *Cyanothece*.

Gaur (2006) demonstrated that biofertilization with blue-green algae can significantly increase rice yields by 15-20 %. This increase is attributed not only to the nitrogen-fixing ability of these algae but also to their secretion of beneficial compounds such as B vitamins, auxins, ascorbic acid, indole-3-acetic acid, and gibberellic acid. These compounds promote the growth and development of rice plants.

Additionally, blue-green algae engage in photosynthesis, producing carbohydrates that serve as essential nutrients for bacteria in the rhizosphere of rice plants. By inoculating rice with blue-green algae, the need for mineral nitrogen fertilizers can be reduced by approximately 25 %. The nitrogen fixation capacity of blue-green algae is estimated to range from 20 to 30 kg of nitrogen per hectare per year in wetland rice-paddy fields. This highlights the significant role blue-green algae play in enhancing soil fertility and improving crop productivity in rice cultivation.

4.2.11.3 Biofertilizers for Organic Phosphorus Mineralization

Certain soil microbes play a crucial role in mineralizing organic phosphorus compounds found in plant and animal residues. These compounds, typically in the form of phosphate (PO_4^{3-}), are abundant in organic matter. Various fungi, bacteria, actinomycetes, and yeast are known for their ability to break down organophosphorus compounds. Some of the most active microorganisms involved in this process include:

* Fungi: *Aspergillus niger*, *Aspergillus awamori* and *Penicillium digitatum*.
* Bacteria: *Pseudomonas striata*, *Bacillus polymyxa*, *Flavobacterium* sp., *Erwinia* sp., *Enterobacter* sp. and *Achromobacter* sp.
* Actinomycetes: *Streptomyces* sp.
* Yeast: *Schwanniomyces occidentalis*.

Efficient strains of these microorganisms are selected and propagated in laboratory settings, and they are then introduced into agricultural soil or applied to plant seeds. Through their metabolic activities, these microorganisms mineralize organic phosphorus, releasing it for plant uptake and utilization, thereby enhancing nutrient availability from organic matter decomposition.

4.2.11.4 Biofertilizers for Phosphate Solubilization

The majority of phosphorus in soil exists in the form of tricalcium phosphate ($Ca_3(PO_4)_2$), which is insoluble and thus not readily available for plant uptake, particularly in neutral or alkaline soils. When mineral phosphate fertilizers are applied in conventional agriculture or rock phosphate is used in organic farming, they rapidly convert into this insoluble form, rendering the phosphorus abundant in the soil but inaccessible to plants.

However, many soil microbes play a crucial role in converting insoluble phosphorus, such as tricalcium phosphate ($Ca_3(PO_4)_2$), into a soluble form, specifically monocalcium phosphate ($Ca(H_2PO_4)_2$). These microbes accomplish this by secreting organic acids like acetic, formic, and succinic acids, along with carbon dioxide. This process is especially important in neutral or alkaline soils. Microbes involved in the dissolution of mineral phosphate can be categorized into two main groups:

- **Non-Symbiotic Microbes**

These microbes live freely in the soil without forming symbiotic relationships with plants. Known as phosphate-solubilizing microbes, they include various fungi, bacteria, and actinomycetes. Among them, *Bacillus megaterium* var. phosphaticum is a key bacterium used as a biofertilizer. These microbes are also crucial in dissolving rock phosphate when it is used as a phosphorus source in organic farming.

- **Symbiotic Microbes (Mycorrhiza)**

Mycorrhizal fungi form beneficial symbiotic relationships with plant roots, known as mycorrhizae, where both the fungus and the plant benefit. Often referred to as "root fungi," these fungi inhabit the roots of most plant species and are integral to the functioning of natural plant ecosystems, with over 90 % of terrestrial plants relying on them. In this symbiosis, the plant provides carbohydrates (produced through photosynthesis) to the fungus, while the fungus enhances the plant's ability to absorb water and nutrients, even from low concentrations or those fixed in the soil. The fungus achieves this through an extensive network of fine filaments, called hyphae, which extend into the soil, increasing the plant's nutrient uptake capacity. In addition, mycorrhizal fungi contribute to plant disease resistance, making their role in ecosystems multifaceted.

Among the most important types of Mycorrhiza fungi are the following:

- **Exogenous Mycorrhiza (Ectomycorrhiza)**

Ectomycorrhiza, also known as exogenous mycorrhiza, is one of the most significant types of Mycorrhizal fungi. It forms a dense mantle around the roots of certain trees or creates a sheath above the root surface, with filaments extending into the soil. This type of mycorrhiza engages in a facultative symbiotic relationship, meaning the association is optional but beneficial. Ectomycorrhiza enhances phosphorus absorption by expanding the surface area for nutrient uptake and helps dissolve tricalcium phosphate or rock phosphate. It also provides protection against soil-borne pathogens and promotes seedling growth by producing growth hormones. Key features of Ectomycorrhizal fungi include:

» Mantle Formation: Ectomycorrhizal fungi form a dense outer layer (mantle) around the host plant's roots, helping to protect them from pathogens and environmental stresses.

» Hyphal Extension: The hyphae of these fungi extend into the soil surrounding the root system, significantly increasing the surface area for nutrient absorption. This network of hyphae helps access nutrients, such as phosphorus, that might otherwise be unavailable to the plant.

» Facultative Symbiosis: The relationship between ectomycorrhiza and the host plant is facultative, meaning it is not essential for survival but provides mutual benefits. The fungi receive carbohydrates from the plant, while the plant benefits from improved nutrient uptake and increased resistance to pathogens.

» Phosphorus Uptake: Ectomycorrhizal fungi play a crucial role in facilitating the uptake of phosphorus by the plant. They produce enzymes and organic acids that can solubilize phosphate compounds in the soil, making phosphorus more accessible to the plant roots.

» Host Range: Ectomycorrhizal fungi are commonly found in certain tree species, particularly in temperate and boreal forests. They form symbiotic relationships with a wide range of trees, including gymnosperms (such as: pines, spruce, larch and fir) and angiosperms (such as: oak, beech, poplar and eucalyptus).

» Propagation: Ectomycorrhizal fungi are isolated and propagated in nutrient-rich environments containing vitamins and amino acids. These fungi are then inoculated onto suitable carrier materials and applied to nursery soil. Once seedlings are transplanted, Ectomycorrhiza enhances phosphorus uptake and increases the plant's drought resilience.

Overall, Ectomycorrhiza plays a crucial role in enhancing the growth, health, and nutrient uptake of trees in various ecosystems, making it an essential component of sustainable forestry and agroforestry practices.

- **Arbuscular Mycorrhiza**

Arbuscular Mycorrhiza (AM), also known as endomycorrhiza, is a type of obligate mutual symbiosis formed between fungi and the roots of a wide range of plants, including many agricultural crops, grasses, and ornamental plants. This symbiosis is characterized by the formation of highly branched structures called arbuscules within root cells, which facilitate nutrient exchange between the fungus and the plant.

Arbuscular Mycorrhiza (AM) is one of the most widespread types of mycorrhizal associations, particularly prevalent in arid and semi-arid regions where phosphorus availability to plants is limited. This symbiotic relationship involves fungi from the phylum Glomeromycota, order Glomales, and family Endogonaceae. Within Endogonaceae, several genera play a significant role in arbuscular mycorrhizal symbiosis, including *Glomus*, *Acaulospora*, *Entrophospora*, *Scutellospora*, *Gigaspora*, and *Archaeospora*. Key features of arbuscular mycorrhiza include:

» Formation of Arbuscules: The fungi penetrate root cells and form intricate branched structures called arbuscules, which provide a large surface area for nutrient exchange, particularly phosphorus and nitrogen.

» Hyphal Extension: Fungal hyphae extend beyond the root surface into the soil, exploring a larger volume of soil than the plant roots alone. This enhances nutrient and water uptake, especially in nutrient-poor or drought-stressed environments.

» Nutrient Exchange: Arbuscular mycorrhizal fungi facilitate the uptake of essential nutrients, especially phosphorus, and transfer them to the plant. In return, the plant provides carbohydrates produced through photosynthesis to the fungus.

» Enhanced Plant Growth and Health: The symbiosis promotes plant growth and health, improves root development, and enhances tolerance to environmental stresses such as drought and salinity. Plants with arbuscular mycorrhizal associations also exhibit greater resistance to certain diseases.

» Wide Host Range: Arbuscular mycorrhizal fungi associate with a broad range of plant species, including cereals, legumes, vegetables, and fruits, making them crucial for soil fertility and plant nutrition in diverse ecosystems.

» Propagation and Application: Arbuscular mycorrhizal fungi are propagated and applied as inoculants to agricultural soils to promote symbiotic associations with crops. Methods of application include seed coating, soil drenching, and inoculation of transplants or seedlings.

Indeed, mycorrhizal inoculation has shown promising results across a wide range of crops and trees, significantly improving growth, nutrient uptake, and overall plant health. Some of the notable crops and trees that have benefited from mycorrhizal associations include corn, barley, rice, grapevines, olive trees, citrus fruits (e.g., oranges, lemons, grapefruits), cocoa trees, tobacco, cotton, sugarcane, pineapple, lettuce, onions, cowpeas, soybeans, strawberries, apples, rubber trees, coffee, tea bushes, broad beans, oil palm trees, and many ornamental bulb plants.

These examples highlight the versatility of mycorrhizal symbiosis in supporting the growth and productivity of various agricultural crops and tree species. By enhancing nutrient uptake, water absorption, and tolerance to environmental stresses, mycorrhizal fungi contribute to sustainable and resilient agricultural practices. As a result, farmers and growers worldwide increasingly recognize the benefits of mycorrhizal inoculation in optimizing crop yields and promoting soil health, reducing the need for chemical fertilizers. Understanding and harnessing the benefits of this symbiotic relationship can lead to more efficient and environmentally friendly crop production systems.

- **The Benefits of Mycorrhiza in Organic Farming**

Mycorrhizal fungi play a vital role in organic farming systems, offering numerous benefits that enhance soil health, plant nutrition, and overall crop productivity. Some key advantages of mycorrhizal associations in organic farming include:

» Improved Nutrient Uptake: Mycorrhizal fungi form extensive networks of hyphae that extend into the soil, significantly increasing the surface area for nutrient absorption. This enhances the plant's ability to uptake essential nutrients such as phosphorus, nitrogen, potassium, and micronutrients, leading to healthier and more vigorous growth.

» Enhanced Drought Tolerance: Mycorrhizal symbiosis improves plant tolerance to drought by facilitating water uptake from the soil. The fungal hyphae act as conduits for water transport, helping plants access moisture from deeper soil layers and enhancing their resilience during water scarcity.

» Disease Resistance: Mycorrhizal associations can help plants resist certain soil-borne pathogens by competing for space and nutrients or by stimulating the

Figure 4.12. Mycorrhizal Hyphae and the Colloidal Substances they Secrete.

plant's immune response. This reduces the incidence of diseases like root rot, damping-off, and wilt, resulting in healthier plants and improved crop yields.

» **Enhanced Soil Structure:** Mycorrhizal fungi secrete glomalin, a glycoprotein that helps bind soil particles together, improving soil aggregation and structure. This enhances soil porosity, water infiltration, and aeration, promoting better root growth and nutrient uptake.

» **Reduced Need for Chemical Inputs:** By improving nutrient uptake efficiency and plant health, mycorrhizal associations reduce the need for synthetic fertilizers and pesticides in organic farming systems. This supports sustainable agriculture and contributes to environmental conservation.

» **Increased Crop Yield and Quality:** Research shows that inoculating crops with mycorrhizal fungi can lead to increased yields and improved crop quality, including enhanced nutrient content, flavour, and shelf life. These benefits translate into higher economic returns for farmers practicing organic agriculture.

» **Ecosystem Restoration:** Mycorrhizal fungi are essential in ecosystem restoration efforts by promoting soil fertility, biodiversity, and ecosystem resilience. They aid in the establishment of native plant species, contribute to soil stabilization, and assist in rehabilitating degraded lands.

Overall, incorporating mycorrhizal fungi into organic farming practices fosters more sustainable and resilient agricultural systems, with benefits that extend beyond individual crop production to improve soil health, enhance ecosystem services, and promote environmental sustainability.

4.2.11.5 Biofertilizers for Sulfur Solubilization

Sulfur-transforming biofertilizers play a crucial role in managing alkaline soils and enhancing plant nutrition by facilitating the oxidation of mineral sulfur compounds to sulfate, an essential nutrient for plant growth. These biofertilizers consist primarily of chemolithotrophic bacteria that oxidize mineral sulfur into sulfuric acid. This process involves converting sulfide salts, thiosulfates, and trithiosulfates into sulfate ions, which are readily available for plant uptake.

Key genera of microorganisms involved in sulfur oxidation include *Sulfobacillus*, *Thiobacillus*, *Sulfolobus*, and *Leptospirillum*. Notably, *Thiobacillus denitrificans* is recognized for its ability to oxidize sulfur under anaerobic conditions, allowing sulfur transformation in a broader range of environments.

In agricultural applications, the addition of mineral sulfur to alkaline soils helps mitigate soil alkalinity and increase sulfate levels, thereby improving soil fertility and promoting healthy plant growth. The activity of sulfur-transforming bacteria is particularly effective in well-aerated soils, where they efficiently convert mineral sulfur into sulfate through oxidation processes.

However, it is important to note that sulfur-transforming biofertilizers primarily focus on mineral sulfur chemistry and may not be as effective with organic fertilizers during the initial stages of soil inoculation. Therefore, to optimize microbial activity and sulfur transformation, it is advisable to avoid simultaneous application of these biofertilizers with organic fertilizers.

By harnessing the capabilities of sulfur-transforming bacteria, farmers can effectively manage alkaline soils, increase sulfate availability for plant uptake, and improve soil fertility and crop productivity in a sustainable manner.

4.2.11.6 Biofertilizers for Extracting Potassium from Clay Minerals

Biofertilizers designed for potassium extraction from clay minerals play a crucial role in enhancing potassium availability for plant uptake, especially in soils where a significant portion of potassium is bound to clay minerals in an insoluble form. These biofertilizers utilize specific microorganisms, often referred to as silicate bacteria, which possess the ability to decompose aluminum silicate in clay minerals, thereby releasing potassium in a soluble form that plants can absorb.

Several types of microorganisms have been identified for their ability to extract potassium from clay minerals. Notable genera include *Penicillium*, *Pseudomonas*, *Bacillus*, *Streptomyces*, and *Aspergillus*. These microbes are skilled at breaking down the complex structure of clay minerals, liberating potassium and making it available for plant uptake.

Bacillus circulans has shown particular proficiency in releasing silicon and potassium from silicate clay minerals such as biotite and orthoclase. These bacteria can be cultivated in specialized growth media to encourage their proliferation, after which they are collected and applied for soil inoculation.

By incorporating biofertilizers for potassium extraction into agricultural practices, farmers can effectively enhance potassium availability in soils with high clay content, promoting healthier plant growth and increasing crop productivity. Furthermore, utilizing these biofertilizers reduces the need for chemical fertilizers, supporting sustainable and environmentally friendly farming practices.

4.2.11.7 Biofertilizers for Microelement Solubilization

Biofertilizers designed to solubilize microelements play a critical role in enhancing the availability of essential micronutrients such as iron, zinc, manganese, and others, particularly in calcareous soils where these elements may exist in forms that are not easily accessible to plants. These biofertilizers utilize the metabolic activities of specific microorganisms to solubilize microelements, making them more readily absorbable by plants.

Several microorganisms have been identified for their ability to solubilize microelements in soils, and they are often included in biofertilizer formulations aimed at enhancing micronutrient availability. Through their metabolic processes, these microorganisms convert insoluble forms of microelements into soluble forms that plants can easily absorb.

The use of biofertilizers for microelement solubilization offers several benefits, including:

» **Enhanced Nutrient Availability:** By converting insoluble forms of microelements into soluble ones, biofertilizers increase the availability of essential micronutrients to plants, ensuring optimal growth and development.

» **Improved Plant Health:** Adequate micronutrient uptake is vital for various physiological processes in plants, including photosynthesis, enzyme activation, and overall metabolism. Biofertilizers that solubilize microelements contribute to better plant health and increased resilience against stressors.

» **Environmental Sustainability:** Using biofertilizers for microelement solubilization reduces dependence on chemical fertilizers, promoting environmentally friendly and sustainable agricultural practices. This approach also minimizes the risk of soil and water contamination associated with excessive chemical inputs.

» **Cost-Effectiveness:** Incorporating biofertilizers into agricultural practices can reduce the need for expensive micronutrient supplements, offering farmers a cost-effective solution to maintain soil fertility and optimize crop yields.

Overall, biofertilizers designed for microelement solubilization provide a valuable tool for addressing micronutrient deficiencies in soils, supporting healthy plant growth and sustainable agricultural production.

4.2.11.8 Biofertilizers for Removing Soil Pollutants

Biofertilizers are increasingly being explored as a sustainable solution for addressing soil contaminants, including pesticides. These contaminants can negatively impact soil health and the broader ecosystem. Certain microorganisms have the ability to degrade or detoxify these pollutants, making them valuable candidates for biofertilizer formulations aimed at soil remediation.

The following points explain how biofertilizers can help address soil contaminants:

» **Microbial Degradation:** Microorganisms such as *Streptomyces*, *Xanthomonas*, *Mucor*, *Aspergillus*, and *Trichoderma* have demonstrated the ability to degrade various pesticides through enzymatic pathways. These microorganisms produce enzymes that break down pesticide molecules into harmless byproducts, reducing their toxicity in the soil.

» **Formulation with Specific Strains:** Biofertilizers can be formulated with specific strains of microorganisms known for their bioremediation capabilities. These strains are selected for their efficiency in metabolizing and detoxifying pesticides. When applied to contaminated soils, these biofertilizers facilitate the breakdown or transformation of pesticide residues into non-toxic forms, thereby reducing environmental pollution.

» **Restoring Microbial Diversity and Activity:** Pesticide-contaminated soils often experience a decline in microbial activity, which can affect nutrient cycling and soil fertility. Biofertilizers containing beneficial microorganisms help restore microbial diversity and activity in these soils. This microbial activity contributes to the breakdown of pesticides and the restoration of soil health.

» **Enhanced Plant Growth:** Some biofertilizers not only degrade pesticides but also promote plant growth. Microorganisms such as *Trichoderma* spp. have been shown to enhance plant growth and stimulate the plant's natural defense mechanisms against environmental stressors, including pesticide contamination.

» **Sustainable Remediation Approach:** Biofertilizers provide a sustainable approach to soil remediation by utilizing microorganisms' natural abilities to degrade pollutants. Compared to conventional remediation methods like chemical treatments or soil excavation, biofertilizers are environmentally friendly, cost-effective, and compatible with organic farming practices.

In summary, biofertilizers containing pesticide-degrading microorganisms represent a promising strategy for mitigating the negative effects of pesticide contamination in soils. By harnessing the power of beneficial microbes, these biofertilizers offer a sustainable solution for restoring soil health and promoting agricultural sustainability.

Indeed, biological control using microorganisms is a valuable approach for managing plant pathogens and maintaining soil health. These microorganisms suppress the growth and activity of harmful pathogens through various mechanisms, including the secretion of antibiotics and other inhibitory substances.

Here are some examples of how microorganisms contribute to biological control:

» **Production of Antibiotics and Antimicrobial Compounds:** Certain microorganisms produce antibiotics or antimicrobial compounds that inhibit the growth of plant pathogens. By applying these beneficial microorganisms to the soil or plant roots, farmers can suppress the proliferation of harmful microbes and reduce the incidence of plant diseases.

» **Modulating Soil pH:** Some microorganisms can metabolize organic matter or release acids that help modulate soil pH. By reducing soil acidity, these microorganisms create conditions that are unfavorable for the growth of certain pathogenic bacteria and fungi, helping maintain a healthy soil microbiome and minimizing the spread of soil-borne diseases.

» **Nematode-Trapping Fungi:** Certain fungi, such as *Arthrobotrys conoides* (Nematode-Trapping Fungi), have evolved specialized structures to capture and parasitize nematodes. Introducing these fungi into the soil can help reduce nematode populations, protecting plant roots from damage.

» **Competitive Exclusion:** Beneficial microorganisms can outcompete pathogenic microbes for nutrients and space, reducing the latter's ability to establish and cause disease. This mechanism of competitive exclusion helps maintain a balanced microbial community in the soil, with beneficial microorganisms playing a dominant role in suppressing harmful pathogens.

» **Induced Systemic Resistance:** Some microorganisms can induce systemic resistance in plants, priming them to mount a stronger defense against invading pathogens. By colonizing plant roots or foliar surfaces, these beneficial microorganisms enhance the plant's natural immune system, making it more resistant to disease.

Overall, biological control using microorganisms offers a sustainable and environmentally friendly approach to managing plant diseases and maintaining soil health. By harnessing the natural antagonistic properties of beneficial microorganisms, farmers can reduce reliance on chemical pesticides and promote a more balanced, resilient agroecosystem.

4.2.12 Peat Moss

Peat moss is derived from partially decomposed plant organic matter and is a valuable resource found in swamps known as peat bogs. It forms under conditions of low temperature, oxygen, and nutrient levels, accumulating organic material from plants, fungi, insects, and animals over time. Peat deposits are commonly found in regions such as Northern Europe, Ireland, Scandinavia, and Canada.

Mosses, which are non-vascular plants, are the primary contributors to the formation of peat. These mosses, particularly species from the *Sphagnum* genus, belong to the Bryophyta class and typically have spiral-lobed leaves. They thrive in swampy environments and possess unique cellular structures that allow them to absorb and retain large quantities of water, even after death, holding up to 16-36 times their dry weight in water.

Peat moss is widely used in agriculture worldwide, especially in organic farming, due to its natural composition. It is often blended with other materials, such as compost fertilizer, sand, regular soil, vermiculite, or perlite, in specific proportions to create customized growing mediums for various plants.

The following are key benefits of using peat moss in organic farming:

» **pH Adjustment:** Peat moss has a naturally low pH, ranging between 3.4 and 4.8, making it ideal for lowering the pH of alkaline soils. This helps improve plant growth and nutrient uptake in conditions that would otherwise be too alkaline.

» Water Retention: Peat moss has excellent water absorption capacity, capable of holding up to 36 times its dry weight in water. It also drains excess water effectively, preventing waterlogging and promoting healthy root development.

» Moisture Retention with Fertilizers: When mixed with organic fertilizers, peat moss acts as a moisture reservoir. It absorbs and retains moisture, gradually releasing it to plant roots, which reduces the frequency of irrigation and helps conserve water.

» Packing Material: Peat moss is often used as a packing material for plants during transportation, especially between countries. Its ability to maintain moisture content helps preserve the health and vitality of plants during transit.

» Rich in Organic Matter: Peat moss contains high levels of organic matter (94-99 %), derived from the partial decomposition of plants in acidic water. This makes it a nutrient-rich medium that provides essential carbon compounds for plant growth.

» Root Aeration: With its high porosity, peat moss provides excellent root ventilation, reducing the risk of root rot by minimizing water accumulation around the roots. This promotes optimal root health and vigorous plant growth.

» Environmental Sustainability: Peat moss is environmentally sustainable and free from pathogens, weed seeds, chemical residues, unwanted salts, and harmful heavy metals, making it safe for both plants and the environment.

Despite its richness in organic carbon, peat moss may lack essential salts and nutrients required for plant growth. Therefore, it is often combined with fertilizers or other soil amendments to provide a balanced nutrient profile. Overall, peat moss is a versatile and valuable resource in organic farming, contributing to soil health, water conservation, and plant vitality.

4.2.13 Seaweed Extracts

The use of seaweed extracts and algae in agriculture as fertilizers dates back to at least the nineteenth century. Initially, coastal farmers collected seaweed, particularly large brown seaweeds washed ashore by storms, and buried it in their fields. Seaweed provided numerous benefits to the soil, such as improving soil structure and moisture retention due to its high fiber content. The minerals in seaweed also acted as natural fertilizers, enriching the soil with essential nutrients.

In the early twentieth century, a small industry emerged to dry and grind seaweed and algae for agricultural use. However, the rise of manufactured chemical fertilizers led to a decline in demand for organic alternatives like seaweed-based products. Despite this, the recent shift toward organic farming has revived interest in seaweed fertilizers.

Today, although the use of seaweed fertilizers is still somewhat limited due to the costs of drying and transportation, liquid seaweed extracts have seen significant growth. These extracts are more accessible and practical, as they can be produced in concentrated forms and diluted for use in agricultural applications.

Seaweed extracts have demonstrated positive effects on crop yields and plant health, particularly in organic farming. They promote robust plant growth, including both vegetative and root development, and enhance seed germination rates. Additionally, they help plants withstand stress conditions such as drought and frost by improving soil moisture retention.

Seaweed extracts also increase plant resistance to pests and diseases, further supporting plant health and productivity. In organic farming, especially for fruit, vegetable, and flower crops, seaweed extracts contribute to improved soil fertility, stronger plant growth, and greater crop resilience to environmental challenges. As demand for sustainable farming practices grows, seaweed-based fertilizers are likely to play an increasingly important role in modern agriculture.

Seaweed and algae are broadly classified into three main groups based on their color: Brown Algae, Red Algae, and Green Algae, Figure 4.13. Examples of each group include *Laminaria digitata* for Brown Algae, *Palmaria palmata* for Red Algae, and *Ulva* spp. for Green Algae. Red algae are typically found in warmer regions, while brown algae thrive in colder regions.

Green algae, specifically species of the genus *Ulva*, commonly known as sea lettuce, offer significant benefits when used as organic fertilizers in sustainable agriculture. These algae are abundant in coastal regions and are increasingly being explored as eco-friendly inputs for organic farming due to their rich nutrient profile, rapid growth, and ease of collection.

Ulva spp. are naturally rich in essential nutrients such as nitrogen (N), potassium (K), and trace elements like magnesium (Mg), calcium (Ca), and sulfur (S), making them ideal for replenishing soil nutrient levels. They also contain growth-promoting compounds, such as auxins and cytokinins, which enhance plant growth and stimulate root development.

When added to soil or compost, *Ulva* algae boost organic matter content, improving soil structure, aeration, and water retention. This increase in organic matter also supports microbial activity, which is crucial for nutrient cycling and overall soil fertility. Additionally, using Ulva algae as fertilizer is sustainable, as they can be harvested without depleting natural resources, making them an excellent renewable source for nutrient recycling in organic agriculture.

Unlike synthetic fertilizers, green algae are non-polluting and reduce the risk of nutrient leaching into waterways, which can lead to eutrophication. They can also help sequester carbon, contributing to carbon capture and mitigating the effects of climate change. *Ulva* spp. act as biostimulants by improving plant resistance to stresses such as drought, salinity, and disease, thanks to the presence of polysaccharides like ulvans. These biostimulant properties result in healthier, more resilient crops, which can lead to increased yields.

The algae can be applied directly to the soil, either fresh or dried and crushed, providing slow-release nutrients as they decompose. *Ulva* spp. can also be composted with other organic materials to enrich compost nutrient content and accelerate the decomposition process. Extracts or teas made from green algae can be used as foliar sprays or soil drenches, delivering nutrients and biostimulants directly to plants.

Because *Ulva* grows in marine environments, it is important to rinse the algae thoroughly to remove excess salts, especially when applying them to salt-sensitive crops. Sustainable harvesting methods should also be practiced to avoid disrupting coastal ecosystems.

In addition, seaweed extracts derived from brown algae are particularly important for agricultural use. Notable examples include *Ascophyllum nodosum*, *Laminaria digitata*, *Sargassum crassifolium*, and various species of *Fucus*, commonly known as kelp.

Kelp, such as *Fucus* spp., is prevalent along rocky coastlines, particularly in cold regions, and can grow to lengths ranging from 30 to 200 cm. These brown algae are characterized by their dark brown colour and possess air bladders that allow them to float on the water's surface. *Ecklonia maxima*, also known as sea bamboo, is another significant species of kelp found in the southern oceans along the South Atlantic coast of Africa, from South Africa to northern Namibia.

Seaweed contains a wide range of essential nutrients that benefit plant growth. It provides all major and secondary plant nutrients, as well as trace elements crucial for plant health. Additionally, seaweed contains alginic acid, vitamins, and auxins, which promote plant growth and development. It also contains at least two plant growth hormones, gibberellins, and natural antibiotics, further enhancing its effectiveness as a natural fertilizer.

Figure 4.13. Green Algae (*Ulva* spp.), as an Environmentally Friendly Organic Fertilizer.

Overall, seaweed and algae extracts, as organic fertilizers, offer a comprehensive source of nutrients and growth-promoting substances, contributing to improved soil fertility and plant health in agricultural applications. Their diverse composition makes them valuable in sustainable farming practices, helping to improve crop productivity and resilience to environmental stressors, while serving as an environmentally friendly alternative to chemical fertilizers.

4.2.13.1 The Importance of Using Seaweed Extracts in Organic Agriculture

Seaweed extracts are rich in a variety of compounds, making them valuable inputs in organic agriculture. Here are key points highlighting their importance:

- Natural Plant Growth Regulators: Seaweed and algae contain natural growth regulators such as Cytokinins and Auxins (e.g., indole acetic acid, betanin, and indole butyric acid). These substances help delay plant aging, prevent leaf, flower, and fruit drop, maintain chlorophyll levels, and stimulate root growth and cell division. They can also reduce the respiration rate in crops, extending their shelf life, as seen in asparagus, lettuce, and parsley.
- Soil Improvement: Compounds like alginic acid, laminarin, mannitol, fucodan, and methyl pentosan found in seaweed enhance soil properties by improving its exchange capacity and stimulating beneficial soil bacteria, which in turn increases nutrient absorption efficiency in plants.
- Enhanced Metabolic Efficiency: When applied as a spray, seaweed extracts boost metabolic efficiency in leaves, enhancing photosynthesis. This increased metabolic activity improves plant resistance to pests and diseases such as red spider mites, aphids, and fungal infections. When applied via irrigation, they can also reduce nematode infestations in the soil.
- Stress Resistance: Seaweed extracts contain compounds like betaines, which activate plant immunity and improve their ability to withstand stress. For example, *Ascophyllum* contains amino butyric acid betaine and amino valeric acid betaine, while Laminaria and *Fucus* contain N6-trimethylglycine (laminine), and *Phaeophyceae* contains glycine betaine.
- Enhanced Immunity: Oligosaccharides formed during the extraction process enhance plant resilience to various stressors and boost immunity by increasing the levels of enzymes responsible for synthesizing immune compounds.
- Antibacterial and Antifungal Properties: Seaweed contains natural phenols (C_6H_5OH), which have strong antibacterial and antifungal properties. These phenols also act as growth hormones and promote lignin formation, increasing plant resistance to diseases.
- Chelating Agent: Alginic acid in seaweed acts as a natural chelating agent, aiding in the absorption of essential micronutrients such as iron, zinc, manganese, magnesium, and calcium. It also activates the formation of polysaccharides, growth regulators, polyamines, natural antibiotics, and immune compounds (phytokines) in plants.
- Stress Tolerance: Laminarin in seaweed helps plants cope with stress conditions such as heavy rain, extreme heat, or transplant shock.
- Free Amino Acids: Seaweed extracts contain many free amino acids, including glycine, alanine, valine, methionine, isoleucine, threonine, cysteine, serine, phenylalanine, lysine, glutamic acid, and aspartic acid. These amino acids promote balanced plant growth, improve response to fertilization, increase disease resistance, enhance root development, boost chlorophyll concentration, and provide energy for protein synthesis. They also prevent ammonia toxicity in plants.
- Vitamins: Seaweed extracts are rich in vitamins, including thiamine (vitamin B1), riboflavin (vitamin B2), B12, vitamin C, vitamin K, vitamin E, pantothenic acid, folic acid, and folinic acid. These vitamins stimulate plant growth, activate photosynthesis, promote sugar formation, induce auxin production, and participate in oxidation-reduction processes within plants.
- Nutritional Supplements: Seaweed extracts provide essential nutrients like organic nitrogen, phosphorus, calcium, iron, and iodine, acting as active nutritional supplements in fertilization programs. They support root and vegetative growth, address micronutrient deficiencies, and enhance plant resistance to physiological diseases caused by calcium deficiency.

4.2.13.2 The Versatility of Seaweed Extracts in Organic Agriculture

The diverse range of compounds found in seaweed extracts makes them invaluable tools in organic agriculture. They promote healthy plant growth, improve nutrient uptake, and increase resistance to environmental stresses and diseases. Seaweed and algae offer flexibility and versatility in their use, with various application methods available in agriculture. Here are some common methods for applying seaweed products:

» Incorporation into Soil: Seaweed and algae can be incorporated into compost piles or mixed directly into the soil during preparation. This method allows for a gradual release of nutrients and organic matter, improving overall soil health and fertility.

» Nursery Applications: In nursery settings, seaweed and algae can be mixed with growing media such as potting soil or peat moss to provide essential nutrients and promote healthy growth in seedlings and transplants.

» Extracts Application: Seaweed and algae extracts are available in liquid or solid concentrated forms. These extracts can be diluted with water and applied as foliar sprays, soil drenches, or through irrigation systems. Foliar sprays enhance nutrient absorption through leaves, while soil drenches provide direct root uptake. Diluted extracts can also be used to soak seeds before planting or treat cutting bases to stimulate rooting.

» Seed Soaking: Soaking seeds in seaweed or algae extract before planting can improve germination rates and seedling vigour. The extract provides essential nutrients and growth-promoting compounds, facilitating quicker and more uniform germination.

» Cutting Treatment: Treating cutting bases with seaweed or algae extract before planting enhances root development and improves the success rate of propagation. The extract's hormones and nutrients stimulate root growth, helping cuttings establish quickly in nurseries or fields.

By adapting the use of seaweed and algae products to specific crop and soil requirements, farmers can maximize their effectiveness and fully benefit from these natural fertilizers and growth enhancers.

4.2.13.3 Examples of Some Commercial Seaweed Extract Products

- **Maxicrop**

Maxicrop is a natural seaweed extract derived from *Ascophyllum nodosum* (also known as Egg Wrack kelp) and is available in a soluble form with a pH of 8-9. It contains essential micronutrients such as iron, manganese, zinc, boron, magnesium, and copper, which are easily absorbed by plants through their leaves. Additionally, Maxicrop includes growth stimulants like cytokinins and auxins, along with key nutrients such as nitrogen, phosphorus, and potassium.

Maxicrop promotes strong root growth, enhances chlorophyll content in leaves, and increases plant resistance to fungal pathogens and insect attacks, such as aphids. It is environmentally friendly, odourless, and available in liquid form, making it easy to dilute and apply through foliar spraying or soil treatment.

Maxicrop is suitable for use on cereal and vegetable crops, fruit trees, landscaping, and ornamental plants. The recommended application rate for foliar spraying is 2-4 liters per hectare or 200-400 ml per 100 liters of water. It can be safely applied weekly, with 3-4 sprays per season at intervals of 10-14 days, depending on crop requirements.

- **Kelpak SL**

Kelpak is a liquid seaweed extract derived from Ecklonia maxima, produced by Kelp Products (Pty) Ltd. in South Africa. It has a pH of 4.6 and contains high levels of natural growth regulators, including auxins (11.0 mg/L) and cytokinins (0.031 mg/L). Auxins promote cell elongation, root development, and overall plant growth, while cytokinins support cell division, growth, and fruit quality. They help maintain RNA and protein levels, delay aging, and enhance photosynthesis.

Kelpak is suitable for a variety of field crops and cereals, with a recommended foliar spraying rate of 1-2 liters per hectare. For vegetable crops and fruit trees, the recommended rate is 2-3 liters per hectare, applied every 2-3 weeks for optimal results. Vegetable seedlings and fruit trees can be treated before planting by dipping their trays or roots in a diluted solution of 1 liter of Kelpak per 100 liters of water. For ornamental flowers and plants, Kelpak can be applied by dipping seedling trays in a diluted solution of 10 ml per liter of water and spraying the flowers and plants with a diluted solution of 3 ml per liter of water. This application should be repeated every 3-4 weeks for optimal results.

- **Greetnal Wiz**

Greetnal Wiz is a pure extract derived from *Ascophyllum* nodosum, a type of algae from the North Atlantic, with a pH of 10-10.5. It contains 4.4 % amino acids and is rich in essential micronutrients such as iron, manganese, and zinc, along with key nutrients like nitrogen, phosphorus, and potassium. Its organic matter content ranges from 45-55 %. Greetnal Wiz also contains plant growth regulators such as cytokinins and auxins, with a cytokinin content of around 600 ppm.

This extract is used for spraying field crops, fruit trees, and vegetable crops, with a recommended application rate of 600-750 grams per hectare, applied 2-4 times per season for optimal results. Greetnal Wiz promotes improved plant growth, vigour, and overall health, making it a valuable resource for organic farming practices.

- **e-dalgin**

e-dalgin is a natural seaweed extract derived from *Ascophyllum nodosum*, produced by Sustainable Agro Solutions (SaS) in Spain. It contains a range of amino acids, carbohydrates, and microelements like iron, manganese, and zinc, along with significant amounts of major nutrients such as nitrogen, phosphorus, and potassium.

e-dalgin is typically applied by spraying the vegetative parts of various crops and fruit trees. The recommended application rate is 200-250 ml per 100 liters of water for foliar spraying and 3-4 liters per hectare for fertigation. Depending on the crop and growing conditions, spraying can be done 1-3 times per crop cycle to promote healthy growth, enhance nutrient uptake, and improve overall plant performance. e-dalgin serves as a valuable natural supplement in organic farming, supporting sustainable agricultural practices.

Chapter 5

5. Pest control Strategies in Organic Agriculture

In organic agriculture, pest control strategies focus on natural and sustainable methods to manage pests while minimizing harm to the environment, human health, and non-target organisms. While biopesticides, plant extracts, and other natural pesticides are part of pest management, they are not the primary reliance in organic farming. In fact, organic farmers often view organic pesticides, such as rotenone and pyrethrin, as a last resort.

Heavy reliance on these pesticides can lead to a detrimental cycle, potentially worsening pest problems over time. Therefore, before resorting to such measures, organic farmers typically assess the population and effectiveness of natural predators and parasites through random surveys. This approach ensures that the use of organic pesticides does not harm beneficial organisms that contribute to natural pest control, promoting a long-term balance within the ecosystem.

Pest control strategies in organic farming focus primarily on the prevention and reduction of infestations rather than reactive measures. Organic farmers must develop well-researched strategies that integrate a variety of pest management methods to minimize reliance on synthetic interventions. These methods include the use of biopesticides, crop rotations, and biological control by attracting natural predators and parasites, providing them with food and shelter. Additionally, farmers can utilize various traps, such as coloured sticky traps and pheromone traps, plant trap crops to divert pests away from main crops, and cultivate pest-resistant crop varieties. The removal of severely damaged crops and implementing successful crop transfers, when feasible, also contribute to effective pest management.

Intercropping with plants that have symbiotic properties or pest-repellent effects, along with timing planting to avoid peak pest periods, are crucial strategies as well. Conducting studies on the host range and preferences of local pests helps farmers adapt their approaches to specific pest pressures.

By integrating these diverse methods, organic farmers can manage pest populations effectively while reducing dependence on synthetic pesticides and maintaining ecological balance within their farming systems. Furthermore, additional practices can be implemented to keep pest populations below economic thresholds in organic agriculture. These holistic and sustainable approaches ensure long-term productivity and environmental preservation.

5.1 Biopesticides

The term "biopesticides" was first introduced by scientists such as Copping (1998) and Hall and Menn (1999). It refers to a variety of pesticides derived from biological processes, including those originating from microorganisms found in the soil or those acting as pathogens for insects (entomopathogens). These microorganisms include fungi, bacteria, viruses, nematodes, and protozoa. Biopesticides also encompass those extracted from plants and insect pheromones used to alter the behavior of insect pests.

While some sources classify genetically modified plants used for pest control under the category of biopesticides, it is important to note that genetically modified plants are not allowed in organic agriculture.

In general, biopesticides can be defined as specific pesticides derived from living organisms or natural materials, such as plants, bacteria, fungi, and natural minerals. As of September 2015, around 1,400 commercial products containing 436 active ingredients had been registered and sold globally as biopesticides (Marrone, 2007).

The following points highlight the key advantages of biopesticides:

- Lower Toxicity: Biopesticides are generally less toxic than conventional pesticides, making them safer for humans, animals, and the environment.
- Target Specificity: Biopesticides are designed to target specific pests or closely related organisms, unlike conventional insecticides, which can affect a wide range of organisms, including birds, insects, and mammals.

» **Rapid Decomposition:** Biopesticides are effective in small quantities and often decompose quickly, leading to shorter exposure periods and reducing the risk of environmental contamination compared to conventional pesticides.

» **Reduced Reliance on Chemicals:** When used as part of an Integrated Pest Management (IPM) program, biopesticides can significantly decrease the reliance on conventional pesticides.

Biopesticides are generally categorized into three main groups based on the active substances:

1. Microbial Biopesticides.
2. Biochemical Biopesticides.
3. Semiochemicals.

Below are the main categories of biopesticides, along with some of the most important biopesticides permitted for use in organic agriculture.

5.1.1 Microbial Biopesticides

Microbial biopesticides consist of microorganisms and pathogens that target pests. Many of these have been commercially produced and packaged for application, typically by spraying plants or using other methods to reach the targeted pest. Examples include insect pathogens such as bacteria, fungi, viruses, nematodes, and protozoa. These microorganisms are often referred to as "living pesticides" or "microbial pesticides," and the term "microbial control" is commonly used when these preparations are employed in pest management. This method has gained significant attention globally, particularly with the expansion of organic farming systems in recent years. Some important microbial biopesticides allowed for use in organic farming systems include *Bacillus thuringiensis* (*Bt*), *Beauveria bassiana*, *Trichoderma* spp., and *Steinernema feltiae*.

Microbial control is a subset of biological control, where microorganisms are used to manage pest populations and mitigate their damage. For instance, organisms used for insect control are often termed "biological insecticides," while those used for fungal control are called "biological fungicides." This distinction underscores the specificity and versatility of microbial agents in pest management strategies.

Though many insect-killing viruses exist, these viruses cannot be cultured or produced outside living organisms. An example is a virus that infects the larvae of *Anticarsia gemmatalis*, a major pest of soybean crops in North and South America. To obtain this virus, infected larvae are collected, ground, and the extract is filtered to create a suspension containing the virus. This suspension is diluted and sprayed onto plants to infect and eliminate the pest larvae. Commercial production of this virus involves processing it into a dry powder for easy application as needed.

Presently, various microorganisms, including fungi, bacteria, viruses, and pest-pathogenic nematodes, are commercially produced and deployed as needed for pest control purposes. However, the use of microbial pesticides in integrated pest management (IPM) or pest control programs in organic agriculture presents several challenges, which can be summarized as follows:

» **Specific Weather Conditions:** Some microbial pesticides require specific environmental conditions to thrive and be effective. For example, fungi often need high humidity levels, exceeding 90 %, to perform optimally.

» **Limited Pest Spectrum:** Many microbial pesticides are highly specialized and target a narrow range of pests, unlike chemical pesticides, which often have broader spectra and can target multiple pests at once.

» **Storage Requirements:** As living organisms, microbial pesticides require specific storage conditions to maintain their viability. Improper storage can lead to a loss of their effectiveness.

» **Production Challenges and Costs:** The production of microbial pesticides, especially those with specialized characteristics, can be challenging and costly compared to chemical pesticides.

» **Time to Effectiveness:** Microbial pesticides often take time to kill the target pest. The timeframe can vary, and in some cases, they may only disrupt the pest's feeding behavior rather than causing immediate death.

» **Complete Coverage Required:** For microbial pesticides to be effective, it is crucial to achieve thorough coverage of plant surfaces, ensuring that pest larvae come into direct contact with the pathogen. This can be especially challenging with pests like borers, which are often difficult to reach.

The following are the key groups of microbial biopesticide preparations commonly used in organic agriculture for pest control.

5.1.1.1 Entomopathogenic Bacteria

Entomopathogenic bacteria consist of various bacterial species that can infect and cause disease in insects. These bacteria are typically divided into two main groups:

* Non-spore forming bacteria: These bacteria are commonly found in soil and the digestive tracts of arthropods. They belong to families such as Pseudomonadaceae and Enterobacteriaceae.
* Spore-forming bacteria: This group includes species from the family Bacillaceae, with many species in the *Bacillus* genus being of particular interest due to their effectiveness in controlling insect pests.

One of the most well-known species of spore-forming bacteria is *Bacillus thuringiensis* (*Bt*), widely recognized as a leading biopesticide. *Bt* has been extensively marketed for its effectiveness in controlling arthropod pests.

Bacillus thuringiensis (*Bt*) was first discovered by Berliner in Germany in 1911, who isolated it from the Mediterranean flour moth (*Ephestia kuehniella*) in infected flour. Berliner named the species *thuringiensis* after the Thuringia region in Germany, where it was isolated. It is worth noting that bacteria from the *Bacillus* genus were first identified in 1901 by Japanese biologist S. Ishiwata, who isolated them from silkworm larvae suffering from a fatal disease called Sotto disease.

- **Mode of Action of *Bacillus thuringiensis* (*Bt*)**

The mode of action of *Bacillus thuringiensis* (*Bt*) in combating insects centers around the production of insecticidal toxins in the form of protein crystals. While the bacteria themselves are not highly effective as direct insect pathogens, they generate a variety of lethal toxins. *Bt* consists of numerous subspecies, each producing unique protein crystals, or delta-endotoxins, encoded by individual genes on bacterial plasmids. The potency of these toxins can vary between different *Bt* strains.

Research by Van Frankenhuyzen (1993) suggests that some *Bt* toxins may exhibit toxicity levels comparable to phosphorus-based pesticides. However, *Bt* toxins are more specialized in targeting harmful insects, making them safer for beneficial organisms such as predators, parasites, and other non-target animals. Additionally, *Bt* toxins are biodegradable, ensuring environmental safety.

In addition to protein crystals, (*Bt*) also produces other toxins, including exotoxins, hemolysins, and enterotoxins, all of which have lethal effects on insects. After an insect ingests *Bt*-contaminated food, the toxic action begins within approximately one hour. Insect larvae cease feeding and experience paralysis within six hours. The toxic protein binds to receptors on the epithelial cells of the midgut, causing these cells to swell and break down. This leads to paralysis of the insect's midgut and mandibles, ultimately causing death from starvation and septicemia. The time it takes for the insect to die varies depending on the species and the specific *Bt* toxin involved.

- **The Commercial Use of *Bacillus thuringiensis* (*Bt*) for Insect Control**

The commercial use of *Bacillus thuringiensis* (*Bt*) for insect control began in the United States in 1958 with the introduction of Thuricide, a compound derived from *Bacillus thuringiensis* subsp. kurstaki. In 1961, the first registration of a *Bt* product was approved by the US Environmental Protection Agency (EPA), and in 1970, Abbott Laboratories introduced Dipel compound, another *Bt*-based product.

Initially, *Bacillus thuringiensis* (*Bt*) bacteria were believed to be effective only against larvae of insects in the Order: Lepidoptera. However, further research revealed additional strains with broader applications. For example, *Bt* subsp. israelensis was found to be effective against mosquito and black fly larvae (Order: Diptera), while *Bt* subsp. tenebrionis, discovered in 1983, was shown to target larvae of certain beetles (Order: Coleoptera).

These discoveries paved the way for the commercial production of specialized *Bt* strains, offering a targeted alternative to chemical pesticides, which often carry environmental and health risks. Today, commercial preparations of *Bt* are available in both liquid and dry forms.

Bacillus thuringiensis (*Bt*) bacteria, which are pathogenic to insect larvae, offer several advantages that set them apart from other types of bacteria. These advantages include:

» Specialization: *Bt* strains are highly specialized, targeting specific insect larvae.

» Dual Toxin Production: *Bt* produces insecticidal proteins both during its vegetative growth phase and in the spore-forming stage.

» Ease of Production: *Bt* can be easily produced through fermentation and stored without significant issues.

» Flexibility in Growth: *Bt* strains can grow well in artificial media and form protein crystals during spore formation.

» Targeted Safety: *Bt* strains used to control mosquito larvae are particularly safe for non-target aquatic organisms, as the larvae are killed by the toxin itself rather than by microbial growth.

Table 5.1. lists several commercial preparations of *Bacillus thuringiensis* (*Bt*) bacteria, which are pathogenic to various insect larvae and are classified as entomopathogenic bacteria. Each of these preparations targets specific insect larvae and is widely used as a biopesticide in organic agriculture.

Table 5.1. Key Commercial Products of *Bacillus thuringiensis* (Bt) Used as Bio-Insecticides.

Active Ingredient (*Bt*)	Strain	Commercial Product	Company Name	Target Insects
***Bt* subsp. *Kurstaki* (Btk)**	EG2348 SA-12 SA-12 ABTS-351 EG2371	*Condor *Thuricide *CoStar WG *Dipel *Cutlass	Ecogen, Inc. Certis, USA Certis, USA Valent Bioscience Co. Ecogen, Inc.	Lepidopteran larvae Coleopteran larvae (*Leptinotarsa decemlineata*).
***Bt* subsp. *aizawai* (Bta)**	ABTS-1857 NB200 GC-91	*XenTari *Florbac *Agree	Valent Bioscience Co. Valent Bioscience Co. Certis, USA	Lepidopteran larvae (Especially that have developed resistance against *Btk*).
Bt* subsp. *tenebrionis	NB-176	*Novodor *Track *Foil	Valent Bioscience Co. Mycogen, USA Ecogen, USA	Coleopteran larvae (*Leptinotarsa decemlineata*)
Bt* subsp. *japonensis	buibu	*M-Press	Mycogen	Coleopteran larvae (Especially beetles that inhabit the soil).
***Bt* subsp. *israelensis* (Bti)**	SA3A AM65-52 AM65-52	*Teknar *Bactimos *VectoBac	Valent Bioscience Co.	Mosquito and black fly larvae.
***Bt* subsp. *aizawai* encapsulated deltaendotoxins**	(kurstaki + aizawai)	*Mycogen *Ecogen		Lepidopteran larvae.

5.1.1.2 Entomopathogenic Fungi

Insect-pathogenic fungi are a diverse group, with over 400 species known to infect insects. Several of these fungi are commercially produced and widely used to combat insect pests. The most notable fungi in this category include *Beauveria* spp., *Metarhizium anisopliae*, *Verticillium lecanii*, and *Paecilomyces* spp.

Although lethal to insects, these fungi act relatively slowly, and their effectiveness is influenced by environmental factors, particularly sunlight, which can hinder their activity. Additionally, the spores of these fungi require high relative humidity to germinate and proliferate. For infection to occur, the spores must come into direct contact with the insect, allowing the germination tubes to penetrate the insect's body. Therefore, thorough coverage of plant surfaces is crucial to ensure that the spores reach the target pests.

It is important to note that insect-pathogenic fungi are not highly specialized, meaning they can infect multiple insect species from different orders and families. This broad spectrum of activity means that beneficial insects, such as predators and parasites, may also be affected.

For instance, *Beauveria bassiana* has been found to infect numerous insects, including some beneficial species like predators from the Coccinellidae family. The pathogenic effects of B. *bassiana* were first discovered by Agostino Bassi in 1835, when he identified the fungus as the cause of a disease in silkworms (*Bombyx mori*). In his honor, the fungus was named *B. bassiana*. The first commercial microbial product for insect control, *Beauveria tenella* (Delacroix) Siemaszko, was produced in France in 1891.

It is important to note that for fungi to effectively infect insects and complete their life cycle, specific environmental conditions, particularly adequate humidity and favorable temperatures, must be present. These factors are crucial when using fungi for insect pest control in open-field conditions, as they significantly impact the fungi's ability to establish and spread within insect populations.

Table 5.2 illustrates the most significant commercial preparations of entomopathogenic fungi used as biopesticides for controlling insects in organic agriculture.

5.1.1.3 Entomopathogenic Nematodes

Insect-pathogenic nematodes parasitize a wide range of insect species from various orders, including Lepidoptera, Coleoptera, Diptera, Hymenoptera, and Orthoptera. These nematodes go through three primary stages: egg, larval, and adult (male and female). The larval stage consists of four phases, with the third larval stage, known as the infective juvenile stage, being responsible for initiating infection. During this stage, the nematodes enter the insect host's body through natural openings, such as spiracles or the anus.

It is important to note that the larval and pupal stages of soil-dwelling insects are the most susceptible to nematode infection. A key factor for successful nematode infection when treating soil is the presence of the appropriate life stage of the insect host in the soil, as well as a high level of soil moisture to facilitate nematode movement.

Table 5.3. lists some of the most important commercial products of entomopathogenic nematodes used to control various insect pests in organic agriculture.

- **Mode of Action of Entomopathogenic Nematodes**

Entomopathogenic nematodes kill infected insects through two primary mechanisms. First, they physically invade the insect's internal tissues. Second, they rely on symbiotic bacteria, such as *Xenorhabdus* spp., which they carry inside their bodies. Once the infective juvenile stage enters the insect, it releases these symbiotic bacteria. The bacteria then produce toxins, causing the insect to die within 24 to 72 hours after infection.

After the insect dies, the bacteria break down the insect's body contents into nutrients that the nematodes can consume. The nematodes subsequently develop into the fourth larval stage inside the dead insect's body. Subsequently, the fourth larval stage matures into sexually mature adult males and females, and mating takes place inside the dead host. After mating, the male nematodes perish, while the females either lay eggs inside the dead insect, if sufficient food is available for the first larval stage or retain the eggs within their own bodies.

The first and second larval stages develop within the female's body, eventually maturing into infective juveniles, which then leave either the host's or the female nematode's body. These infective juveniles move into the soil to find new insect hosts. Typically, the nematodes complete 2-3 generations within the dead insect host, depending on the availability of food resources.

Infective juvenile nematodes can move several centimeters through the soil in search of new hosts. They enter insects through natural openings such as spiracles or the anus.

The life cycle of nematodes is heavily influenced by soil conditions, temperature, and the availability of food, particularly host insects in their environment. Entomopathogenic nematodes are most effective in controlling insect pests that reside in the soil or periodically visit it in search of shelter.

Research conducted by Figueroa (1990), Smith *et al*. (1993), and Sen Selvan *et al*. (1994) supports this, highlighting the importance of environmental factors in the effectiveness of these nematodes for pest control.

Table 5.2. The Most Important Commercial Entomopathogenic Fungi Used as Bio-Insecticides.

Entomopathogenic Fungi	Commercial Product	Company Name	Target Insects
Beauveria bassiana	*Naturalis-L	Troy	Strain (Bb 147) against *Ostrinia* spp.
	*Naturalis-T	Troy	Strain (GHA) against sucking insects such as: Aphids, Thrips, Whiteflies and Mealybugs.
	*Mycotrol	Mycotech	Strain (ATCC 74040) against soft insects of orders: Coleoptera and Homoptera.
	*Corn Guard	Mycotech	Corn Borers.
	*Bio-Power	Stanes	Aphids, Thrips, Whiteflies, Mealybugs, Borers, Lepidopteran larvae.
Beauveria brongniartii	*Engerlingspilz	Andermatt NPP	Coleopteran Larvae (*Hoplochelis marginalis*).
	*Betel	Andermatt NPP	Grubs (*Melolontha melolontha*).
Verticillium lecanii	*Bio-Catch	Stanes	Aphids, Thrips, Whiteflies, Mealybugs and Leafhoppers.
Metarhizium anisopliae	*Bio-Magic	Stanes	Mealybugs, Leafhoppers, Lepidopteran &Coleopteran Larvae, Termites, Borers and Red Palm Weevil.
Paecilomyces fumosoroseus	*Priority	Stanes	Many plant mites on various crops.
	*PreFeRal	Thermo Trilogy	Many piercing-sucking insects such as: Aphids, Thrips, Whiteflies, and Mites.

Table 5.3. The Most Important Commercial Entomopathogenic Nematodes Used as Bio-Insecticides.

Entomopathogenic Nematodes	Commercial Product	Company Name	Target Insects
Heterorhabditis bacteriophora	*Heteromask	BioLogic	Many insects but mainly against the Japanese Beetle.
	*Cruiser	Ecogen	
	*Lawn Patrol	Hydro-Gardens	
	*Nema-green	e-nema	
Heterorhabditis megidis	*Larvanem	Koppert	Soil insects such as: Black vine weevil (*Otiorhynchus sulcatus*).
	*Nemasys H	MicroBio	
Steinernema carpocapsae	*Exhibit SC-WDG	Novartis BCM	Many soil insects such as: Black vine weevil, Mole cricket, Fleas, Cutworm, Stem borers, and others.
	*Bio Safe WG	Thermo Trilogy	
	*BioVector WG	Thermo Trilogy	
	*Guardian	Hydro-Gardens	
Steinernema feltiae	*Nemasys	MicroBio	Different species of Sciarid flies such as: *Bradysia*, *Lycoriella* and *Sciara* spp. and some Soil insects.
	*Entonem	Koppert	
	*Traunem	Andermatt	
	*X-Gnat	Thermo Trilogy	
Steinernema glaseri	*Steinernema glaseri	Thermo Trilogy	White Grubs (Family: Scarabaeidae).
Steinernema riobrave	*Biovector WG	Thermo Trilogy	Nymphs and adults of the borer in the grass, the blue-green citrus weevil, (*Pachnaeus litus*) and the sugarcane root-boring weevil (*Diaprepes abbreviatus*).
	*Devour WG	Thermo Trilogy	
	*Vector MC	Thermo Trilogy	
Steinernema scapterisci	*Otinem S	Ecogen	The Mole Crickets such as: *Scapteriscus vicinus* *Gryllotalpa* spp.

5.1.1.4 Entomopathogenic Virus

Entomopathogenic viruses are classified into three main groups:

1. Nuclear Polyhedrosis Virus (NPV).
2. Cytoplasmic Polyhedrosis Virus (CPV).
3. Granulosis Virus (GV).

Among these, Nuclear Polyhedrosis Virus (NPV) holds practical significance. NPVs infect the nuclei of host insect cells and replicate within the nucleus. The infection spreads from one cell to another, eventually affecting various tissues throughout the insect's body. The nuclei of epithelial cells lining the gastrointestinal tract of many larvae, particularly those belonging to the order Lepidoptera, are especially susceptible to infection.

Entomopathogenic viruses are highly specialized insecticides and are often referred to as "insecticidal baculoviruses". Each virus typically targets a specific insect or a group of closely related species. This specialization is advantageous because it ensures that the virus does not harm other species, including beneficial insects such as predators and parasites.

Entomopathogenic viruses are available commercially as wettable powders or emulsions, which usually require storage at low temperatures. These virus preparations are applied as sprays on plants. However, they should not be mixed with copper or sulfur compounds. Table 5.4. lists the key commercial preparations of various entomopathogenic viruses used for controlling insect pests in organic agriculture.

5.1.1.5 Bio-Fungicides

Bio-fungicides, also known as biological or microbial fungicides, are formulations containing beneficial microorganisms, such as fungi and bacteria, that help control fungal diseases in plants. These microorganisms act against plant pathogens through several mechanisms, including competing for nutrients and space, producing antifungal compounds, and inducing systemic resistance in plants. Bio-fungicides offer an environmentally friendly approach to managing plant diseases, particularly in organic agriculture.

Table 5.5. illustrates some of the key commercial bio-fungicide preparations used to control various fungal pathogens in organic agriculture systems.

- **The Use of *Trichoderma* spp. in Organic Agriculture**

Plant diseases, particularly those caused by soil-borne pathogens or transmitted through seeds, pose significant challenges in organic agriculture. These diseases can lead to seedling death, root rot, wilting, and fruit rot, resulting in diminished plant vigour and significant yield losses. Addressing these fungal diseases is critical to maintaining crop health and productivity in organic systems.

To combat these issues, organic farmers frequently turn to bio-fungicides containing beneficial microorganisms like *Trichoderma* spp. These bio-fungicides are highly effective in suppressing the growth of soil-borne pathogens and preventing fungal infections in crops. Commercial preparations of *Trichoderma* spp. are widely utilized in organic farming to enhance disease resistance and support sustainable crop management practices.

Table 5.6. presents examples of commercial preparations of *Trichoderma* spp. bio-fungicides that are widely used in organic farming for controlling various fungal diseases. These products are key elements in sustainable disease management strategies, contributing to healthier crops and improved yields within organic production systems.

Trichoderma preparations are particularly effective in controlling a wide range of pathogenic fungi that affect vegetables, fruits, and field crops. They are known to combat fungi from genera such as *Fusarium*, *Pythium*, *Rhizoctonia*, *Botrytis*, *Sclerotinia*, *Verticillium*, *Heterobasidion*, *Didymella*, and *Macrophomina* spp.

- **Mode of Action of *Trichoderma* in Combating Pathogenic Fungi**

» **Root Protection:** *Trichoderma* grows around the root system and root hairs, creating a protective barrier that prevents pathogenic fungi from reaching and infecting the roots.

» **Parasitism of Pathogens:** *Trichoderma* directly parasitizes harmful fungi by encircling them and ultimately killing them through physical contact.

» **Secretion of Antifungal Substances:** *Trichoderma* secretes compounds like Trichodermine, which are highly effective in eliminating pathogenic fungi.

» **Enhancing Plant Immunity:** When applied to plant foliage or the root zone, *Trichoderma* strengthens the plant's natural defenses, increasing its resistance to infections caused by pathogenic fungi.

This multifaceted mode of action makes *Trichoderma* an invaluable tool for organic farmers seeking sustainable and effective solutions for disease control in their crops.

Table 5.4. The Most Important Commercial Entomopathogenic Viruses Used as Bio-Insecticides.

Entomopathogenic Viruses	Commercial Product	Company Name	Target Insects
***Adoxophyes orana* (granulovirus) (GV)**	*Capex 2	Andermatt	The Larvae of: *Adoxophyes orana* Fischer.
***Anagrapha falcifera* (nucleopolyhedrovirus) (NPV)**	*Anagrapha falcifera NPV	Thermo Trilogy	Lepidopteran larvae.
***Anticarsia gemmatalis* (nucleopolyhedrovirus) (NPV)**	*Polygen	Agroggen	Sugarcane borer larvae: *Diatreae saccharalis*
	*Multigen	EMBRAPA	The velvetbean caterpillar: *Anticarsia gemmatalis*
***Autographa californica* (nucleopolyhedrovirus) (NPV)**	*VPN 80	Agricola El Sol	Lepidopteran larvae.
	*Gusano	Thermo Trilogy	
***Cydia pomonella* (granulovirus) (CpGV)**	*Madex 3	Andermatt	Codling Moth (Apple Worm): *Cydia pomonella*
	*Carposin	Agrichem	
	*Carpovirusine	Calliope	
	*CYD-X HP	Certis, USA	
***Helicoverpa zea* (nucleopolyhedrovirus) (NPV)**	*GemStar	Thermo Trilogy	Cotton Bollworm: *Helicoverpa zea* Tobacco Budworm: *Heliothis virescens*
***Lymantria dispar* (nucleopolyhedrovirus) (NPV)**	*Gypcheck	US Forestry Service	The Caterpillar of Gypsy Moth: *Lymantria dispar*
***Mamestra brassicae* (nucleopolyhedrovirus) (NPV)**	*Mamestrin	NPP and Calliope	The Cabbage Armyworm: *Mamestra brassicae*
***Spodoptera exigua* (nucleopolyhedrovirus) (NPV)**	*Spod-X	Thermo Trilogy	The Beet Armyworm: *Spodoptera exigua*
	*Ness-A	Applied Chemicals	

Table 5.5. The Most Important Commercial Bio-Fungicides.

Bio-Fungicide	Commercial Product	Company Name	Target Fungi
		1. Fungi	
Candida oleophila	*Aspire	Ecogen	Post-harvest diseases in citrus, apples, pears and quince such as: *Botrytis cinerea*
Coniothyrium minitans	*Contans	Prophytia	*Sclerotinia* spp.
Endothia parasitica	*Non-pathogenic strain	CNICM	To combat the fungus *Endothia parasitica*, which causes chestnut blight disease in chestnut trees.
***Fusarium oxysporum* (strain Fo 47)**	*Fusaclean L *Fusaclean G	NPP	Diseases of vascular wilt caused by fungi: *Fusarium oxysporum and Fusarium moniliforme*
Gliocladium catenulatum	*Primastop	Kemira	Soil Borne Fungi such as: *Pythium* and *Rhizoctonia* Post-harvest fungi from genera: Botrytis, *Didymella* and *Helminthosporium*
Gliocladium virens	*SoilGard	Thermo Trilogy	Fungi that cause seedling fall diseases and root rot such as: *Rhizoctonia*, *Pythium*, *Fusarium*, *Thielaviopsis*, *Sclerotinia* and *Sclerotium* spp.
Pythium oligandrum	*Polyversum	Biopreparaty Co.	Many soil borne fungi such as: *Botrytis* and *Sclerotinia* spp.
Trichoderma harzianum	*Trianum-P *Trianum-G *Harzan *Trichodex	Koppert Koppert NPP Makhteshim	Many soil borne fungi such as: *Botrytis* and *Sclerotinia* spp.
Trichoderma harzianum ***Trichoderma polysporum***	*PlantGard WG	BINAB Bio-Innovation AB, Sweden	Many soil borne fungi such as: *Rhizoctonia*, *Pythium*, *Fusarium*, *Verticillium*, *Chondrostereum* and *Didymella*.
Trichoderma viride	*Bio-Cure F	Stanes, India	Many soil borne fungi such as: *Rhizoctonia*, *Pythium*, *Fusarium*, *Verticillium*, *Chondrostereum* and *Sclerotium* spp.
Ampelomyces quisqualis	*AQ10	Ecogen	White rot in onions and garlic, downy mildew, powdery mildew purple blight, rust and fusarium wilt.
		2. Bacteria	
Bacillus subtilis	*Kodiak *System 3 *Serenade	Gustafson Uniroyal Bayer	Seed treatment against fungi such as: *Fusarium*, *Pythium* and *Rhizoctonia* spp.
***Bacillus amyloliquefaciens* Strain D747**	*DoubleNickel 55	Certis, USA	Powdery & Downy mildew and Leaf spots.
Burkholderia cepacia	*Deny *Intercept	CCT Corp Soil Technologies	Many soil borne fungi and Nematodes.
Pseudomonas chloraphis	*Cedoman	BioAgr.	Many soil borne fungi and seed fungi.
Pseudomonas fluorescens	*Bio-Cure B *Dagger *BlightBan	Stanes Ecogen Plant Health Tech.	Many soil borne fungi such as: *Fusarium*, *Rhizoctonia* and *Pythium* spp. Bacteria causing fire blight in apples and pears: *Erwinia amylovora*
Pseudomonas syringae	*BioBlast		Fungi that attack stored material.
Streptomyces griseoviridis	*Mycostop	Kemira Bioyech, Finland	Soil borne fungi especially *Fusarium*, which cause wilt and root rot. Also against *Alternaria*, *Pythium* and *Phomopsis* spp.

Table 5.6. Some Commercial Products of *Trichoderma* spp. as Bio-Fungicides.

Commercial Product	*Trichoderma* spp.	Company Name	Target Fungi
Trianum-P (WP) Trianum-G	*Trichoderma harzianum* strain T22	Koppert	Soil-borne fungi that cause root rot and wilting, such as: *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani* and *Sclerotinia rolfsii*
Biocontrol T34 WP	*Trichoderma asperellum* strain T34	Fargro, uk. Biocontrol Tec., Spain	Soil-borne fungi such as: *Fusarium oxysporum*
Promot WP	*Trichoderma harzianum* *Trichoderma koningii*	JH Biotech, Inc., USA	Soil-borne fungi that cause root rot and wilting, such as: *Pythium* spp., *Rhizoctonia solani*, *Fusarium solani* and *Sclerotium rolfsii*
PlantGard WG	*Trichoderma harzianum* *Trichoderma polysporum*	BINAB Bio-Innovation AB, Sweden	White rot in onions and garlic. Downy mildew and purple blight. *Fusarium wilt* (*Fusarium* spp.).
Bio-Cure-F	*Trichoderma viride*	Stanes, India	Soil-borne fungi that cause root rot and wilting, such as: *Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp., *Botrytis cinerea*, *Sclerotium rolfsii* and *Sclerotinia homoeocarpa*

- **Methods of Treatment with *Trichoderma* Fungi**

Several methods can be employed to treat plants with *Trichoderma* bio-fungicide to combat pathogenic fungi:

» Nursery Application: *Trichoderma* can be mixed with peat moss at a ratio of 1 kg per 500 kg of peat moss for use in nurseries.

» Compost Treatment: It can be applied by spraying onto compost piles or directly onto the soil surface after compost has been added.

» Irrigation: *Trichoderma* can be applied through drip irrigation systems by mixing it with the irrigation water for efficient delivery to plant roots.

» Fruit Protection: To protect fruits from rot caused by Botrytis fungus, *Trichoderma* can be sprayed at a rate of 85 g per 100 liters of water.

» Soil Application: *Trichoderma* can be incorporated into the soil by watering around plants to protect against diseases like root rot, stem ulcers, or wilting. The recommended application rate is 1.5 kg per hectare.

» Potato Seed Treatment: *Trichoderma* can be used as an alternative to chemical fungicides for treating potato seeds, helping to prevent soil-borne fungi such as black scurf caused by *Rhizoctonia solani*. The recommended application rate is 1-2 kg of *Trichoderma* per 500-1000 kg of potato seeds.

5.1.1.6 Bio-Nematicides

Bio-Nematicides are commercially produced microorganisms, including fungi and bacteria, specifically designed to combat nematodes. These bio-nematicides are widely used in organic agriculture to manage nematode infestations without harming the environment. Table 5.7. presents some examples of commercial Bio-Nematicide preparations that can effectively control nematodes in organic agriculture.

5.1.1.7 Bio-Herbicides

Bio-Herbicides are microorganisms, primarily fungi and bacteria, that are commercially produced for weed control. These bio-herbicides offer an environmentally friendly alternative to chemical herbicides. Table 5.8. showcases examples of commercial Bio-Herbicide preparations that are commonly used to manage weeds in organic agriculture.

5.1.1.8 Anti-viral Biopesticides

Anti-viral biopesticides consist of microorganisms that are commercially produced to target specific plant viruses. In organic agriculture, these biopesticides help control viral infections by inhibiting their growth or spread, thus minimizing the damage to crops. Table 5.9. lists some of the commercially available anti-viral biopesticides that are effective in managing plant viruses in organic agriculture.

Table 5.7. Some Commercial Products of Bio-Nematicides.

Bio-Nematicides	Commercial Product	Company Name	Target Nematodes
1. Fungi			
Myrothecium verrucaria	*DiTera	Abbott	Plant parasitic nematodes, such as: Root-knot nematodes, Cyst Nematodes, and Burrowing nematodes.
***Paecilomyces lilacinus* (Strain 251)**	*Bio-Nematon *MeloCon WG	Stanes, India Certis, USA	Plant parasitic nematodes, such as: Root-knot nematodes, Cyst Nematodes, and Burrowing nematodes.
2. Bacteria			
Pasteuria usage	*Econem	Pasteuria Bioscience, Inc.	Sting Nematodes on turfgrass: *Belonolaimus longicaudatus*
Pasteuria nishizawae	*Clariva	Syngenta	Cyst nematode on soybean & sugar beet: *Heterodera glycines* *Heterodera schachtii*

Table 5.8. Some Commercial Products of Bio-Herbicide.

Bio-Herbicides	Commercial Product	Company Name	Target Nematodes
1. Fungi			
Chondostereum purpureum	*Biochon *Chontrol	Koppert	Used in forests to prevent the growth of some unwanted plants.
2. Bacteria			
Pseudomonas gladioli	*AM 301 *Camperico	Japan Tobacco Microgen	Used to combat *Poa annua* L. on turfgrass.

Table 5.9. Commercial Product of Anti-Viral Biopesticides.

Anti-viral	Commercial Product	Company Name	Target Nematodes
Zucchini yellow mosaic virus (weak strain).	*Curbit	Bio-Oz Biotechnologies,Ltd	Zucchini yellow mosaic virus in zucchini, cantaloupe, and watermelon.

5.1.2 Biochemical Pesticides

Biochemical pesticides are derived from the fermentation processes of certain soil microorganisms. Since the early 1980s, many of these pesticides have been commercially produced on a large scale through the fermentation of these microbes. Examples include Abamectin, an insecticide and miticide, and Spinosad, another widely used insecticide.

In addition to insecticides, certain antibiotics have proven effective in controlling plant diseases and are commercially utilized for this purpose. For example, Streptomycin and Terramycin are commonly used to treat diseases such as fire blight on apples and pears, caused by specific bacteria. These antibiotics are also effective against infections caused by mycoplasma, particularly in peaches and cherries. For date palms, they are used in the treatment of Al Wijam disease, where a concentration of 100 ppm or 20 grams per tree is applied. This treatment is generally performed three times a year, with two-month intervals between applications, ideally when temperatures range between 20°C and 30°C.

This group of pesticides is effectively used in various pest control programs across a wide range of crops, including vegetables and fruit trees.

Botanical pesticides are also classified as biochemical pesticides. Some of the most important examples include Nicotine, Azadirachtin extract, Pyrethrum, Rotenone, Ryania, and others.

It is important to note that biochemical pesticides, including botanical pesticides, are classified as Reduced Risk Products. These products are registered in the Green Chemicals group by the US Environmental Protection Agency (EPA) and are considered more environmentally friendly than conventional pesticides. Despite their lower toxicity to humans, caution must still be exercised when handling and applying these biochemical pesticides. Prolonged exposure or misuse can still lead to adverse effects. Therefore, it is essential to follow proper safety measures, including the use of personal protective equipment (PPE), during application to ensure safe and effective use.

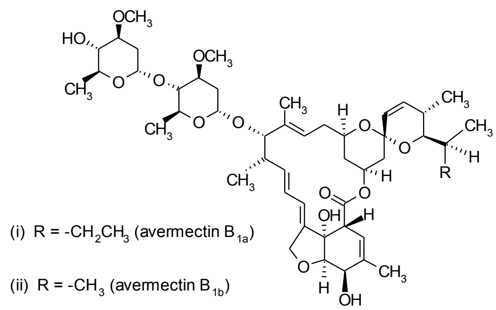
Furthermore, most pesticides in this group are compatible with the release of beneficial parasites and predators used in biological control programs. These pesticides preserve beneficial organisms, making them highly effective in Integrated Pest Management (IPM) strategies, particularly those incorporating the release of beneficial organisms. Many of these biochemical pesticides are also approved for use in organic farming systems.

The following are examples of widely commercially produced biochemical pesticides approved for use in organic farming systems:

5.1.2.1 Fermentation Products

- **Abamectin**

Microbial "Insecticide and Acaricide"



Abamectin, a Bio-pesticide, is derived from the fermentation of soil actinomycetes, particularly *Streptomyces* avermitilis, which naturally occur in soil. It is highly effective against the mobile stages of pests such as mites, leaf miners, beetles, and certain ants, including fire ants (Solenopsis spp.). Commercially, it is available in Emulsifiable Concentrate (EC) or Ready for Use Bait (RB) forms. Abamectin is sold under brand names like Vertimec, Dynamec, Avid, Agri-Mek, Silsau, and Abacide.

Abamectin demonstrates limited systemic activity in plants, primarily being absorbed through the roots, stems, or leaves. When pests ingest treated plant material, the bio-pesticide targets their nervous system, inducing paralysis within hours. This paralysis is irreversible, and affected pests typically die within three to four days.

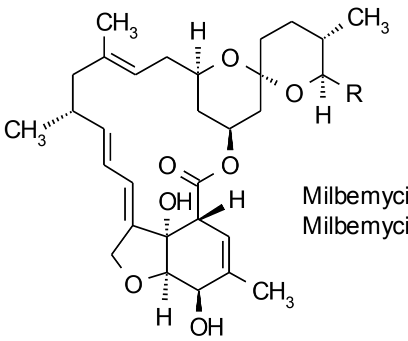
Abamectin is widely used to control mites, sucking insects, and leaf miners across various crops, including vegetables, fruits, beans, and nuts. According to the Environmental Protection Agency (EPA), Abamectin is categorized in the fourth toxicity group, indicating relatively low toxicity for humans. The toxicity estimations are as follows:

Acute oral (LD_{50}): rats 10, mice 13.6 mg/kg.

Acute dermal (LD_{50}): rabbit > 2,000 mg/kg.

- **Milbemectin**

Microbial “Acaricide, Insecticide and Nematicide”



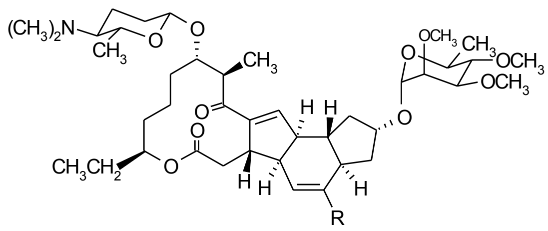
Milbemectin is a bio-pesticide produced through the fermentation of the soil actinomycete *Streptomyces* hygroscopicus subsp. aureolacrimosus (Jensen) Waksman and Henrici. It consists of a mixture of two compounds: milbemycin A3 (25-35 %) and milbemycin A4 (65-75 %). Its mode of action involves contact and stomach toxicity, where it targets the nervous system of pests by acting as an allosteric modulator of the glutamate-gated chloride channel (GluCl). This disrupts chloride ion flow in nerve and muscle cells, leading to paralysis and death of the pest. Milbemectin is highly effective against a range of pests, including spider mites, tarsonemid mites, leaf miners, and pinewood nematodes. It is commercially formulated as an Emulsifiable Concentrate (EC) under the brand name Milbeknock. Its target crops include soft fruits such as strawberries, blackberries, currants, raspberries, and gooseberries; tree fruits like apples, pears, cherries, and plums; citrus fruits including oranges; vegetables like eggplant; and various ornamental plants. Milbemectin's toxicity is estimated as follows:

Acute oral (LD_{50}): 762 in male rats and 456 mg/kg in female rats.

Acute dermal (LD_{50}): > 5,000 mg/kg in male and female rats.

- **Spinosad**

Microbia Insecticide



spinosyn A, R = H- spinosyn D, R = CH_3-

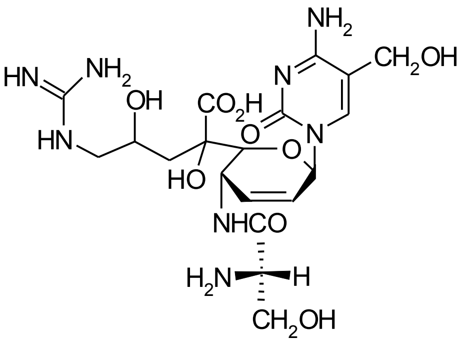
The commercial compound Spinosad consists of two primary chemicals: spinosyn A (50-95 %) and spinosyn D (5-50 %), both of which are by-products of the fermentation processes of the actinomycete *Saccharopolyspora spinosa*. The mode of action of Spinosad involves both contact and stomach action. When applied, it stimulates the insect nervous system, leading to involuntary muscle contractions and eventual paralysis in the target pests. Spinosad is widely used to control a variety of pests, including caterpillars, leafminer, thrips, and foliage-feeding beetles. It targets a broad range of crops such as onions, leeks, corn, sweetcorn, maize, lettuce, leafy vegetables, potatoes, eggplants, peppers, tomatoes, celery, grapes, cane fruits, berries, currants, as well as herbs and edible flowers. Additionally, Spinosad is highly effective in managing several pests affecting date palms, including the greater date moth (*Arenipses sabella*), lesser date moth (*Batrachedra amydraula*), larvae of the genus (*Ephestia* spp.), and the pomegranate butterfly (*Virachola livia*). Commercially, Spinosad is available as a Suspension Concentrate (SC) under brand names such as Tracer and Conserve Its toxicity estimation is as follows:

Acute oral (LD_{50}): 3,783 in male rats and > 5,000 mg/kg in female rats.

Acute dermal (LD_{50}): > 5,000 mg/kg in rabbits.

- **Mildiomycin**

Microbial Fungicide



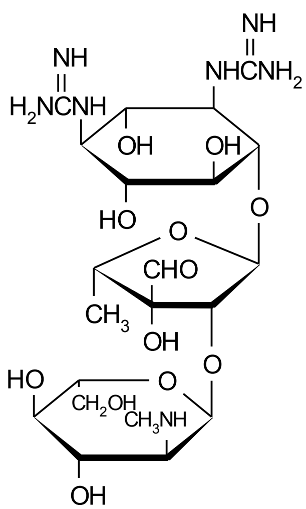
Mildiomycin is a naturally occurring substance produced by the soil actinomycete Strepto*verticillium rimofaciens* strain B-98891. It is commercially produced through controlled fermentation processes. Mildiomycin is specifically effective against powdery mildew, making it a valuable tool in combating this fungal disease. It is typically formulated as a Wettable Powder (WP) and applied as a foliar spray. Commercially, Mildiomycin is available under brand names like Mildiomycin WP. The estimated toxicity for Mildiomycin is as follows:

Acute oral (LD_{50}): 4,300 mg/kg in male rats and 4,120 mg/kg in female rats.

Acute dermal (LD_{50}): > 5,000 mg/kg in male and female rats.

- **Streptomycin**

Microbial bactericide



Streptomycin is an antibiotic produced through the fermentation of the soil bacterium *Streptomyces griseus*. It is widely used in agriculture to combat the growth of bacteria, fungi, and algae across a broad range of crops. Streptomycin is particularly effective against bacterial diseases such as bacterial shot-hole, bacterial rots, bacterial canker, bacterial wilts, and fire blight. Its target crops include fruits (e.g., apples, pears, stone fruit, and citrus), olives, vegetables (e.g., beans and peppers), potatoes, cotton, ornamentals, and others.

In addition to its agricultural uses, streptomycin is employed as a bactericidal antibiotic for medical purposes. A notable application in agriculture is its use in controlling Al Wijam disease on date palms, achieved by injecting palms with a 100 ppm solution or applying 20 grams per tree via foliar spray. Streptomycin is particularly effective against the following bacterial species: *Xanthomonas oryzae* Dows., *X. citri* Dows., *Pseudomonas tabaci* Stevens and *P. lachrymans* Carsner.

Commercial formulations of streptomycin include Wettable Powder (WP), Pellets, and Emulsifiable Concentrate (EC). It is sold under various brand names, such as Agrimycin 17, AS-50, Plantomycin, and Paushamycin. According to the US Environmental Protection Agency (EPA), streptomycin falls into the fourth toxicity group, indicating relatively low toxicity. The toxicity estimates for streptomycin are as follows:

Acute oral (LD_{50}): >10,000 mg/kg in mice.

Acute dermal (LD_{50}): 400 in male mice and 325 mg/kg in female mice.

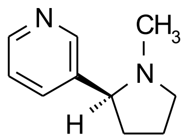
5.1.2.2 Botanical Pesticides

Botanical pesticides are derived from natural plant sources and offer an environmentally friendly alternative to synthetic chemical pesticides. These pesticides are composed of plant extracts or compounds with insecticidal, fungicidal, or herbicidal properties. Examples include nicotine, extracted from tobacco plants; pyrethrins, derived from chrysanthemum flowers; and neem oil, obtained from the seeds of the neem tree.

Botanical pesticides act through various mechanisms, such as disrupting the nervous system of insects, interfering with their growth and development, or acting as repellents. Although they are considered safer for beneficial insects like pollinators and natural predators, their use still requires careful application to avoid harm to non-target organisms and the environment.

To maximize the effectiveness of botanical pesticides while minimizing risks, proper handling, formulation, and application methods are essential. Below are examples of plant-derived pesticides.

- **Nicotine**

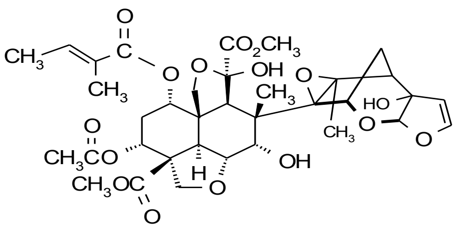


Nicotine is extracted from tobacco plants, specifically from the species *Nicotiana rustica* L. The name "nicotine" and the genus Nicotiana are derived from Jean Nicot, a French diplomat who introduced tobacco to Europe from Spain and Portugal in the 16th century. Nicotine is effective against various insects like aphids, thrips, and whiteflies on crops including vegetables, fruits, and ornamentals. It is available in various forms, such as dispersible powders (DP), soluble concentrates (SL), and in smokers, under trade names like Nico Soap, XL-All Nicotine, and Nicotine 40 % Shreds.

Nicotine is a non-systemic insecticide that acts upon contact and ingestion, functioning as a neurotoxin. It is effective against pests but must be handled carefully due to its high toxicity at elevated concentrations. While it is generally non-toxic to humans in low doses, exposure to high levels through inhalation or skin absorption can be lethal. The estimated lethal oral dose for humans is 40 to 60 mg. The toxicity of nicotine is estimated as follows:

Acute oral (LD_{50}): 50 – 60 mg/kg in rats.
Acute dermal (LD_{50}): 50 mg/kg in rabbits.

- **Azadirachtin (Neem Oil)**



Azadirachtin (Neem Oil) is a well-known natural pesticide widely used in organic agriculture due to its broad-spectrum insecticidal, fungicidal, and nematicidal properties. Extracted from the seeds of the neem tree (*Azadirachta indica* A. Juss), native to Burma and now cultivated worldwide, neem oil contains compounds such as azadirachtin, nimbin, and salannin, which disrupt the life cycle of many pests.

Azadirachtin, the primary active compound in neem oil, works by disrupting the hormonal systems of insects, preventing them from feeding, molting, mating, and laying eggs. This mode of action makes neem oil particularly effective against soft-bodied insects such as aphids, whiteflies, mealybugs, thrips, caterpillars, scale insects, rosy apple aphid (*Dysaphis plantaginea*), woolly apple aphid (*Eriosoma lanigerum*), plant mites, and pear psylla (*Cacopsylla pyricola*).

Additionally, neem oil acts as a natural insect repellent and anti-feedant. Pests such as beetles, ants, and certain types of moths are deterred from feeding on treated plants due to the oil's bitter taste and strong odour. Beyond its insecticidal properties, neem oil is also effective against fungi such as *Fusarium* spp., *Aspergillus flavus*, and *Botryodiplodia theobromae*. It excels at inhibiting mycelial growth and reducing spore germination rates, particularly in stored grains and pears. Azadirachtin also helps limit the spread of seed-borne fungi while enhancing germination rates.

Neem oil can be diluted and sprayed directly on plants to protect them from pests. A common dilution is 5-10 ml of neem oil mixed with 1 liter of water, along with a few drops of soap as an emulsifier. The spray should be applied to the leaves, stems, and soil to control a variety of insects. Regular applications are essential, as the oil must come into contact with pests to be effective. Neem oil should be applied every 7-14 days, depending on pest pressure, and more frequently in cases of heavy infestations. It's important to avoid spraying during extreme temperatures to prevent plant stress.

Neem oil is also effective against certain fungal diseases such as powdery mildew, black spot, rust, and downy mildew. By inhibiting fungal spore growth, it serves as a useful preventive measure for fungal infections in crops. Neem oil can also be used as a soil drench to control root-knot nematodes and other soil-dwelling pests, disrupting their life cycle and reducing their populations over time.

Neem oil is non-toxic to beneficial insects such as bees, ladybugs, and butterflies when applied correctly. Since it primarily affects insects that feed on plant tissue, pollinators and other beneficial organisms remain unharmed if the oil is applied in the evening or early morning, when beneficial insects are less active.

Neem oil is also partially systemic, meaning it can be absorbed by plants and distributed through their tissues, providing protection even after the oil on the surface has degraded.

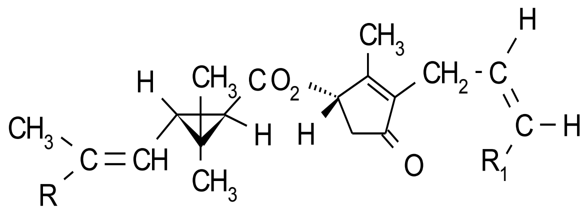
In general, neem oil is safe for humans, animals, and the environment when used at recommended concentrations. It degrades quickly in the environment, minimizing the risk of contamination, and is widely used in organic farming for its eco-friendly properties.

Commercially, Azadirachtin is available in various formulations, including emulsifiable concentrates (EC) and crude extracts, and is marketed under brand names such as Neemix 90 EC, Neemazid, Thermo Trilogy, Azatin, Bio-neem, and NeemAzal. The Environmental Protection Agency (EPA) classifies Azadirachtin as having very low toxicity to mammals and humans, placing it in the least toxic category, with the following toxicity estimates:

Acute oral (LD_{50}): > 5,000 mg/kg in rats.

Acute dermal (LD_{50}): > 2,000 mg/kg in rabbits.

- **Pyrethrum (Pyrethrins)**



R = $-CH_3$ or $-CO_2CH_3$

R_1 = $-CH{=}CH_2$ or $-CH_3$ or $-CH_2CH_3$

Since ancient times, dried powder from the flower heads of *Chrysanthemum cinerariaefolium* (now classified under the genus *Tanacetum*) has been used as an insecticide. Initially known as "Persian Insect Powder," this species was introduced from China to Persia via the Silk Road. By the 19th century, its cultivation had spread to coastal areas of the Adriatic, and later to France, the United States, and Japan. Today, *Tanacetum cinerariaefolium* is widely cultivated in East Africa (particularly Kenya), Ecuador, New Guinea, and Australia.

Pyrethrum, extracted from the flower heads of *Tanacetum cinerariaefolium*, is used to control a broad range of insects and mites on various crops, including fruit trees and vegetables. It functions as a contact insecticide and is non-systemic. The toxic mechanism of Pyrethrum involves binding to sodium channels in insects, causing rapid paralysis and eventual death. This process is characterized by a "knockdown" effect followed by mortality.

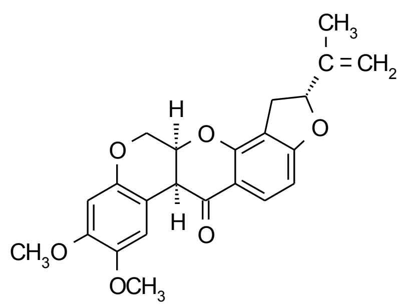
Commercial preparations of Pyrethrum are available in several forms, including Aerosol Dispensers (AE), Dispersible Powders (DP), Fogging solutions, Ultra-Low Volume liquids (ULV), and Emulsifiable Concentrates (EC). These formulations are marketed under numerous brand names such as Alfadex, Pyrocide, Evergreen, Milon, CheckOut, Pycon, and ExciteR.

Natural pyrethrum preparations, derived from pyrethrum flowers without the addition of synergists like piperonyl butoxide, are approved for use in organic agriculture. Pyrethrum is relatively low in toxicity to mammals and humans and is classified in the third toxicity group by the Environmental Protection Agency (EPA). Its toxicity is outlined as follows:

Acute oral (LD_{50}): 2,370 mg/kg in rats.

Acute dermal (LD_{50}): 5,000 mg/kg in rabbits.

- **Rotenone**



Rotenone is a natural pesticide derived from certain plants in the family Leguminosae, native to the Far East (Philippines, Malaysia) and the Amazon Valley of South America. It is extracted primarily from the roots of species in the genera *Tephrosia*, *Derris*, and *Lonchocarpus*, with *Derris elliptica* serving as a major commercial source. Rotenone acts as both a stomach poison and a contact insecticide, effectively controlling a wide range of pests including aphids, thrips, caterpillars, mosquito larvae, ticks, and fleas on animals.

When used at normal concentrations for pest control, rotenone is considered relatively harmless to humans and animals. However, it is highly toxic to fish and has traditionally been used as a fish poison in parts of Asia and South America.

Rotenone is typically applied as a spray or fog, requiring thorough coverage of plant surfaces for effective pest control. For fogging, rotenone powder is diluted with carriers like talcum powder, gypsum, or sulfur, with the powder typically containing 4-5 % of the active ingredient.

Commercial formulations of rotenone are available in different forms, such as Dispersible Powders (DP), Emulsifiable Concentrates (EC), or Wettable Powders (WP). It is marketed under various trade names including Cube Root, Rotenone Extract, Noxfire, and Rotenone FX-11.

The estimated lethal dose of rotenone for humans ranges from 300 to 500 mg per kilogram of body weight. Inhalation of rotenone is more toxic than ingestion, and it is particularly toxic to pigs. Its toxicity is outlined as follows:

Acute oral (LD_{50}): 132 – 1,500 mg/kg in white rats.

Acute dermal (LD_{50}): 350 mg/kg in white mice.

- **Ryania**

Ryania is a botanical pesticide derived from the bark and roots of the tropical plant *Ryania speciosa*, a member of the family Salicaceae. Native to the West Indies and tropical South America, *Ryania speciosa* has traditionally been used in these regions for pest control due to its natural insecticidal properties.

The primary active compound in Ryania is an alkaloid called ryanodine. This compound exerts toxic effects on insects by disrupting calcium ion channels in their muscle cells, causing prolonged muscle contraction, paralysis, and eventual death. By targeting both the nervous and muscular systems, Ryania is particularly effective in controlling various pests.

Ryania is primarily effective against a variety of caterpillars and other insects that feed on fruits and vegetables. Its target pests include Codling moth (*Cydia pomonella*), European corn borer (*Ostrinia nubilalis*), Fruit tree pests such as leaf rollers and budworms and Sugarcane borer (*Diatraea saccharalis*). Ryania is most effective against caterpillars and lepidopteran pests, but it may be less effective against other insect types, such as beetles or aphids.

Ryania acts as both a contact and stomach poison. Once ingested or absorbed, ryanodine disrupts calcium ion channels in the insect's body, leading to prolonged muscle contraction, paralysis, and eventual death.

Commercially, Ryania is available under various brand names, including Natur-Gro R-50, Natur-Gro Triple Plus, and Ryan 50. It is typically formulated as a wettable powder (WP), dust, or soluble (liquid) concentrate (SL) for application to crops. Depending on the target pest and crop, Ryania can be applied as a foliar spray or directly to the soil around plant roots.

Ryania is classified by the U.S. Environmental Protection Agency (EPA) in the third toxicity group, indicating relatively low toxicity to mammals and humans. The acute oral (LD50) for rats is estimated to be 1,200 mg/kg. Despite its low toxicity, proper handling and application are still essential to minimize exposure.

Ryania degrades relatively quickly in the environment, reducing the risk of long-term contamination in soil or water. It is permitted for use in organic agriculture in some countries, provided it meets specific regulatory standards.

5.1.2.3 Plant Oils

Vegetable oils, such as orange oil, canola oil, mustard oil, castor oil, soybean oil, and neem oil, are approved by the US Environmental Protection Agency (EPA) for use in organic farming. These oils are effective organic pesticides against various insect pests and plant mites, and they can also be used to repel larger animals like cats, dogs, or deer. These versatile oils play a key role in organic pest control strategies. Below are examples of some commonly used plant oils:

- **Mustard Oil**

Mustard oil can be used as a natural pesticide in organic agriculture due to its strong insecticidal properties. It contains compounds such as glucosinolates and allyl isothiocyanate, which are effective in repelling or killing various insect pests, particularly soft-bodied insects like aphids, whiteflies, mites, and nematodes. It is also effective against Lepidopteran larvae on different crops.

One method for using mustard oil as a pesticide is through direct application. Mustard oil can be diluted with water and sprayed directly onto plants. A common mixture is 10-15 ml of mustard oil in 1 liter of water. Alternatively, a mixture of mustard oil and soap can be prepared for better control of insect pests. A typical mixture consists of 750 ml of mustard oil and 250 ml of soap, creating a liter of mustard oil solution. This solution is then applied by spraying 500 ml per 100 liters of water onto affected plants. This spray is effective against aphids, mites, and other small insects. It can be applied to leaves, stems, and the surrounding soil to deter pests.

Mustard oil can also be used as a soil treatment for root pests such as nematodes. When incorporated into the soil, the oil breaks down and releases isothiocyanates, which have nematicidal properties, helping to reduce the population of root-knot nematodes and other soil pests.

In addition, mustard oil can be combined with other natural pest repellents like neem oil, garlic extract, or chili extract to enhance its effectiveness. These combinations create a more potent deterrent for a broader range of pests.

The strong odour of mustard oil also acts as a natural repellent, discouraging pests like ants, termites, and certain species of beetles from attacking plants. The repellent effect can be enhanced by regularly applying the oil around the base of plants or in pest-prone areas.

As a natural product, mustard oil is non-toxic to humans and animals when used in appropriate concentrations. It biodegrades easily in the environment, making it an ideal option for organic farming systems that aim to minimize chemical residues. However, its effectiveness as a pesticide may vary depending on the pest species and environmental conditions. Regular application and proper dilution are crucial to avoid phytotoxic effects on plants and ensure optimal results.

- **Eucalyptus Oil (*Eucalyptus globulus*)**

Eucalyptus oil is an effective natural pesticide with broad-spectrum repellent and insecticidal properties, making it highly useful in organic agriculture. Derived from the leaves of Eucalyptus globulus, eucalyptus oil is widely known for its aromatic properties, but it also plays a significant role in pest control and disease management. The leaves of the eucalyptus plant contain volatile oils, primarily cineole (eucalyptol), which makes up 54-95 % of the oil. Other compounds, such as tannins, flavonoids, and triterpenes, also contribute to its pesticidal effectiveness. Additionally, eucalyptus oil exhibits antibacterial properties, particularly against Gram-negative bacteria, making it useful in combating bacterial infections in plants.

Eucalyptus oil's strong odour and chemical composition make it an excellent repellent against pests such as mosquitoes, flies, fleas, cockroaches, ants, and mites. The oil disrupts the sensory receptors of insects, making treated plants or areas unattractive to pests. It is also toxic to certain pests, particularly soft-bodied insects like aphids, whiteflies, and spider mites. The oil works by suffocating the insects and disrupting their nervous systems, effectively killing them on contact.

A common method for using eucalyptus oil as a pesticide is by creating a spray. Typically, 10-15 ml of eucalyptus oil is mixed with 1 liter of water, with a few drops of soap added to help emulsify the oil. This solution can be sprayed directly onto plant leaves, stems, and the surrounding soil to deter and kill pests. It is important to reapply the spray every 7-10 days, or after rain, to maintain its effectiveness.

Eucalyptus oil can also be used as a soil treatment to repel soil-dwelling pests such as ants, termites, and root-feeding insects. When mixed with water and applied as a soil drench, the oil helps create a barrier that deters pests from attacking plant roots. Additionally, eucalyptus oil is effective in managing soil-borne fungal diseases such as root rot caused by *Rhizoctonia solani* or *Fusarium solani*. When added to the soil, eucalyptus leaf powder or extracts can inhibit fungal mycelial growth and reduce spore germination rates. It is also effective against powdery mildew and leaf spot, which attack various plants. When applied as a spray, it inhibits fungal growth and helps protect plants from infections.

Eucalyptus oil is generally non-toxic to beneficial insects like bees and ladybugs when applied correctly. It primarily affects pests that come into direct contact with the oil, leaving pollinators and other helpful insects unharmed when used in low concentrations and applied during times when these insects are less active, such as early morning or late evening. Eucalyptus oil can also be combined with other natural pesticides such as neem oil, garlic oil, or chili extract to enhance its effectiveness. These combinations can help control a broader range of pests while remaining safe for organic farming.

As a natural product, eucalyptus oil is safe for humans, animals, and the environment when used in appropriate concentrations. It is biodegradable and breaks down quickly in the soil, making it a suitable option for organic and environmentally conscious farming. As a result, eucalyptus oil serves as a versatile tool in organic agriculture, offering both antimicrobial and insect-repellent benefits for effective pest and disease management.

However, eucalyptus oil is potent and may cause phytotoxicity in some plants, especially when used in high concentrations. It is advisable to test the mixture on a small section of the plant before applying it widely. Proper dilution is essential, as excessive concentrations can damage plant leaves or interfere with growth. Overall, eucalyptus oil is an effective, natural, and environmentally friendly solution for controlling pests and protecting plants in organic agriculture.

- **Biomite (Miticide)**

Biomite is an effective and environmentally friendly solution for managing mites and soft-bodied insects in organic agriculture. It offers pest control while maintaining the safety of beneficial organisms, making it a valuable tool in sustainable agriculture.

Biomite, produced by the Organic Materials Review Institute (OMRI) in the USA, is a minimum-risk biochemical miticide approved for use in organic agriculture. It effectively controls various plant mites, including Two-Spotted Mites (*Tetranychus urticae*), Pacific Spider Mites (*Tetranychus pacificus*), Willamette Spider Mites (*Eotetranychus willamettei*), Citrus Rust Mites (*Phyllocoptruta oleivora*), Broad Mites (*Polyphagotarsonemus latus*), and European Red Mites (*Panonychus ulmi*). It may also target small soft-bodied insects like aphids, whiteflies, and thrips.

The active ingredients in Biomite include Geraniol, Citronellol, Nerolidol, Farnesol, and other natural compounds. These ingredients work synergistically to disrupt the life cycle of mites, preventing infestations. Biomite should be applied as soon as mites are identified on plants or when conditions favor mite outbreaks. It is most effective in cooler conditions early in the season and works best on low to moderate infestations. One of Biomite's key advantages is its novel mode of action, which inhibits mites from developing resistance. It can be used on a wide variety of crops, including apples, cucurbits, grapes, hops, nuts, pears, stone fruits, nursery crops, and ornamentals, making it a versatile solution for organic farming.

Biomite works primarily through physical contact. It suffocates mites and other pests by disrupting their cell membranes or blocking their respiratory systems, leading to desiccation and death. Unlike synthetic pesticides, Biomite does not rely on chemical toxins, making it safer for the environment.

Biomite is usually applied as a foliar spray, either alone or in combination with other natural products. For maximum effectiveness, the product must make direct contact with the pests, so thorough coverage of the plant, including the undersides of leaves, is essential. Biomite is typically diluted with water according to the manufacturer's recommendations and often mixed with a surfactant to ensure even coverage on plant surfaces.

One of the major advantages of Biomite is its minimal impact on beneficial insects like bees, ladybugs, and predatory mites. This makes it an ideal choice for integrated pest management (IPM) programs, where preserving beneficial insect populations is crucial. Biomite is biodegradable and breaks down quickly in the environment, reducing the risk of residues in soil or water. It is also safe for use around humans, pets, and wildlife when applied according to guidelines.

- **Garlic Oil**

Garlic oil is a highly effective natural pesticide widely used in organic agriculture for its broad-spectrum repellent and insecticidal properties. It is rich in sulfur compounds, particularly allicin, which acts as both a deterrent and a toxin to various pests. In addition to sulfur, garlic oil contains volatile oils, enzymes, carbohydrates (such as sucrose and glucose), and essential minerals like selenium. It also includes amino acids such as cysteine, glutamine, isoleucine, and methionine. Furthermore, garlic oil is a good source of vitamins C, E, A, niacin, B1, B2, and beta-carotene, which help protect plants against oxidative damage.

The strong odour of garlic oil effectively repels a wide range of pests, including aphids, ants, mosquitoes, beetles, and caterpillars by disrupting their sensory receptors, making plants less attractive to them. Additionally, garlic oil has antifungal properties and can be used to manage fungal diseases such as powdery mildew and downy mildew. The sulfur content inhibits fungal spore germination, making it a valuable preventive measure against fungal infections in crops.

Garlic extract is also potent against numerous plant pathogens, particularly those affecting the vegetative system. It effectively combats bacterial and fungal pathogens like *Pseudomonas phaseolicola*, *Xanthomonas* spp., *Pyricularia oryzae*, *Colletotrichum* spp., *Pseudoperonospora cubensis*, and *Monilia fructicola*.

Garlic oil is typically diluted with water and applied as a foliar spray to protect plants from pests. A typical mixture consists of 10-20 ml of garlic oil in 1 liter of water, often combined with a few drops of dish soap as an emulsifier to help the oil spread evenly across plant surfaces. This spray can be applied to leaves, stems, and surrounding soil to repel pests. It can also be applied to the soil to control soil-dwelling pests like nematodes and root-feeding insects, as the sulfur compounds in garlic oil are toxic to these pests and can reduce their populations with regular application. To maintain its effectiveness, garlic oil spray should be reapplied every 7-10 days, especially after rain or heavy dew, as the odour fades over time.

Garlic oil can be combined with other natural pesticides such as neem oil, chili extract, or pyrethrin to create a more potent treatment. This mixture helps target a broader range of pests and increases the effectiveness of pest control. It is non-toxic to humans, animals, and beneficial insects when used at appropriate concentrations.

While garlic oil is generally safe for plants, some sensitive species may experience leaf burn if applied at high concentrations. Therefore, it is important to test the mixture on a small area of the plant before full-scale use. Garlic oil biodegrades quickly in the environment, making it a sustainable and eco-friendly solution for pest and disease management in organic agriculture.

- **GC-Mite**

GC-Mite is a natural miticide and insecticide commonly used in organic agriculture to manage mite populations and control soft-bodied insects. It is an environmentally friendly solution that targets pests such as spider mites, broad mites, russet mites, and other soft-bodied insects like aphids and whiteflies. Made from natural ingredients, GC-Mite is a suitable option for organic farming systems, as it minimizes harm to beneficial organisms and the environment. It is typically certified for use in organic farming by organizations such as the Organic Materials Review Institute (OMRI).

Applied as a foliar spray, GC-Mite is a valuable addition to well-managed Integrated Pest Management (IPM) programs. Composed of 100 % organic components, it ensures no toxic effects on humans or animals. The active ingredients in GC-Mite include cottonseed oil (40 %), clove oil (20 %), garlic extract (10 %), oleic acid (2 %), lauric acid (1 %), sodium bicarbonate (2 %), and water (25 %). This combination of ingredients works synergistically to target and control mite and insect populations while being environmentally friendly and safe for organic agriculture.

GC-Mite kills pests by physical contact. It coats the pests, blocking their respiratory systems and disrupting their cellular structures, leading to rapid death. Unlike chemical pesticides, it does not rely on poisoning the pests, but instead on physical effects, reducing the likelihood of resistance development. GC-Mite is particularly useful for controlling mite infestations in crops such as tomatoes, cucumbers, peppers, strawberries, and ornamental plants.

GC-Mite is primarily applied as a foliar spray. It should be diluted with water according to the manufacturer's instructions, and thorough coverage of the plant is essential for maximum effectiveness. Special attention should be paid to the undersides of leaves, where mites and insects typically reside. It can also be combined with other natural pest control products such as neem oil or insecticidal soap to enhance its effectiveness. For optimal results, GC-Mite is usually applied every 7-10 days, depending on the severity of the infestation and environmental conditions.

- **EcoTrol EC**

EcoTrol EC is a versatile botanical insecticide/miticide designed for use in organic agriculture to control a wide range of mites, soft-bodied insects, and other pests. These include spider mites, broad mites, rust mites, aphids, thrips, whiteflies, diamondback moths, cabbage loopers, fall armyworms, beet armyworms, and other pests that attack crops such as fruits, nuts, vegetables, ornamentals, landscapes, turf, greenhouses, and nurseries.

In addition to its insecticidal and miticidal properties, EcoTrol EC has mild fungicidal effects due to the essential oils it contains, which can help manage some fungal diseases, such as powdery mildew, by preventing spore germination.

EcoTrol EC is derived from essential oils, making it a biodegradable, environmentally friendly, and non-toxic alternative to synthetic chemical pesticides. It contains the following essential oils: rosemary (10 %) and peppermint oil (2 %), with the remaining (88 %) consisting of inert ingredients. These oils act as insecticides and miticides, providing a natural method for pest control by disrupting the nervous systems of insects and suffocating them on contact. To apply EcoTrol EC, it is typically mixed with water at a rate of 1-3 liters per 100 liters of water and sprayed onto plants. This concentration allows for effective pest control while minimizing any potential negative impacts on the environment.

EcoTrol EC works by physical contact with pests. The essential oils in the formulation act as insect repellents and disrupt the normal functioning of insect nervous systems. The oils also have a suffocating effect, blocking the respiratory openings (spiracles) of the insects, leading to dehydration and death.

EcoTrol EC is applied as a foliar spray, typically diluted with water. The dilution rates are usually around 1-2 % solution (10-20 ml per liter of water), depending on the pest and crop. Thorough coverage of the plant's surface, including the undersides of leaves, is important to ensure the oil comes into contact with the pests. Applications are usually repeated every 7-10 days, especially during periods of high pest pressure or infestation.

EcoTrol EC is certified for use in organic agriculture and complies with standards set by organizations such as the USDA National Organic Program (NOP) and the Organic Materials Review Institute (OMRI). When used correctly, EcoTrol EC is considered safe for beneficial insects like bees, ladybugs, and predatory mites. The product primarily targets pests in direct contact with the spray and does not persist in the environment long enough to harm beneficial organisms.

EcoTrol EC can be combined with other organic treatments, such as neem oil or insecticidal soap, to increase its effectiveness in integrated pest management (IPM) programs. This combination allows farmers to control a broader range of pests while maintaining an organic system.

- **Sporan EC2**

Sporan EC2 is a natural, broad-spectrum contact fungicide and insecticide primarily used in organic agriculture. It is formulated from botanical ingredients, making it an environmentally friendly option for managing fungal diseases and pests across various crops, such as fruits, nuts, vegetables, ornamentals, landscapes, turf, greenhouses, and nurseries.

The active ingredients in Sporan EC2 include rosemary oil (16 %), clove oil (10 %), thyme oil (10 %), peppermint oil (2 %), and other inert ingredients (62 %). These ingredients, which also contain a blend of other essential oils and plant extracts, contribute to the product's fungicidal and insecticidal action.

Sporan EC2 effectively controls a range of specific diseases, including Botrytis gray mold in strawberries, powdery mildew in grapes and gerbera daisies, and Phytophthora late blight in tomatoes, among others. It achieves control by disrupting the cell walls of fungal spores and hyphae, thereby inhibiting fungal growth and proliferation. In addition, it possesses insecticidal properties, particularly against soft-bodied insects such as aphids, thrips, whiteflies, and mites.

Sporan EC2 is generally applied as a foliar spray, with thorough coverage of the plant being crucial for its effectiveness. Special attention should be given to the undersides of the leaves to ensure maximum contact with pests or diseases. It is recommended to apply Sporan EC2 every 7-10 days, particularly during periods of high disease pressure or pest infestations. The product can be applied at any stage, including up to the day of harvest.

The rate of application for Sporan EC2 typically depends on the target pest or disease and the level of infestation. For light to moderate infestations, lower application rates are generally sufficient, using a 1-2 % solution, which equals 10-20 ml of Sporan EC2 per liter of water. For heavy infestations, a higher concentration of 3-4 % solution is recommended, which equals 30-40 ml of Sporan EC2 per liter of water.

Sporan EC2 poses minimal risk to fish and aquatic organisms. However, it may be toxic to bees, making it crucial to avoid application during times when bees are actively foraging. As a botanical product, Sporan EC2 is considered safe for use in organic farming systems and is approved by various organic certification organizations, including the Organic Materials Review Institute (OMRI).

- **Lemongrass Oil**

Lemongrass oil is a natural, plant-based pesticide widely used in organic agriculture for its potent insecticidal and fungicidal properties. Extracted from the lemongrass plant (*Cymbopogon citratus*), the oil contains active compounds like citral, which makes up 65-85 % of the oil, along with other essential oils such as geraniol, citronella, citronellol, and myrcene.

The lemongrass plant is native to tropical and subtropical regions of Asia, including countries such as India, Sri Lanka, and Thailand. It has been cultivated for its culinary, medicinal, and aromatic properties for centuries. Today, global demand for lemongrass oil has expanded its cultivation to other regions, including parts of Africa, South America, and Central America, ensuring a steady supply for a wide range of applications, including eco-friendly pest control solutions.

Lemongrass oil is highly effective as a repellent for a variety of pests, including mosquitoes, flies, aphids, ants, whiteflies, and thrips. The strong aroma of citral in lemongrass oil disrupts the sensory receptors of insects, deterring them from feeding on or settling on treated plants. In addition to its repellent properties, lemongrass oil also has direct insecticidal effects. It can kill soft-bodied insects, such as aphids, mites, and caterpillars, on contact by disrupting their cell membranes and causing dehydration, making it an effective option for managing small pest populations.

Lemongrass extract also exhibits anti-inflammatory properties, while its volatile oil inhibits the growth of various fungi, including *Penicillium chrysogenum*, *Aspergillus fumigatus*, *Aspergillus flavus*, and *Macrophomina phaseolina*. It also demonstrates inhibitory effects against certain bacteria, such as *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Pseudomonas fluorescens*. Additionally, lemongrass powder contains glycosides, alkaloids, and tannins, which help prevent the harmful effects of microbes. Treating cowpea and corn with lemongrass powder before storage can effectively reduce microbial damage without compromising seed vitality, thereby extending safe storage periods.

Moreover, lemongrass extract inhibits the growth of fungi such as *Ustilago maydis*, *Ustilaginoidea virens*, *Curvularia lunata*, and *Rhizopus* species. It can also be used to combat plant diseases caused by fungal infections, such as *Botrytis cinerea* and *Rhizoctonia solani*.

Lemongrass oil is typically applied as a foliar spray at a rate of 5-10 ml per liter of water. A few drops of natural soap or an emulsifier can be added to ensure even distribution across plant surfaces. The spray should be applied thoroughly, covering both the tops and undersides of leaves, stems, and surrounding soil to deter or kill pests. Applications may need to be repeated every 7-10 days, particularly in areas with high pest pressure or after rainfall, as the oil may be washed off.

Lemongrass oil is considered safe for beneficial insects, such as bees and ladybugs, when applied properly. Since it works primarily through contact and as a repellent, it poses minimal risk to non-target organisms, especially if sprayed when beneficial insects are less active (early morning or late evening).

Lemongrass oil can be combined with other natural pesticides, such as neem oil, garlic oil, or insecticidal soap, to create a more potent, multi-action pest control solution. This combination can be particularly useful in integrated pest management (IPM) strategies.

Widely used in organic farming, lemongrass oil complies with organic certification standards. It is a preferred option for pest control in organic systems where synthetic pesticides are prohibited. Lemongrass oil can be used on a wide variety of crops, including vegetables, fruits, and ornamental plants.

In conclusion, lemongrass oil is an effective, natural solution for managing pests and fungal diseases in organic agriculture. Its insect-repellent, insecticidal, and fungicidal properties, combined with its excellent safety profile, make it a valuable choice for organic farmers seeking to protect their crops without compromising environmental or ecological health.

- **Basil Oil**

Basil oil, extracted from the leaves and stems of the basil plant (*Ocimum basilicum*, Family: Lamiaceae), commonly known as sweet basil, is a natural pesticide widely used in organic agriculture. It contains active compounds such as estragole, linalool, citronellol, and eugenol, which contribute to its strong insecticidal and repellent properties. Additionally, basil oil is valued in aromatherapy and traditional medicine for its medicinal benefits.

In agriculture, basil oil is recognized for its insecticidal and repellent effects against a wide range of pests, including aphids, thrips, whiteflies, mosquitoes, and caterpillars. It works by disrupting the physiology of insects, affecting their feeding behavior, growth, and reproduction. Basil oil can function as a contact insecticide, causing direct mortality upon contact, or as a repellent, deterring pests from feeding on or laying eggs on plants.

Beyond its pesticidal properties, basil oil also has antifungal and antibacterial effects, helping to control plant diseases caused by fungi and bacteria, such as damping-off, powdery mildew, and bacterial wilt. Basil oil may inhibit the growth of pathogens and suppress disease development when applied preventatively or curatively. It also acts against many seed-borne fungi, such as *Aspergillus niger* and *Fusarium moniliforme*.

Basil oil can be diluted with water and used as a foliar spray to protect plants from pests and diseases. The recommended application rate is 5-10 ml of basil oil mixed with 1 liter of water. Adding a few drops of dish soap or another natural emulsifier helps disperse the oil evenly across the plant's surface. Spray the solution on the leaves, stems, and surrounding soil, ensuring thorough coverage, especially on the undersides of the leaves where pests often hide. Reapplication may be necessary every 7-10 days or after rain. Basil oil works best when applied early in the morning or late in the evening to prevent evaporation and avoid disturbing beneficial insects.

In addition to its agricultural uses, basil oil is prized for its aromatic and medicinal properties. It is commonly used in aromatherapy for its calming and uplifting effects and in traditional medicine for its antimicrobial, anti-inflammatory, and analgesic properties.

Overall, basil oil is an effective and eco-friendly pesticide for organic agriculture, offering both insecticidal and fungicidal benefits. Its ability to repel and kill a wide range of pests while being safe for beneficial organisms makes it a valuable tool for organic farmers seeking to maintain crop health without resorting to synthetic chemicals.

- **Peppermint and Spearmint Oils**

Peppermint (*Mentha piperita*) and spearmint (*Mentha spicata*) oils are gaining popularity in organic agriculture due to their natural pesticidal, fungicidal, and repellent properties. Peppermint oil contains volatile compounds like menthol and menthone, while spearmint oil is rich in carvone and limonene.

These oils exhibit insecticidal effects when applied directly to pests, disrupting cell membranes and causing dehydration and death in soft-bodied insects such as aphids and mites. The strong aroma of menthol and other volatile compounds overwhelms the sensory systems of insects, making treated plants unattractive for feeding and reproduction. Their rapid action makes them effective in managing pest populations in an eco-friendly way.

Peppermint and spearmint oils are particularly known for their insecticidal and repellent properties against a variety of agricultural pests, including aphids, thrips, whiteflies, and beetles. They can act as contact insecticides, causing mortality upon direct contact, or as repellents, deterring pests from feeding or laying eggs on plants. These oils are often included in natural insecticide formulations or as additives in integrated pest management (IPM) programs to reduce the reliance on synthetic chemical pesticides.

Mint oils also demonstrate antifungal properties, making them effective in preventing and controlling fungal infections such as powdery mildew and rust by inhibiting spore germination and mycelial growth. This makes them valuable in managing plant diseases within organic farming systems. Additionally, peppermint and spearmint oils are known for their nematicidal properties, helping to reduce soil-dwelling pests like root-knot nematodes. Regular applications help control nematode populations without the need for synthetic chemicals.

Peppermint leaf extract affects the growth of fungi like *Aspergillus* nidulans and bacteria such as *Escherichia coli*, while peppermint volatile oil has been shown to impact the first larval instar of bollworms in cotton. Extracts from Mentha species are also commonly used against the rice blight fungus, *Rhizoctonia solani*.

These oils are typically diluted with water and applied as a foliar spray or soil drench. A common dilution rate is 5-10 ml of mint oil per liter of water, with an emulsifier added to ensure even distribution. Regular applications every 7-10 days help maintain protection, particularly in areas with high pest pressure or after rainfall.

Mint oils are non-toxic to beneficial insects like bees and ladybugs when used correctly. They degrade quickly in the environment, leaving no harmful residues, which makes them an ideal option in organic farming. Incorporating peppermint and spearmint oils into pest management practices supports environmentally friendly and sustainable agriculture by minimizing the use of synthetic chemical pesticides, preserving biodiversity, and reducing potential harm to non-target organisms.

In conclusion, *Mentha piperita* and *Mentha spicata* oils provide a natural, holistic solution for pest control in agriculture, while also offering additional benefits in aromatherapy and medicinal applications. Their versatile properties make them valuable tools in promoting organic agriculture and supporting overall well-being.

5.1.2.4 Other Plant Extracts Used for Pest Control in Organic Agriculture

The use of plant extracts for pest management aligns with the principles of sustainable and eco-friendly agriculture. Medicinal and aromatic plants such as lantana, oleander, marshmallow, eucalyptus, and datura have shown effectiveness in repelling or controlling pests, making them valuable tools in organic farming. By harnessing the natural properties of these plants, farmers can reduce reliance on synthetic pesticides, minimize environmental impact, and promote biodiversity. Integrating these plant extracts into pest management strategies strengthens agricultural resilience and contributes to the overall health and sustainability of farming ecosystems. Below are additional examples of plant extracts that can be utilized for pest control in organic agriculture:

- ***Lantana camara***

Lantana camara (family: Verbenaceae), an ornamental plant known for its vibrant flowers, has been studied for its potential as a natural pesticide due to its bioactive compounds, which exhibit insecticidal, antimicrobial, and repellent properties. Despite being an invasive species in many regions, its extracts are being explored for pest and disease control in organic agriculture.

Key bioactive compounds in *Lantana camara* include lantadenes, pentacyclic triterpenoids found in the leaves, which are toxic to a wide range of pests. Additionally, its essential oils contain terpenoids, flavonoids, and alkaloids, which are responsible for its repellent and insecticidal effects. Other compounds, such as phenolics, glycosides, and saponins, enhance its pesticidal action by disrupting insect metabolism and growth.

In organic farming, *Lantana* extracts can be prepared by soaking the plant's leaves and stems in water or alcohol to release the bioactive compounds, which are then filtered and applied as a spray. Fresh leaves can also be crushed, boiled, and used as a foliar spray. Alternatively, dried leaves can be ground into a powder and applied around plants to repel soil-borne pests or used for seed treatment. *Lantana* essential oils can also be diluted and sprayed to repel insects and inhibit fungal growth.

Lantana extracts exhibit strong repellent action against a wide range of insect pests, including mosquitoes, aphids, whiteflies, caterpillars, and mites. Its insecticidal properties allow it to kill pests upon contact or ingestion, effectively disrupting the growth and feeding mechanisms of mosquito larvae, caterpillars, and other soft-bodied insects. Additionally, *Lantana camara* has shown nematicidal effects, as its compounds can control plant-parasitic nematodes that attack crop roots, causing paralysis or death in the nematodes and protecting crops.

The antifungal properties of *Lantana camara* are also notable. Its extracts can control fungal diseases such as powdery mildew, rust, and leaf spots by inhibiting fungal spore germination and mycelial growth.

Studies have shown its efficacy against *Fusarium oxysporum*, responsible for wilt disease, and its ability to inhibit the growth of *Aspergillus sydowii* in stored seeds. *Lantana* also combats soft rot disease caused by *Erwinia carotovora* in stored potato tubers and inhibits the growth of *Alternaria* spp. spores, which cause spots on various plants. Additionally, *Lantana* extracts are effective against fruit rot diseases and fungal pathogens in tomato and other crops, making it a versatile tool in organic farming.

In conclusion, *Lantana camara* holds significant potential as a natural pesticide in organic agriculture due to its insecticidal, repellent, and antimicrobial properties. Its extracts can be used to manage a variety of pests, including insects, nematodes, and fungal pathogens. However, care must be taken to control its invasiveness and manage application rates to avoid phytotoxicity. Overall, *Lantana camara* fits well into sustainable pest management strategies, offering a natural, eco-friendly alternative to synthetic chemicals.

- ***Nerium oleander***

Nerium oleander, an evergreen shrub that can reach heights of up to 4 meters, belongs to the family Apocynaceae. Widely cultivated for its ornamental value, oleander is a common feature in public gardens. However, it is important to note that oleander is among the most toxic plants found in gardens, necessitating caution in its handling. In addition to its toxicity, oleander is valued for its medicinal properties. It contains compounds such as oleandrin, adinerin, neriantin, and nerin, which are known for their effects in strengthening heart muscles.

The use of *Nerium oleander* as a pesticide in organic agriculture is attributed to its content of cardiac glycosides, primarily oleandrin, which are highly toxic to many pests. These compounds disrupt the nervous and cardiovascular systems of pests, ultimately leading to their death. The presence of such toxic compounds makes oleander a potentially powerful tool for pest control.

Oleander extracts have demonstrated significant insecticidal properties against a variety of pests, including aphids, caterpillars, and other soft-bodied insects. Studies have shown that oleander extracts can effectively control pests such as the Egyptian cotton leafworm (*Spodoptera littoralis*). The plant acts as both a repellent and an insecticide due to its bitter taste and the toxic effects that occur when pests ingest it.

In addition to its insecticidal properties, oleander extracts possess fungicidal properties. These extracts inhibit the growth of fungal mycelium and the germination of spores. They are particularly effective against fungi that commonly contaminate seeds, such as *Alternaria alternata*, *Fusarium moniliforme*, *Cochliobolus lunatus*, *Aspergillus flavus*, and *Rhizopus stolonifera*. As a result, oleander extracts can play a critical role in preserving seed quality and preventing fungal infections during seed storage and propagation.

Preparations of oleander as a pesticide usually involve extracting the plant's leaves by soaking them in water or using alcohol to create a spray. However, it is crucial to use protective gear, as even handling the plant can be hazardous. The resulting solution can be sprayed on crops to kill or repel pests. Careful dilution is necessary to avoid harming beneficial insects or the plants themselves.

Since oleander's toxicity is not selective to harmful pests, it can also affect beneficial insects like bees, as well as predatory and parasitic insects. This can disrupt the ecological balance in organic farming systems. Accordingly, many regulatory bodies restrict or discourage the use of highly toxic plants like *Nerium oleander* in organic farming due to the risks posed to human health and non-target species. For organic pest control, other less toxic botanical pesticides, such as neem oil, pyrethrum, or garlic extract, are more commonly recommended. These alternatives are safer for non-target organisms and are widely approved in organic farming practices.

In conclusion, while *Nerium oleander* has demonstrated potential as a natural pesticide, its high toxicity poses significant risks to human health, animals, and the environment. For this reason, it is generally not recommended for use in organic agriculture without strict controls and careful application. Safer alternatives with proven efficacy and lower risk profiles are preferable for organic pest management.

- **Marshmallow**

Marshmallow (*Althaea officinalis*), a member of the Malvaceae family, is a versatile plant with both medicinal and ornamental uses. Renowned for its medicinal properties since ancient times, marshmallow has been valued for its ability to treat a variety of ailments.

Mucilaginous substances extracted from its roots have traditionally been used to treat respiratory infections, gastritis, gastric ulcers, nasal and oral infections, kidney pain, and tonsillitis. Both the roots and leaves of the marshmallow plant contain numerous active compounds that contribute to its therapeutic effects. These compounds may also be effective in combating plant pathogens, making marshmallow extracts valuable for pest and disease management in organic agriculture.

Marshmallow can be a valuable addition to organic farming systems due to its ability to improve soil health, attract pollinators, and provide medicinal benefits. Its role as a low-maintenance crop that enhances biodiversity makes it well-suited for organic agriculture.

- ***Datura stramonium***

Datura (*Datura stramonium*), commonly known as jimsonweed, has been recognized for its potential as a natural pesticide due to the presence of toxic alkaloids. It contains potent compounds such as atropine, hyoscyamine, and scopolamine, which exert neurotoxic effects on pests. These alkaloids disrupt the normal functioning of the nervous system in insects and other pests, leading to paralysis or death.

Atropine blocks acetylcholine receptors, which are critical for transmitting nerve signals. In insects, this disruption can cause loss of coordination, paralysis, and eventually death, making atropine a powerful neurotoxin capable of controlling pest populations. Similarly, hyoscyamine, like atropine, affects the central nervous system by inhibiting acetylcholine, disrupting communication between nerves and muscles. This results in impaired movement and loss of motor function in pests. Scopolamine also interferes with neurotransmitters, specifically by blocking muscarinic receptors in the nervous system, leading to disorientation, impaired motor function, and ultimately, death in insects.

In addition to its insecticidal properties, Datura extract is effective against various plant pathogens. It has been observed to resist fungi such as *Aspergillus flavus*, *Botryodiplodia theobromae*, and *Fusarium oxysporum*. Furthermore, Datura extract has shown success in inhibiting the growth of the bacterium *Erwinia carotovora*, which causes soft rot disease in potatoes. Whether applied as a treatment for tubers before planting or for extending their storage duration, Datura extract has proven beneficial in reducing disease incidence. Moreover, its application has demonstrated effectiveness in mitigating the spread of fungal soft mildew caused by *Fusarium scirpi* in various fruit crops.

In organic agriculture, *Datura stramonium* extract can be used to manage various insect pests and plant pathogens. However, its use must be carefully regulated, as the plant's high toxicity poses risks to humans, animals, and non-target organisms. Proper dilution and application techniques are essential to avoid negative environmental impacts while ensuring its effectiveness as a biopesticide.

- ***Ammi visnaga* (Khella)**

Ammi visnaga, a member of the Apiaceae family (also known as Khella or toothpick weed), has potential as a natural pesticide due to its bioactive compounds, which have demonstrated insecticidal and antimicrobial properties. While it is not as widely used as other botanical pesticides, its chemical constituents make it a candidate for organic pest management.

Khellin and visnagin, compounds found in *A. visnaga*, exhibit bioactive properties that can affect insect physiology and behavior. Additionally, furanocoumarins, another class of compounds present in *A. visnaga*, may have toxic effects on insects, particularly when exposed to sunlight, as these compounds can increase sensitivity to UV radiation.

Research suggests that extracts of *Ammi visnaga* have potential as a botanical insecticide, particularly against pests like aphids and caterpillars. These compounds may interfere with pest feeding or development, leading to a reduction in populations over time. Essential oils from *A. visnaga* have also shown repellent and insecticidal effects on various insect species, though more research is needed to standardize their use in organic agriculture.

Aqueous or alcohol-based extracts of *A. visnaga* can be prepared and applied as a natural pesticide. The plant material can be steeped in water or alcohol to release its active compounds, which can then be sprayed onto affected crops. Essential oils extracted from the plant can be diluted and used as a foliar spray to repel or kill pests. However, proper dilution and application methods are essential to avoid harming crops or beneficial insects.

The bioactive compounds in *A. visnaga* have also been studied for their allelopathic effects, meaning they may suppress the growth of other plants. This characteristic could make it useful as a natural herbicide in certain organic farming systems, though its selectivity and impact on non-target plants need to be carefully managed.

Additionally, khella extracts have shown efficacy in inhibiting the growth of *Aspergillus flavus*, a fungus known for producing aflatoxins. Both aqueous and alcoholic extracts of khella have also been used as antiviral agents, effectively reducing the incidence of tomato mosaic virus in tomato plants.

In conclusion, *Ammi visnaga* has potential as a botanical pesticide due to its bioactive compounds, which exhibit insecticidal, repellent, and antimicrobial properties. Although it is not yet widely used in organic agriculture for pest control, it could become a valuable addition to integrated pest management strategies, especially when combined with other natural methods. Further research and development are needed to optimize its use and ensure safety and efficacy in agricultural applications.

- ***Acacia nilotica***

Acacia nilotica, a member of the Fabaceae family (commonly known as the gum Arabic tree or babul), is a medium-sized, rapidly growing evergreen tree capable of reaching heights of up to 8 meters. Native to Arabia, India, and Africa, this drought-resistant tree thrives in sandy and saline soils, producing yellow flowers in the spring and summer. Beyond its ecological significance, *A. nilotica* has practical applications, including the production of animal medicines and livestock feed. Its fruits yield a tannin-rich powder, valuable to the leather tanning industry for its antimicrobial properties. It has also demonstrated potential as a natural pesticide in organic agriculture due to its bioactive compounds.

Tannins, flavonoids, saponins, and alkaloids found in *A. nilotica* are the primary bioactive compounds responsible for its insecticidal, antifungal, and antimicrobial properties. These compounds have proven effective in disrupting the life cycles of certain pests, as well as in repelling insects.

Extracts from *A. nilotica* have shown repellent and toxic effects against various insect pests, including aphids, whiteflies, caterpillars, and mosquito larvae. These extracts can deter feeding and reproduction in some pest species. Studies have also found that *A. nilotica* can act as a larvicide, particularly against mosquitoes and other small insects, making it useful in managing insect populations at the larval stage.

Additionally, *A. nilotica* possesses antifungal properties that can help control certain fungal pathogens affecting crops. Extracts from the flowers of the acacia tree have been shown to inhibit both the germination and growth of *Aspergillus solani*, a fungus known to cause extensive damage to plants. Furthermore, acacia extract has demonstrated efficacy in inhibiting the growth and germination of spores from various fungi responsible for post-harvest mold diseases in agricultural products, including species from genera such as *Colletotrichum*, *Alternaria*, *Aspergillus*, *Fusarium*, *Drechslera*, and *Curvularia*.

The leaves, bark, or pods of *A. nilotica* can be used to make water-based or alcohol-based extracts, which can be applied as a foliar spray to protect crops from pests. The active compounds work by inhibiting the growth of pests or killing them through contact. Powdered bark or pods can also be applied to the soil or around plants to protect them from soil-borne pests or as a deterrent for above-ground pests. Though less common, essential oils extracted from *A. nilotica* can be used in diluted form as an insect repellent or fungicide. Some studies also suggest that *A. nilotica* can be effective in protecting stored grains from insect infestations, such as weevils.

Overall, *A. nilotica* shows promise as a natural pesticide in organic agriculture due to its insecticidal, antifungal, and antimicrobial properties. Its extracts can be applied to crops as a foliar spray or soil amendment to control various pests and diseases. However, further research and standardization are needed to optimize its use in pest management and ensure it can be safely and effectively applied in organic farming systems.

- **Chilli Pepper**

Chilli pepper (*Capsicum frutescens*), a member of the Solanaceae family, particularly varieties with high capsaicin content like Sudanese chilli, is widely used as a natural pesticide in organic agriculture. The active compound, capsaicin, found in chilli peppers, has strong insecticidal and repellent properties.

Capsaicin is the primary bioactive compound that makes chilli peppers effective as a natural pesticide. It acts as an irritant to many pests, affecting their feeding and reproductive behaviors. Capsaicin disrupts the sensory nerves of insects, causing them to avoid treated plants, and in some cases, it can kill small pests. Chilli pepper-based sprays are effective in controlling a wide variety of pests, including aphids, whiteflies, mites, beetles, and caterpillars. The strong smell and taste of capsaicin also deter other pests, such as rabbits, squirrels, and deer, from feeding on plants. In addition, chilli pepper extracts have shown some antifungal properties, helping to protect crops from fungal diseases. Research has also found that chilli extract can effectively mitigate the spread of viral diseases, such as cucumber mosaic virus and cyclic spot virus, in cucumber plants.

A common method of preparation involves crushing fresh or dried chilli peppers and mixing them with water. The mixture is then strained and sprayed onto plants. Adding a small amount of soap can help the spray adhere to plant leaves. Chilli powder can also be used by sprinkling it directly on plants or around the base to deter pests.

In some commercial products, capsaicin is extracted from chilli peppers and formulated as a pesticide. These formulations are more concentrated and potent than homemade versions and can be applied more precisely.

However, chilli pepper sprays can affect beneficial insects like pollinators (e.g., bees) if applied indiscriminately. Therefore, targeted application is important to avoid harming beneficial organisms. High concentrations of chilli spray or excessive application can also cause damage to sensitive plants, so it is advisable to test the spray on a small area before widespread use. Additionally, the effectiveness of chilli pepper as a pesticide may be short-lived, as rain or irrigation can wash the spray away, requiring frequent reapplication. Capsaicin is also an irritant to skin, eyes, and mucous membranes, so farmers and gardeners should wear protective gear (gloves, masks, goggles) when preparing and applying chilli pepper sprays.

Chilli pepper can be combined with other natural pesticides like garlic, neem oil, or soap to create more potent pest control solutions. These combinations can enhance effectiveness while broadening the range of pests controlled.

Overall, chilli pepper is an effective and eco-friendly natural pesticide that can be used in organic agriculture to control a variety of pests. Its active compound, capsaicin, repels and kills insects, making it a versatile tool for pest management. While it has some limitations, such as short-lasting effects and potential irritation, its low cost, ease of use, and environmental safety make it a valuable component of organic pest control strategies.

5.1.3 Semiochemicals

Semiochemicals are chemical substances that mediate interactions between organisms, influencing their behavior or physiology. They play a crucial role in communication among species, particularly in insects, plants, and microorganisms. These chemicals are secreted by insects to convey messages that affect various behaviors, such as mating, foraging, seeking shelter, and selecting egg-laying sites. Semiochemicals are extensively used in pest management and organic agriculture to control pests without the need for synthetic chemicals.

The term "**Semiochemicals**" originates from the Greek word "Semeon," meaning sign or signal. Semiochemicals can be further categorized into pheromones and allelochemicals, both of which play essential roles in shaping insect behavior and ecological interactions.

Pheromones are a type of Semiochemicals emitted by an organism to influence the behavior of other individuals of the same species. They can attract mates, signal alarm, mark trails, or indicate the presence of food sources. Pheromones are commonly used in mating disruption or as attractants in pest control.

Allelochemicals are Semiochemicals that mediate interactions between individuals of different species. **Allomones** are allelochemicals that benefit the emitter by affecting another species, such as when certain plant chemicals repel herbivores. **Kairomones**, on the other hand, benefit the receiver, such as chemicals released by plants that attract insect predators or parasitoids. Additionally, **Synomones** are allelochemicals that benefit both the emitter and the receiver, like plant volatiles that attract natural enemies of herbivores.

5.1.3.1 Insect Pheromones

Natural pheromones play a vital role in insect communication and behavior regulation. These chemicals are secreted by insects from external glands and elicit specific responses within individuals of the same species. They serve various functions, including sexual attraction, aggregation, alarm signaling, trail marking, and mate finding.

In the context of pest management, the term "behavioral control" refers to the use of chemicals that mimic or interfere with natural pheromones to manipulate insect behavior for pest suppression. For example, synthetic pheromones can be used to attract insects to specific locations, such as traps or mating disruption dispensers, where they can be monitored, captured, or prevented from mating. However, this manipulation of insect behavior can sometimes lead to unintended consequences, such as the disruption of mating patterns or diversion of insects from their natural paths, which may affect population dynamics or pest control efficacy. Therefore, careful consideration and monitoring are necessary when implementing behavioral control strategies in pest management programs.

The scientist Edward O. Wilson classified pheromones into two primary types:

- Releaser Pheromones: These induce immediate behavioral responses in receiving insects, primarily through odour-specific effects that target the central nervous system. Examples include:
  - » Sex Pheromones (Aphrodisiacs): These pheromones attract individuals of the opposite sex for mating purposes. They play a crucial role in reproductive behavior and mate selection.
  - » Alarm Pheromones: Released in response to danger or threat, alarm pheromones warn nearby individuals of potential danger, triggering defensive behaviors or dispersal. They are common in social insects like ants and bees.
  - » Trail-Following Pheromones: Certain species lay down these pheromones to mark paths to food sources, nesting sites, or other important locations. They help guide conspecifics to specific destinations efficiently.
  - » Dispersal Pheromones: These pheromones encourage individuals to move away from crowded areas or to disperse from aggregations, helping to prevent overcrowding.
  - » Aggregation Pheromones: Released by individuals to attract others of the same species, facilitating group formation or the assembly of individuals in specific locations. These pheromones include sex pheromones (Lures) and gathering pheromones for "Food Lures" and "Oviposition Lures".
- Primer Pheromones: Unlike releaser pheromones, primer pheromones exert their effects over a longer period and can influence physiological or developmental processes in the recipient. These pheromones may regulate various aspects of the target organism's biology, including growth, development, or reproductive processes. Primer pheromones typically have a broader and more profound impact on the recipient's physiology and behavior compared to releaser pheromones.

Sex pheromones have garnered significant attention and extensive study, especially since the discovery in the early 20th century that certain insects are attracted from long distances by these chemical signals. For instance, it was observed that female Chinese silk moths can attract males from distances exceeding 11 km, while female gypsy moths have been found to attract males from up to 3 km away.

Recent advancements in chemical analysis techniques have enabled the precise determination of the chemical composition of pheromones secreted by many insects, even in very small quantities. To date, approximately 170 species of sex pheromones have been identified for Lepidoptera, along with pheromones for other insect orders such as Coleoptera.

Pheromones identified for use in Integrated Pest Management (IPM) programs are actively employed for pest control. One of the key advantages of pheromones is their high specificity, low toxicity to mammals, and rapid biological degradation, which prevents their accumulation in the environment.

As a result, many pheromones have been commercially produced for use in insect pest control, offering an effective and environmentally friendly approach to managing pest populations. Pheromones have diverse applications in pest control across various areas, including:

- » Monitoring Pest Density: Pheromone traps are used to monitor and assess the population density of pests, aiding in the selection and organization of control programs. They are deployed in IPM strategies to monitor and control insect pests such as almond weevils, American bollworms, corn earworms, red scale insects, and red palm weevils.
- » Mass Trapping: Pheromone traps with toxic baits are employed to attract and eliminate large numbers of insect pests. In organic agriculture, natural pesticides such as pyrethrum or rotenone may be used in combination with pheromone traps for mass trapping.
- » Area-Wide Control: In conventional farming, pheromones can be used to attract pests to specific areas, where they can be treated with insecticides or eliminated through other methods. In sterilization programs for endemic insects, pheromones attract pests to sources of chemical sterilizers.
- » Mating Disruption: Pheromones are used in behavioral control programs to confuse and disrupt the mating process of male insects, preventing or

halting reproduction. This strategy, known as mating disruption, helps reduce pest populations.

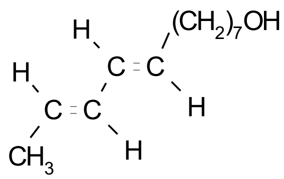
» **Early Season Control:** Pheromone traps can be deployed early in the season to capture the initial stages of pest emergence, providing a means of controlling low-level pest populations before they escalate.

» **Stimulation of Pesticide Effectiveness:** In traditional agriculture, stimulant pheromones can be used to agitate insects, making them more susceptible to pesticides. For example, applying the pheromone farnesene to plants treated with pesticides can enhance the effectiveness of contact insecticides against aphids. Farnesene stimulates aphids, causing them to move from the undersides of leaves, thereby increasing their exposure to the pesticide.

The following are examples of some commercially produced pheromones that can be used in pest control programs in organic agriculture:

- **Codling Moth Sex Pheromone**

Codlemone

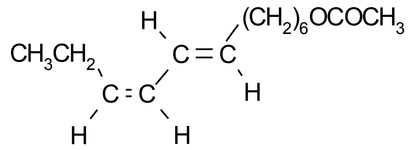


Codlemone is a sex pheromone used for managing the codling moth (*Cydia pomonella*), a significant pest that infests apple trees, pears, and other fruit-bearing plants. Naturally secreted by virgin female codling moths to attract males for mating, Codlemone is commercially prepared in low concentrations for pest management purposes.

When deployed in the field, Codlemone disrupts the mating process by causing confusion and dispersion among male insects within the target pest population. As a result, mating and reproduction are interrupted, with the eggs laid by females remaining unfertilized due to the disruption in mating behavior. This strategy effectively helps to control codling moth populations and reduce crop damage.

- **European Grapevine Moth Sex Pheromone**

(E,Z)-7,9-dodecadien-1-yl acetate



(7*E*,9*Z*)- isomer

The sex pheromone for the European grape moth (*Lobesia botrana*) plays a crucial role in pest management strategies targeting this vineyard pest. Like other sex pheromones, its primary function is to disrupt the mating behavior of male moths, preventing successful mating and reproduction. By dispersing and confusing male moths in the area, the pheromone interferes with their ability to locate female moths. As a result, the mating process is disrupted, leading to reduced egg fertilization and, consequently, population control of the European grape moth. This pheromone is commercially available under trade names such as RAK 2 and Quant L.B., and is utilized in integrated pest management (IPM) programs to mitigate damage caused by *Lobesia botrana* infestations in vineyards and other grape-growing regions.

- **Red Palm Weevil Aggregation Pheromone**

Ferrolure+

$CH_3(CH_2)_2CH(CH_3)CH(OH)(CH_2)_3CH_3$ — 4-methylnonan-5-ol

$CH_3(CH_2)_2CH(CH_3)C(O)(CH_2)_3CH_3$ — 4-methylnonan-5-one

Ferrolure+ is a potent aggregation pheromone emitted by the red palm weevil (*Rhynchophorus ferrugineus*), a destructive pest that infests palm trees, particularly date palms. This pheromone plays a critical role in pest management strategies aimed at controlling red palm weevil populations.

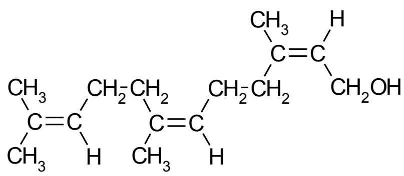
Pheromone traps utilizing Ferrolure+ are highly effective in attracting both female and male red palm weevils, resulting in the capture of significant numbers of these pests. This method, known as quantitative pheromone trapping, aids in monitoring and managing the population density of red palm weevils. Commercially available under the name "Red Date Palm Weevil Attract, Kill, and Dispensers," Ferrolure+ is a valuable tool in integrated pest management (IPM) programs, helping to suppress red palm weevil populations and protect palm trees from infestation.

- **Farnesol with Nerolidol (Spider Mite Alarm Pheromone)**

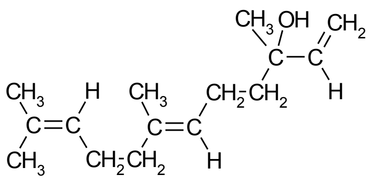
Farnesol, combined with Nerolidol, is an alarm pheromone naturally emitted by female two-spotted spider mites (*Tetranychus urticae* Koch) in response to threats or perceived attacks by predatory spiders. This pheromone triggers heightened alertness and agitation among spider mites, causing them to become more active and mobile. As a result, they become more susceptible to acaricides when applied concurrently. Additionally, mites that receive the warning signal from the pheromone tend to reduce their feeding activity.

Commercial formulations of this pheromone, such as Stirrup M and Stirrup Mylox (combined with sulfur), are available for use in pest management programs targeting spider mites. These formulations exploit the alarm pheromone's disruptive effect on spider mite behavior to enhance the efficacy of acaricidal treatments and help reduce mite populations in agricultural settings.

Spider Mite Alarm Pheromone



farnesol (2*Z*,6*E*)- isomer



nerolidol *trans*- isomer

5.1.3.2 Allelochemicals

The term "Allelochemicals" was introduced by Whittaker (1970), who defined them as "chemicals that mediate certain reactions between organisms of different species." Borner (1960) reported that plants release allelochemicals in various ways. These chemicals can seep from dead tissue and pass directly into the soil or be excreted from living plant tissue. Many plants exhibit biochemical antagonism, as noted by Tobiessen and Werner (1980). This biochemical antagonism is believed to be an important mechanism in regulating the succession of plant communities.

Allelochemicals are categorized into four groups: Allomones, Kairomones, Synomones and Apneumons. This classification is based on the extent of benefit or harm to the emitter (the organism secreting allelochemicals) and the receiver (the organism affected by the allelochemicals).

- **Allomones**

Allomones are a type of allelochemical that benefit the organism that produces them (the emitter) while having a detrimental effect on the receiving organism (the receiver), typically from a different species. Allomones are primarily used for defense or offense, allowing the emitter to repel predators, attract prey, or compete with other species for resources.

Examples include substances secreted by certain insects as a defense mechanism against predators or parasites. These insects release chemicals that repel attackers and prevent predation. Additionally, some predatory insects secrete substances that lure or attract their prey, aiding in their hunting efforts. In both cases, the allelochemicals benefit the emitter while negatively impacting other organisms in their environment.

- **Kairomones**

Kairomones are a type of allelochemical that benefit the organism receiving the signal (the receiver) while having a detrimental or neutral effect on the organism producing the chemical (the emitter). Unlike allomones, which benefit the emitter, kairomones unintentionally benefit another species, often making the emitter more vulnerable to predation or parasitism. The term "kairomone" is derived from "kairos," meaning exploitation or opportunistic advantage.

Kairomones are often emitted by plants or animals and inadvertently signal their presence to predators, parasites, or herbivores. These chemical cues can attract predators or parasitoids to their prey, allowing them to locate the emitter more easily.

For example, some plants emit volatile organic compounds (VOCs) when damaged by herbivores. These VOCs attract predatory insects or parasitoids that feed on the herbivores. Although the plant emits these signals in response to being attacked, they inadvertently benefit the predators or parasitoids, which use the signal to locate their prey. For instance, when aphids feed on plants, the plants release VOCs that attract parasitic wasps. The wasps use the plant-emitted kairomones to locate the aphids and lay their eggs inside them, helping control aphid populations.

Kairomones are also used by parasites or parasitoids to locate their hosts. For example, the carbon dioxide (CO_2) exhaled by humans or animals serves as a kairomone for mosquitoes, helping them detect and find their blood hosts. The CO_2 and body odours emitted by humans attract mosquitoes, which use these kairomones to locate their hosts for blood-feeding.

In integrated pest management (IPM), kairomones can be used to attract natural enemies of pests. By mimicking the natural chemical signals emitted by pests, kairomones can help attract predators or parasitoids, reducing pest populations in an eco-friendly manner.

In summary, kairomones benefit the receiving organism and often result in unintended harm to the emitter. They play a significant role in ecological interactions, particularly in predator-prey and host-parasite dynamics.

- **Synomones**

Synomones are a type of allelochemical that benefit both the organism producing the chemical (the emitter) and the organism receiving the signal (the receiver), making them mutually advantageous. The term "synomone" is derived from "syn," meaning together or linked. Synomones play a critical role in various ecological interactions, particularly in symbiotic and mutualistic relationships between different species. They often facilitate cooperation between organisms, leading to improved survival or reproductive success for both parties involved.

Many flowering plants emit synomones in the form of floral scents to attract pollinators such as bees, butterflies, or moths. The plant benefits by having its flowers pollinated, while the pollinators benefit from the nectar or pollen they consume as a food source. Additionally, when plants are attacked by herbivores, they can release synomones that attract the herbivores' natural enemies, such as predators or parasitoids. This benefits the plant by reducing herbivory, while the predator or parasitoid benefits by locating its prey or host. For example, corn plants emit volatile organic compounds when attacked by caterpillars. These volatiles attract parasitic wasps, which lay their eggs in the caterpillars, benefiting the plant by reducing herbivore damage and providing the wasps with a suitable host. In some cases, plants release synomones to attract ants, which provide protection from herbivores in exchange for food or shelter. This mutually beneficial relationship allows both species to thrive.

Synomones are being explored for use in sustainable agriculture and integrated pest management (IPM) as a way to naturally enhance crop protection. By leveraging synomones, farmers can attract beneficial insects that prey on pests or provide pollination services. Synomones emitted by plants under attack can be artificially applied to crops to attract natural enemies of pests, reducing the need for chemical pesticides. For example, synthetic synomones can be used to attract parasitic wasps to crops infested with aphids, helping control aphid populations in an eco-friendly manner. Synomones can also be used to enhance pollination by attracting beneficial pollinators to crops, increasing yield and crop quality.

Overall, synomones are a unique type of allelochemical that foster mutual benefits between different species. They play a vital role in facilitating positive ecological interactions and hold significant potential for improving sustainable agricultural practices.

- **Apneumones**

Apneumones are a type of allelochemical that benefit the organism receiving the signal (the receiver) but have a neutral or no effect on the non-living source (the emitter). Unlike other allelochemicals like kairomones or allomones, which involve interactions between living organisms, apneumones are emitted from non-living sources, often as byproducts of decay or decomposition. The term "apneumone" is derived from the Greek words "a," meaning without, and "pneuma," meaning breath, referring to substances secreted by non-living matter.

The source of the chemical (apneumones) is non-living, such as decaying organic matter or inanimate objects. The organism that benefits from the chemical signal typically finds food, shelter, or resources. Apneumones benefit the receiver (e.g., insects or scavengers) by signaling the presence of a resource (such as decaying matter or dead organisms) but provide no direct benefit to the source.

For example, parasites of the family Scolytidae (bark beetles) may rely on odours emanating from materials associated with pests inside trees. These odours are detected by insect parasites, which navigate to their target locations by following these signals. In this case, apneumones serve as chemical cues that guide the parasites to their host organisms. Similarly, chemicals emitted by fermenting or rotting fruit can attract insects like fruit flies, which lay eggs or feed on the decaying fruit.

Generally, when dead plants or animals decay, they release volatile chemicals that attract scavengers, decomposers, or parasites. For instance, some beetles or flies use the chemical cues emitted from decomposing bodies (apneumones) to locate food or breeding grounds. While less studied compared to other types of allelochemicals, apneumones are significant in the behavior of many organisms, particularly those that rely on decaying matter for survival.

5.2 Chemical Compounds for Pest Control in Organic Agriculture

5.2.1 The Use of Sulfur Compounds in Organic Agriculture

Sulfur compounds are essential natural fungicides used in organic agriculture. They effectively control various fungal diseases such as powdery mildew, scab, rust, and black spot. Additionally, sulfur compounds are lethal to plant mites, which can damage a wide range of crops. However, it is important to note that sulfur can have adverse effects on beneficial predatory mites, such as those from the Amblyseius genus, particularly when used in high concentrations or under high-temperature conditions. Despite these concerns, sulfur is non-toxic to humans and animals and is generally permitted in organic agriculture without requiring specific approval from certification bodies.

While sulfur is a versatile fungicide, its use requires careful management to avoid negative effects on certain plant varieties and under specific environmental conditions. Sulfur can be mixed with most fungicides and insecticides, except for oils. However, on certain varieties of apples, pears, apricots, and cucurbits, sulfur may cause stunted growth and leaf burns, especially when temperatures exceed 32°C. These considerations emphasize the importance of taking environmental factors and plant sensitivities into account when using sulfur-based fungicides.

Additionally, caution is necessary when treating trees with oils, as sulfur should not be applied until at least a month after oil treatment to avoid leaf burns and other damage, commonly referred to as "sulfur shock."

Sulfur can be applied through spraying or fogging, with fogging best conducted early in the morning when dew is present to ensure the sulfur adheres effectively to plant surfaces. Thiovit is one of the sulfur compounds approved for use in organic agriculture, typically applied at a rate of 200–300 grams per 100 liters of water.

5.2.1.1 How Sulfur Affects Plant Fungi

There are several theories that explain how sulfur affects fungi, providing insights into the mechanisms by which sulfur inhibits fungal growth:

» **Electrical Charges:** Sulfur's natural properties include the presence of electrical charges, which can disrupt fungal cellular processes and ultimately lead to fungal death. These charges may interfere with essential biochemical reactions within fungal cells, rendering them non-functional.

» **Sunlight Collection:** Sulfur grains can act as lenses, focusing sunlight onto fungal spores and hyphae. The concentrated heat generated by this process can raise the temperature of the fungi to lethal levels, effectively killing them.

» **Barrier Formation:** The application of sulfur creates a protective layer on the surface of plant tissues, acting as a physical barrier against invading fungal spores. This barrier prevents direct contact between the spores and the plant, reducing the likelihood of fungal infection.

» **Toxicity:** The toxic action of sulfur on fungi may result from its conversion into hydrogen sulfide gas, which is toxic to fungi, or its oxidation into sulfur dioxide. When sulfur dioxide reacts with moisture, it forms pentathionic acid, which destroys fungi responsible for plant diseases.

These theories highlight the multifaceted nature of sulfur's antifungal properties, involving both physical and chemical mechanisms to inhibit fungal growth and proliferation.

5.2.1.2 How Sulfur Affects Plant Mites

Sulfur is widely used in organic agriculture not only for its fungicidal properties but also for its effectiveness in controlling plant mites. The following are key theories explaining how sulfur affects plant mites:

» Direct Contact Toxicity: Sulfur acts as a contact poison for mites. Upon direct contact, mites experience irritation and chemical burns that damage their exoskeletons. This leads to dehydration and desiccation, ultimately killing the mites.

» Chemical Reaction: Sulfur's toxic effect on plant mites may occur through its oxidation to sulfur dioxide or trioxide. In the presence of moisture, these compounds convert into pentathionic acid, which is toxic to mites.

» Generation of Toxic Gas: Sulfur can be reduced to hydrogen sulfide gas (H_2S), which is toxic to mites when inhaled, leading to respiratory distress and death.

» Intracellular Effects: Sulfur may transform into sulfuric acid within the cells of mites, causing the precipitation of cellular proteins and eventually leading to cell death.

» Respiratory Interference: Sulfur interferes with the respiratory systems of mites by disrupting their ability to exchange gases. When mites come into contact with sulfur particles, they experience respiratory failure, leading to suffocation and death.

» Behavioral Changes: The presence of sulfur on plant surfaces can irritate mites, causing changes in their behavior. Mites may reduce feeding and reproduction, or abandon the treated plant entirely, which leads to a gradual reduction in mite populations.

» Environmental Impact: Sulfur is most effective in controlling mites under moderate environmental conditions. However, at very high temperatures, sulfur can harm both plants and beneficial predatory mites, such as those from the Amblyseius genus, which play a vital role in pest control.

5.2.2 The Use of Copper Compounds in Organic Agriculture

Copper compounds play an essential role in organic agriculture, primarily for their fungicidal and bactericidal properties. They are commonly used to prevent and control a wide range of fungal and bacterial diseases in crops, including downy mildew, powdery mildew, late and early blight, leaf spot, and others. The key areas of application include vineyards, orchards, and vegetable production. Copper works by disrupting the enzymes and proteins involved in the cellular processes of fungi and bacteria, inhibiting spore germination, and preventing the spread of diseases by destroying pathogens on contact.

The use of copper compounds as fungicides back to 1807. However, it wasn't until 1882 that Bordeaux mixture, a blend of copper sulfate and lime, was developed and became widely employed as a fungicide, marking the beginning of copper compounds' pivotal role in plant disease management.

Copper is applied in various forms, including copper hydroxide, copper oxychloride, copper sulfate, copper oxide, copper dioxide, and Bordeaux paste. These compounds have demonstrated efficacy in preventing the spread of fungal diseases such as downy mildew, late and early blight, root rot, and more. The main forms of copper application include:

* Copper hydroxide: This form is used to prevent and control fungal pathogens like mildew and blight.

* Copper oxychloride: Another popular form of copper used in organic agriculture, known for its effectiveness in controlling both fungal and bacterial diseases.

* Copper sulfate: Also known as Bordeaux mixture when combined with lime, this is one of the most widely used copper-based fungicides. It is particularly effective against fungal diseases like downy mildew and blight.

Copper is widely used in organic agriculture for several purposes, including:

» Fungicide: Copper compounds are used to control fungal diseases in crops. They are effective against a wide range of fungal pathogens, including downy mildew, late blight, early blight, and root rot.

» Bactericide: Copper is also effective against bacterial diseases in plants, helping manage issues like bacterial blight and bacterial spot in various crops.

» Algaecide: Copper compounds can control algae growth in aquatic environments, particularly in irrigation systems and water bodies associated with agricultural land.

- **Seed Treatment:** Copper-based formulations are applied as seed treatments to protect seeds from soil-borne pathogens and ensure healthier seedlings.

- **Soil Amendment:** Copper is sometimes used to correct copper deficiencies in soils. However, this must be done carefully, as excessive copper levels can be toxic to plants.

- **Foliar Spray:** Foliar applications of copper compounds help prevent and manage fungal and bacterial diseases on leaves and other above-ground plant parts.

- **Post-Harvest Treatment:** Copper-based products are used post-harvest to extend the shelf life of fruits and vegetables by inhibiting the growth of spoilage organisms.

Copper compounds are generally applied as a foliar spray, creating a protective layer on the surface of leaves and fruits that prevents pathogens from penetrating plant tissue. Proper application timing, particularly before the disease establishes itself, is crucial for effective disease management.

While copper compounds are approved for use in organic agriculture, their use must be carefully regulated. Excessive copper application can lead to copper accumulation in the soil, which may negatively impact soil microorganisms, earthworms, and overall plant health over time. High concentrations of copper in the soil can also result in toxicity to plants. For this reason, organic certification bodies often limit the annual amount of copper that can be applied.

In organic agriculture, it is recommended that copper usage does not exceed 3 kg/ha/year. Additionally, obtaining approval from certification authorities before using copper compounds ensures transparency and accountability in organic farming practices. Adherence to recommended application rates and regulations is crucial for maintaining environmental sustainability and compliance with organic certification standards.

5.2.2.1 Bordeaux Mixture

Bordeaux mixture is a traditional fungicide and bactericide used in organic agriculture to control fungal diseases, particularly in vineyards, fruit orchards, and vegetable crops. It is made by combining copper sulfate and hydrated lime (calcium hydroxide) with water. Developed in the Bordeaux region of France in the 19th century, it remains widely used due to its effectiveness against a variety of plant pathogens. The mixture is easy to prepare and can be made locally by farmers. The composition and preparation of Bordeaux mixture are as follows:

- **Copper sulfate ($CuSO_4$):** The primary active ingredient responsible for the fungicidal and bactericidal effects. Dissolve one kg of copper sulfate powder in 50 liters of water.

- **Hydrated lime ($Ca(OH)_2$):** Added to neutralize the acidity of copper sulfate, making the solution less phytotoxic. Dissolve one kg of hydrated lime in another 50 liters of water.

- **Mixing:** The copper sulfate solution is slowly added to the lime solution with constant stirring. Alternatively, both solutions may be poured simultaneously into a third container and mixed well.

The copper ions in the Bordeaux mixture disrupt the enzymes and proteins in fungal and bacterial cells, preventing the pathogens from growing and spreading. Copper acts as a contact fungicide, meaning it must be present on plant surfaces to prevent or halt the spread of fungal spores. Lime helps stabilize the solution, making it less harmful to plants while ensuring the copper remains effective.

When preparing Bordeaux mixture, it is important not to use metal containers, as they can react with the copper sulfate. It is advisable to prepare the mixture in the field immediately before use, as it can decompose quickly if left for an extended period after mixing. Additionally, copper compounds are not compatible with pesticides sensitive to alkaline mediums, such as phosphorus pesticides or carbamates commonly used in conventional agriculture.

Bordeaux mixture is highly effective against fungal diseases like powdery mildew, downy mildew, leaf spots, blights, and anthracnose. It is also used to control bacterial diseases such as fire blight in apple and pear orchards. The mixture is commonly applied to grapes, apples, pears, peaches, tomatoes, potatoes, and other crops prone to fungal and bacterial infections. It is typically applied as a foliar spray during the growing season, with early-season preventive spraying being the most effective.

The concentration of copper sulfate and lime in the mixture can vary depending on the crop and disease being treated. Common formulations are 1:1:100 (1 kg copper sulfate, 1 kg lime, 100 liters of water), but this can be adjusted for specific needs. Since Bordeaux mixture is a contact fungicide, it needs to be reapplied after rain or irrigation to ensure continued protection.

Bordeaux mixture is allowed under most organic certification programs, including the European Union's organic regulations and the U.S. National Organic Program (NOP).

One of the most significant advantages of Bordeaux mixture is its ease of preparation, cost-effectiveness, ability to adhere to plants without the need for additional adhesives, and effectiveness against a wide range of fungal diseases, some bacteria, and algae. It also has minimal toxicity to humans and animals.

However, one of the main concerns with Bordeaux mixture is the accumulation of copper in the soil over time. High levels of copper can be toxic to soil organisms, including earthworms and beneficial microbes, leading to long-term soil degradation. Although lime reduces the risk of plant damage, Bordeaux mixture can still cause phytotoxicity (leaf burn or damage) if applied in excessive concentrations or during hot weather. Additionally, copper is a heavy metal, and while Bordeaux mixture is allowed in organic farming, its use is regulated due to concerns about its environmental impact, particularly in aquatic ecosystems where copper runoff can be toxic to aquatic life.

Overall, Bordeaux mixture is an effective and widely used fungicide and bactericide in organic agriculture, particularly for managing fungal and bacterial diseases in fruit orchards, vineyards, and vegetable crops. While it remains a reliable solution, farmers must carefully manage its application to prevent copper accumulation in the soil and mitigate potential environmental concerns. Organic farmers often incorporate Bordeaux mixture as part of an integrated disease management strategy, using it alongside other natural fungicides and cultural practices.

5.2.2.2 Bordeaux Paste

Bordeaux paste is a variation of Bordeaux mixture, primarily used as a protective treatment for trees and woody plants to prevent fungal and bacterial infections, especially during the dormant season. It is applied directly to wounds or damaged areas of trees, such as pruning cuts, bark cracks, or grafting sites.

The general formulation of Bordeaux paste involves a 1:1 ratio of copper sulfate and lime, with water added to create a thick, spreadable paste. Essentially a 10 % Bordeaux mixture, it is prepared by mixing 1 kg of copper sulfate and 1 kg of hydrated lime in 10 liters of water. To prepare Bordeaux paste, dissolve the copper sulfate in half of the water and the hydrated lime in the other half. Once fully dissolved, the two solutions are mixed to form a thick paste.

Bordeaux paste is primarily applied to treat and protect tree wounds caused by pruning, mechanical injury, or grafting. It helps prevent the entry of fungal pathogens and bacteria through open wounds and is effective against common fungal diseases such as canker, anthracnose, and bacterial blight. By applying the paste to vulnerable areas, infections can be prevented during the dormant season when trees are most susceptible. The paste forms a physical and chemical barrier over treated areas, preventing spores, insects, or bacteria from entering damaged tissues. It adheres well to plant tissues and releases copper ions over time, inhibiting the growth of pathogens. This targeted protection promotes plant health and supports overall disease management in agriculture and horticulture.

Bordeaux paste is commonly applied to pruning cuts or other injuries on fruit trees such as apples, pears, peaches, and plums. It can also be used on ornamental trees and vines. When grafting, Bordeaux paste is often used to protect the graft union from fungal infections and to help the graft heal properly. It is typically applied during the dormant season, before new growth begins, ensuring that the protective coating remains on the plant during periods of higher disease risk.

In addition to its effectiveness in preventing fungal and bacterial infections, especially during the vulnerable winter months, Bordeaux paste offers several advantages. The paste adheres to treated areas longer than liquid sprays, providing a more persistent barrier against pathogens. Moreover, the risk of phytotoxicity is lower compared to sprays, as the copper concentration is localized to the specific treated area, minimizing the potential for widespread damage.

5.2.3 The Use of Silicon (Si) Compounds in Organic Agriculture

Silicon compounds play an increasingly important role in organic agriculture due to their ability to improve plant health, enhance stress resistance, and protect against pests and diseases. Although silicon is not considered an essential nutrient for plant growth, its benefits are well-documented, especially in crops that experience abiotic and biotic stresses.

There are several types of silicon compounds used in organic farming. Silicon dioxide (SiO_2) is the most common form found in nature, present in soil minerals like quartz and sand. While not readily available to plants, certain silicon dioxide-based amendments can be processed to enhance silicon availability. Sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) are more soluble forms of silicon, often used as foliar sprays or soil amendments to provide plants with available silicon. Another option is calcium silicate ($CaSiO_3$), commonly used as a soil amendment to improve soil pH and increase silicon levels, as well as manage soil acidity. Additionally, rice husk ash or other plant-based silica sources are rich in silicon and are frequently used in organic farming as a soil amendment.

Silicon offers several benefits to plants. It helps improve resistance to abiotic stress such as drought, salinity, and heavy metal toxicity. By improving water retention in plant tissues and enhancing photosynthetic efficiency, silicon helps plants thrive under stressful conditions. Additionally, silicon strengthens plant structures by being deposited in cell walls, providing mechanical strength to stems, leaves, and roots. This reduces the risk of physical damage from wind or rain and decreases lodging in crops like rice and wheat. Silicon also increases tolerance to biotic stress, such as pests and diseases, by forming a physical barrier in plant tissues, making it harder for pests and pathogens to penetrate the plant. In terms of disease resistance, silicon enhances the plant's defense mechanisms against fungal diseases like powdery mildew, blights, and leaf spots, by reinforcing cell walls.

Silicon is applied in several ways in organic agriculture. Soil amendments, particularly calcium silicate or plant-based silicates, are applied to improve silicon availability, which is especially beneficial in sandy or depleted soils where natural silicon levels may be low. Foliar sprays of potassium silicate or sodium silicate are commonly used in organic farming. When applied to leaves, silicon strengthens plant tissues, helping them resist insect attacks and foliar diseases like powdery mildew. Crops like rice, sugarcane, and cereal grains accumulate large amounts of silicon and benefit from silicon applications, which improve their tolerance to stresses like drought, pests, and fungal diseases. Silicon can also be added to organic fertilizers or compost to enhance nutrient uptake and improve the plant's resilience to stress.

The benefits of silicon in organic farming are numerous. It improves pest and disease resistance by strengthening plant cell walls, making it harder for pests to feed and pathogens to invade. This reduces the need for pest control interventions, aligning with organic farming practices that minimize pesticide use. Additionally, silicon enhances stress tolerance, allowing plants to handle environmental stresses like drought and heat, reducing water requirements, and improving overall plant health. By improving plant health and resistance to stress, silicon can also increase yield and quality in fruits, grains, and vegetables. Finally, silicon amendments contribute to sustainable soil management by improving soil structure and nutrient retention, which supports long-term soil health.

However, there are challenges and considerations with silicon use in organic agriculture. Not all soils have readily available silicon, so supplementation with silicon-rich materials is sometimes necessary. In organic systems, sourcing and applying natural forms of silicon that comply with organic certification standards can be challenging. Additionally, some silicon products, particularly soluble forms like potassium silicate, can be expensive compared to traditional fertilizers or soil amendments. Overapplication of silicon can also lead to nutrient imbalances in the soil, so it is important to apply silicon at recommended rates to avoid negative impacts on soil and plant health.

Examples of silicon use in organic farming include rice cultivation, where silicon is applied to strengthen rice plants, reduce lodging, and increase resistance to diseases like blast and sheath blight. Silicon-rich amendments, such as rice husk ash, are used to naturally supplement silicon levels in the soil. In vegetable crops, organic farmers use silicon-based foliar sprays to protect crops like cucumber and tomato from insect pests and fungal diseases such as powdery mildew and aphid infestations. In fruit orchards, silicon applications can help reduce disease pressure from fungal pathogens like scab in apples and protect against damage from fruit pests.

Several commercial preparations of registered silicon compounds are approved for use in organic agriculture, primarily to enhance plant resistance to fungal diseases, insect pests, and mites. One such product is Sil-Matrix, which contains approximately 29 % potassium silicate. It is typically applied as a foliar spray at a rate of 0.5 to 0.75 liters per 100 liters of water.

5.2.4 The Use of Kaolin Clay in Organic Agriculture

Kaolin clay used in organic agriculture is a type of natural clay composed entirely of 100 % natural minerals. Approved by the U.S. Environmental Protection Agency (EPA) in 1998 for agricultural use as a natural insect repellent and plant protectant, its chemical composition consists primarily of aluminum silicate, with the chemical formula $Al_2Si_2O_5(OH)_4$. In Egypt, Kaolin clay is extracted from the depths of the earth in the Sinai Peninsula and undergoes several mechanical processing stages, remaining free from any chemical additives that would alter its natural properties.

Kaolin clay is often applied in the form of a wettable powder or as a spray-on suspension mixed with water, creating a thin layer or white film that acts as a physical barrier between pests and plants. This layer protects plants from various insect pests, plant mites, fungi, and bacteria responsible for plant diseases. Additionally, plants treated with kaolin clay experience several other benefits, which will be discussed later. Commercially, Kaolin clay is available under the trade name Surround WP.

The thin, white film formed on the surface of plants treated with kaolin clay deters pests in several ways:

» Physical Barrier: The film creates a physical barrier that makes it difficult for pests, such as aphids, beetles, and moths, to feed on the plant's surface.

» Deterrent: The reflective surface of kaolin-coated plants disorients insects and reduces their ability to recognize plants as food sources. This helps control pests like whiteflies, thrips, leafhoppers, and apple maggots.

» Egg-Laying Deterrence: Certain insects are less likely to lay eggs on plants covered with kaolin, as the film makes it difficult for them to attach their eggs.

» Protection from Sunburn and Heat Stress: The white coating created by kaolin clay reflects sunlight, reducing heat stress on plants and preventing sunburn, especially in fruit trees and crops that are sensitive to high temperatures.

» Disease Prevention: Kaolin clay can also help reduce the spread of fungal diseases by creating a dry surface on leaves, which prevents moisture accumulation and reduces the likelihood of fungal spore germination.

5.2.4.1 The Benefits of Using Surround WP in Organic Agriculture

Surround WP consists of 95 % kaolin clay finely ground into a wettable powder and has been approved by the Organic Materials Review Institute (OMRI) for use in organic agriculture since March 2000. The benefits of using kaolin clay (Surround WP) in organic farming are extensive and can be summarized as follows:

» Protection from Insect Pests: Surround WP creates a physical barrier on plant surfaces, making them less appealing to insect pests. It disguises the appearance of fruits and plants, making it difficult for pests to identify them. Additionally, the film formed by Surround WP acts as a protective shield, preventing pests from feeding or laying eggs on plants. It effectively controls a diverse range of insect pests, including thrips, aphids, whiteflies, mealybugs, moth species, fruit flies, hoppers, grasshoppers, locusts, and plant mites.

Specific pests controlled by Surround WP include woolly aphids (*Eriosoma lanigerum*), cutworms (*Agrotis ipsilon*), spiny bollworms (*Earias insulana*), pink bollworms (*Pectinophora gossypiella*), tomato leaf miners (*Tuta absoluta*), citrus leaf miners (*Phyllocnistis citrella*), codling moths (*Cydia pomonella*), Mediterranean fruit flies (*Ceratitis capitata*), olive fruit flies (*Bactrocera oleae*), peach fruit flies (*Bactrocera zonata*), black watermelon bugs (*Coridius viduatus*), pear rust mites (*Epitrimerus pyri*), peach silver mites (*Aculus cornutus*), and red spider mites (*Tetranychus urticae*). Surround WP is frequently used on fruit trees in orchards, such as apples, pears, citrus, and stone fruits like peaches and cherries. It is also applied to vegetables like tomatoes, peppers, and squash, and in vineyards to protect grape clusters from grape berry moths and prevent sunscald.

» Protection from Fungal Diseases: Surround WP minimizes the presence of free water on plant surfaces, which is necessary for fungal spore germination. The non-hydrophilic layer acts as an insulating barrier, reducing the likelihood of fungal infections.

» Enhanced Photosynthesis: Surround WP allows light penetration and gas exchange essential for photosynthesis while reflecting ultraviolet and infrared rays. This reflection helps control plant pathogens like fungi and bacteria.

» Increased Productivity: By reducing water transpiration, protecting plants from heat stress, and enhancing drought tolerance, Surround WP improves plant growth and productivity.

- **Post-Harvest Benefits:** Treating fruits with Surround WP before harvesting or storage helps maintain freshness, reduces water loss, minimizes deformities, and protects fruits from physical damage during storage.

- **Resistance to Environmental Stresses:** Surround WP contains silicon, which enhances plant resistance to environmental stresses and promotes overall plant health.

- **Frost Protection:** The film formed by Surround WP helps protect plants from frost damage by reducing water loss from leaves, minimizing the risk of frost injury.

- **Sunburn Protection:** Surround WP shields plants and fruits from sunburn caused by intense sunlight, especially during hot summer months, and enhances fruit colour in certain varieties.

- **Grain Preservation:** Surround WP can be mixed with stored grains to prevent infestation by stored grain pests.

- **Temperature Regulation:** Surround WP reduces plant temperatures by about 7°C, making it suitable for use on deciduous trees to prevent excessive heat stress or to assist in breaking dormancy.

- **Fruit Quality Improvement:** Applying Surround WP to fruit trees enhances fruit quality, increases yield, improves fruit colouration, reduces fruit cracking, and minimizes fruit drop. For instance, spraying Empire apple trees with Surround WP between weeks 6 and 8 after petal fall has shown benefits, including increased yield, enhanced fruit colour, and reduced fruit cracking. These findings align with research conducted by Hinman and Ames (2011), which observed similar results in other apple varieties such as Gala and Stayman.

- **Increased Yield:** Studies have shown that Surround WP can lead to increased yields and improved fruit quality, demonstrating its positive impact on crop productivity.

Overall, Surround WP offers numerous advantages in organic agriculture, providing effective pest and disease control while promoting plant health and productivity. Contrary to misconceptions, the kaolin clay film does not hinder photosynthesis due to reduced light penetration. In fact, it enhances photosynthetic efficiency by keeping treated plants cool. While untreated plants may stop photosynthesis during intense heat, those sprayed with kaolin clay continue the process into the afternoon, mitigating heat stress.

Importantly, the use of kaolin clay, specifically Surround WP, poses no harm to beneficial organisms such as predators and parasites essential for organic agriculture. These beneficial species can thrive on untreated weeds and intercrops. However, it is crucial to note that raw kaolin clay cannot be used directly for agricultural purposes, as it may cause severe damage or death to plants. Only authorized kaolin clay compounds formulated for agricultural use, such as Surround WP, should be employed. Using other forms of kaolin clay may result in plant toxicity and adverse outcomes.

5.2.4.2 How to Prepare and Use a Spray Solution from Surround WP

When preparing and using a spray solution from Surround WP (kaolin clay) in organic agriculture, it is essential to follow these important guidelines:

- **Slow Addition and Continuous Stirring:** Slowly add Surround WP powder into the spray tank while continuously stirring with the inverter on the spray machine. Continue stirring throughout the spraying process until the solution is completely sprayed.

- **Complete Coverage:** Ensure the spray solution covers the entire plant surface. After the water evaporates, a dry white film of kaolin clay should form on the plant, indicating proper distribution. The presence of a hazy white colour on all parts of the plant confirms that the kaolin is well-distributed, Figure 5.1.

- **Application Rate:** The typical application rate for Surround WP is 3-6 kg per 100 liters of water. This rate may double for certain crops, depending on plant size or leaf density.

- **Sufficient Spray Volume:** Use enough spray volume to ensure full coverage of all plant parts, including leaves, stems, fruits, and branches. Multiple sprays may be needed for complete coverage.

- **Factors Affecting Stability:** Severe rainfall and strong winds may reduce the stability of the kaolin clay film. Re-spraying may be necessary under these conditions or for new plant growth.

» **Worker Safety:** Although Surround WP is environmentally friendly and safe, workers should wear protective clothing and masks to avoid exposure to dust during mixing and spraying.

» **Thorough Cleaning:** Wash the spray tank and hoses thoroughly with water after completing the spraying process. Ensure there are no sediments in the tank to prevent blockages in the spraying machine and hoses.

» **Pre-Harvest Interval (PHI):** There is no Pre-Harvest Interval (PHI) for plants treated with Surround WP, meaning they can be harvested on the same day as treatment. However, treated plants and fruits should be washed after harvest to remove the kaolin clay layer, especially for fruits intended for market. For fruits or vegetables that are difficult to wash after maturity, it is advisable to apply kaolin clay only during the initial growth stages to avoid reducing market value.

Figure 5.1. Pomegranate Trees After being Sprayed with Surround WP to Prevent Infection by Aphids and the Pomegranate Butterfly.

In conclusion, kaolin clay is a versatile and effective tool in organic farming, offering a non-toxic and environmentally friendly solution for pest control and plant protection. Its use as a barrier against insect pests, sunburn, and certain plant diseases makes it an essential component of Integrated Pest Management (IPM) strategies. While it requires frequent application and may leave a white residue on plants, its safety, broad-spectrum efficacy, and ability to protect crops without harming beneficial organisms make it a highly valuable asset in organic agricultural systems.

5.3 Mechanical Pest Control in Organic Agriculture

Mechanical pest control is a crucial component of organic agriculture, offering a non-chemical approach to managing pest populations through physical means. This method involves using tools, devices, or manual techniques to prevent, reduce, or eliminate pests from crops, promoting a safer environment for both the ecosystem and human health. In organic farming, where synthetic pesticide use is restricted, mechanical pest control methods play a particularly valuable role in sustainable pest management.

Several techniques fall under the category of mechanical pest control, including light traps, which attract nocturnal insects by emitting light during the night, and coloured sticky traps that use bright colours and sticky surfaces to capture insects. Another common method is pheromone traps, which utilize insect pheromones to lure and trap specific pest species. The goal of using these insect traps is to capture pests intensively and reduce their population densities, a technique known as "mass trapping."

Other mechanical pest control methods include fruit bagging, which involves enclosing fruits in protective bags to prevent damage from insects and larger pests like birds. Another method is the use of trap crops, where certain crops are planted to attract pests away from the main crop, thus reducing damage to the primary harvest.

5.3.1 Use of Light Traps for Pest Control

Light Light traps are an effective tool in organic agriculture for managing nocturnal insect pests, facilitating mass trapping of both male and female insects, and significantly reducing pest spread and population. Various types of light traps are used to capture nocturnal insects, including solar-powered light traps (Figure 5.2.). Light traps are particularly useful for the intensive or collective capture of nocturnal pests such as moths, butterflies, beetles, leafhoppers, and flies. These pests are commonly found in a variety of crops, including cereal crops like rice, corn, and sorghum; legumes such as chickpeas, peas, and lentils; vegetable crops like okra, cauliflower, cabbage, tomatoes, and eggplants; and horticultural crops such as mangoes, pomegranates, apples, guava, coconuts, and bananas.

Table 5.10. illustrated examples of using light traps to control insect pests in various crops in organic agriculture through mass trapping.

Table 5.10. Examples of Mass Trapping Insect Pests in Organic Agriculture.

Target Pest		Host Plants
Common Name	**Scientific Name**	
Fruit Stalk Borer	*Oryctus agamemnon* Burmeister (Coleoptera: Scarabaeidae)	Date palm
Rhinoceros Beetle	*Oryctus rhinoceros* (Linnaeus) (Coleoptera: Scarabaeidae)	Date palm and coconut palm.
Longihorn Stem-Borer	*Jebusea hammerschmidti* Reiche (Coleoptera: Cerambycidae)	Date palm.
Tomato Leafminer	*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)	Tomato and eggplant.
Tobacco Hornworm	*Manduca sexta* (L.) (Lepidoptera: Sphingidae)	Tobacco, tomato and pepper.
True armyworm	*Mythimna unipuncta* (Haworth) (Lepidoptera: Noctuidae)	Barley, corn, millet, oats, rice, rye, sorghum and sugarcane.
Black cutworm	*Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae)	Alfalfa, clover, rice, sorghum, strawberry and sugarbeet.
Cabbage looper	*Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae)	Cabbage, cauliflower, mustard, turnip, beet, cucumber and lettuce.
Cotton bollworm	*Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)	Tomato, cotton, chickpea, rice, sorghum, and cowpea.

Figure 5.2. Solar Powered Light Trap.

5.3.2 Use of Coloured Sticky Traps for Pest Control

Coloured sticky traps are an effective and environmentally friendly tool for pest control in organic agriculture. These traps consist of brightly coloured surfaces coated with a sticky adhesive that captures insects upon contact. The colour of the trap is crucial, as different colours attract different types of pests. For instance, yellow traps are highly effective in attracting whiteflies, winged aphids, leaf miners, and thrips, while blue traps are commonly used to control thrips in specific crops.

Coloured sticky traps are widely used in various organic farming systems, including vegetable, fruit, and ornamental crop production. They are particularly useful for monitoring and controlling pest populations in crops like tomatoes, cucumbers, peppers, lettuce, and citrus trees. Additionally, they are highly effective in reducing greenhouse infestation rates by capturing insect pests. Sticky traps can be used in the form of boards or strips for mass trapping in greenhouses and nurseries, as shown in Figure 5.3.

In addition to controlling pests, sticky traps serve as valuable monitoring tools, helping farmers assess pest pressure and determine when further control measures may be necessary.

To maximize the effectiveness of coloured sticky traps, they should be strategically placed at various heights throughout the crop field, depending on the specific pest species targeted. Traps should be regularly checked, cleaned, and replaced to maintain their effectiveness.

Figure 5.3. Yellow and Blue Sticky Traps Used as Boards or Strips for Mass Trapping of Insect Pests.

5.3.3 Use of Pheromones for Pest Control

Pheromones are chemical substances secreted by insects that play a crucial role in communication, particularly in mating and aggregation. These compounds are used by insects to exchange information and are categorized based on their function, including sex pheromones, aggregation pheromones, anti-aggregation pheromones, alarm pheromones, trail pheromones, dispersal pheromones, and marking pheromones.

Among these, sex pheromones and aggregation pheromones have gained significant attention and practical use in pest control. These pheromones are highly specific to particular insect species and are biologically effective even at very low concentrations. Importantly, they pose no risk to the environment, including humans, animals, and plants, when used in insect pest management practices. In organic agriculture, pheromones are utilized through three primary methods: mass trapping, mating disruption, and lure and kill.

5.3.3.1 Mass Trapping

Mass trapping is a highly effective pest control method in organic agriculture that uses pheromone traps containing high concentrations of aggregation or sex pheromones to reduce the population of specific insect pests. Pheromones, which are chemical signals used by insects for communication, are deployed in traps to lure pests in large numbers. This method disrupts the reproductive cycle, preventing pests from finding mates and reproducing, thereby reducing pest populations over time.

Aggregation pheromones, such as those used in date palm plantations to control the Red Palm Weevil (*Rhynchophorus ferrugineus*), attract both males and females. Sex pheromones, like those used in apple orchards to control the Codling Moth (*Cydia pomonella*), in date palm for the Lesser Date Moth (*Batrachedra amydraula*), and in apples and pears for the Leopard Moth (*Zeuzera pyrina*), attract only males.

Figures 5.4. and 5.5. illustrate pheromone traps used for mass trapping. Table 5.11. provides examples of pests controlled through mass trapping using commercial pheromones in traps.

Pheromone traps are highly specific to the targeted pest species, ensuring that beneficial insects and other non-target organisms are not affected. By capturing large numbers of pests, mass trapping helps manage pest populations over time, reducing the risk of infestations and damage to crops. To maximize the effectiveness of mass trapping, pheromone traps should be strategically placed based on pest behavior, crop type, and the season. Regular monitoring and maintenance of the traps are essential to ensure their continued efficiency in capturing pests.

Figure 5.4. Mass Trapping of Red Palm Weevil Using Pheromone Traps.

Figure 5.5. Mass Trapping of Codling Moth and Lesser Date Moth Using Pheromone Traps.

Table 5.11. Examples of Using Pheromone Traps to Control Insect Pests in Organic Agriculture by Means of Mass Trapping.

Target Pest		Host Plants	Commercial Pheromone
Common Name	**Scientific Name**		
Red Palm Weevil	*Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae)	Date palm and coconut palm.	Ferrolure+
American Palm Weevil	*Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae)	Pineapple, oil palm, banana and avocado.	Rhyncolure.
Rhinoceros Beetle	*Oryctes rhinoceros* (Linnaeus) (Coleoptera: Scarabaeidae)	Coconut palm and date palm.	Oryctalure.
Lesser Date Moth	*Batrachedra amydraula* Meyrick (Lepidoptera: Batrachedridae)	Date palm.	(4z,7z) decadien-1-yl-acetate & 5z decen-1-yl-acetate (1/2 ratio).
Codling Moth	*Cydia pomonella* (L.) (Lepidoptera: Tortricidae)	Apples, pears and walnuts.	Isomate-C, Codlemone.
Citrus Flower Moth	*Prays citri* (Millière) (Lepidoptera: Yponomeutidae)	Citrus.	(Z) -7- tetracdecenal.
Western Flower Thrips	*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)	Vegetables and berries.	Thripline.
Leopard Moth	*Zeuzera pyrina* L. (Lepidoptera: Cossidae)	Apples, pears, olives and plums.	(E,Z)- 2,13-octodecadienil acetate.

5.3.3.2 Mating Disruption

Mating disruption is an advanced pest control method that involves the release of synthetic sex pheromones into a pest's environment to interfere with the normal mating behavior of the target insect species. This strategy primarily confuses male insects by overwhelming them with a high concentration of pheromones, making it difficult for them to locate female insects for mating. As a result, the reproduction cycle is disrupted, leading to a gradual decline in the pest population over time.

In organic agriculture, mating disruption is a valuable tool as it provides an eco-friendly alternative to chemical pesticides, aligning with the principles of Integrated Pest Management (IPM). Mating disruption relies on the mass release of synthetic pheromones that mimic the natural sex pheromones produced by female insects.

These pheromones are delivered using various dispensers, such as: Rubber capsules, Twist-tie polyethylene dispensers, Laminate flakes, and Twin ampulla dispensers. These pheromone dispensers are strategically placed throughout the farm to ensure widespread distribution and coverage of the target area.

The pheromones are often released in timed intervals to coincide with the pest's mating period, maximizing the effectiveness of the disruption. Mating disruption is commonly used to control pests like the Codling Moth (*Cydia pomonella*) in apple orchards, the Grapevine Moth (*Lobesia botrana*) in vineyards, and the Peach Twig Borer (*Anarsia lineatella*) in stone fruit crops.

The benefits of using mating disruption to control pests in organic agriculture are significant, as it is an environmentally friendly method that is non-toxic and reduces reliance on chemical pesticides. This approach is highly targeted, affecting only the specific pest species and minimizing harm to beneficial insects and other wildlife. Additionally, mating disruption offers long-term control by preventing reproduction, leading to a sustained reduction in pest populations over time.

Figure 5.6. illustrates the use of mating disruption to control the Codling Moth, and Table 5.12. provides examples of other pests controlled through mating disruption.

5.3.3.3 Lure and Kill

The lure and kill method is a pest control strategy that combines the attraction of pests with a lure (such as pheromones or food attractants) and the subsequent killing of the attracted pests with organic pesticides, such as pyrethrum or rotenone. This method is highly effective in organic agriculture, as it reduces the need for broad-spectrum chemical pesticides while specifically targeting the pest species.

In the lure and kill approach, a combination of sex pheromones, food baits, or visual attractants is used to lure pests to a specific location, where they come into contact with a toxic substance, such as an insecticide-treated surface or trap. The toxicity comes from natural substances or those approved for use in organic farming. Once attracted, the pests are killed either directly by the toxic agent or after prolonged exposure.

Figure 5.6. Mating Disruption Pheromone Used to Control Codling Moth (*Cydia Pomonella*).

The lure and kill method is widely used across a variety of crops, including fruit orchards, vineyards, and vegetable farms. It is especially beneficial for managing insect populations that are challenging to control with traditional methods. This approach is particularly effective for controlling pest species that rely heavily on chemical communication for mating and foraging, such as the Mediterranean fruit fly (*Ceratitis capitata*), codling moth (*Cydia pomonella*), and various species of weevils.

Various types of traps, including electronic traps and aquatic traps with insect attractants, are used in the lure and kill method. Table 5.13. provides examples of pests controlled using commercially available lure and kill traps.

Table 5.12. Examples of Using Sex Pheromones to Control Insect Pests in Organic Agriculture Through Mating Disruption.

Target Pest		Host Plants	Commercial Pheromone
Common Name	**Scientific Name**		
European Grapevine Moth	*Lobesia botrana* (Denis & Schi.) (Lepidoptera: Tortricidae)	Grapes.	RAK 2 Quant L.b.
Codling Moth	*Cydia pomonella* (L.) (Lepidoptera: Tortricidae)	Apples, pears and walnuts.	Isomate-C Codlemone Disrupt CM
Beet Armyworm	*Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae)	Cotton and vegetables.	Isomate BAW Hercon Disrupt BAW No-Mate BAW
Peach Twig Borer	*Anarsia lineatella* Zeller (Lepidoptera: Gelechiidae)	Stone fruits.	RAK 6 CheckMate PTB-F Hercon Disrupt PTB
Tomato Pinworm	*Keiferia lycopersicella* (Walsingham) (Lepidoptera: Gelechiidae)	Vegetables.	NoMate TPW ChekMate TPW Frustrate TPW
Oriental Fruit Moth	*Grapholita molesta* (Busck) (Lepidoptera: Tortricidae)	Peach and nectarine.	Isomate-M Hercon Disrupt OFM RAK 5
Diamondback Moth	*Plutella xylostella* (L.) (Lepidoptera: Plutellidae)	Cabbage and vegetables.	NoMate DBM Isomate DBM
Pink Bollworm	*Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae)	Cotton.	Nomate PBW Pectone Frustrate PBW
Rice Stripped Stem Borer	*Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae)	Rice.	Isomate RSB Selibate CS
Apple Clearwing Moth	*Synanthedon myopaeformis* Borkh. (Lepidoptera: Sesiidae)	Plum, apricot, peach and apple.	RAK 7
Artichoke Plume Moth	*Platyptilia carduidactyla* (riley) (Lepidoptera: Pterophoridae)	Vegetables.	Disrupt APM Isomate APM

Table 5.13. Examples of Using Lure and Kill Method to Control Insect Pests in Organic Agriculture Through Traps Containing Pheromones.

Target Pest		Host Plants	Commercial Pheromone
Common Name	**Scientific Name**		
Melon Fly	*Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae)	Cucurbits.	Cuelure
Mediterranean Fruit Fly	*Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae)	Citrus.	Trimedlure
Olive Fly	*Bactrocera oleae* Gmel. (Diptera: Tephritidae)	Olive.	Polycore SKL
Pink Bollworm	*Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae)	Cotton.	Sirene PBW (plus permethrin)

5.3.4 Fruit Bagging

Fruit bagging is an effective preventive measure in organic agriculture to protect fruits from insect pests such as fruit flies, thrips, and aphids. This method involves covering individual fruits or branches with bags, which serve as physical barriers, preventing pests from reaching the fruits and laying eggs.

Three types of bags are commonly used for fruit bagging: polythene or plastic bags (as shown in Figures 5.7. and 5.8.), wax paper bags (Figure 5.9.), and paper exclusion bags (Figure 5.10.). In addition to protecting against insect pests, bagging banana fruits also shields them from thrips and aphids, particularly *Pentalonia nigronervosa*, a vector of the Banana Bunchy Top Virus.

Figure 5.7. Bagging of Grapes, Mangoes, Bananas, and Guava fruits with Polythene Bags to Prevent Insect Pest Infestation in Oman.

For date palms, bagging fruit bunches with various materials influences yield and fruit quality by protecting them from weather conditions, insects, birds, and bats. Bagging also helps ensure fruit setting, reduces fruit drop, and accelerates ripening. The process typically lasts for 20-25 days or until the fruits ripen and harvesting begins. Date palm fruit bunches are often covered with plastic mesh net bags, (Figure 5.11.), which are available in different colours based on environmental conditions and the desired ripening speed. Black bags are used in regions with rapid temperature fluctuations between summer and winter to delay ripening, while green bags are employed in hotter climates to accelerate ripening. White bags are typically used to delay ripening and maintain the Khalal or Bisr stage, which can enhance market returns, especially for varieties like Barhi. However, applying bags before the colouring phase can increase moisture around the fruits, making them more susceptible to fungal diseases.

Figure 5.8. Bagging of Nectarine and Bidam Fruits with Polythene Bags to Prevent Fruit Fly Infestation in Oman.

Figure 5.9. Bagging of Pear Fruits with Sulfur-Treated Wax Paper Bags to Prevent Fruit Fly Infestation in South Korea.

Figure 5.10. Bagging of Mango Fruits with Paper Exclusion Bags to Prevent Fruit Fly Infestation in Oman.

Figure 5.11. Bagging of Date Bunches with Different Colours of Plastic Bags to Prevent Insect Infestation and Protect Dates from Bird and Bat Attacks in Oman.

5.3.5 Trap Crops

The use of trap crops is a proven method for mechanically controlling pests in organic agriculture, effectively diverting insect pests away from the main crop. This technique protects the main crop by either preventing pests from reaching it or by confining them to specific areas of the field where they can be economically managed. The fundamental principle behind trap crops lies in the host preferences of insects. When trap crops are strategically planted alongside or around the main crop, they attract pests, which can then be trapped and effectively controlled. To be successful, trap crops must be more attractive to pests than the main crop. They may belong to a different species or be of the same species but planted at a different time.

Trap crops offer numerous benefits, including improved crop quality, the attraction of beneficial insects, and enhanced biodiversity. For example, Indian mustard planted alongside cabbage serves as a trap crop for controlling the diamondback moth, aphids, and leaf webbers. African marigold is another effective trap crop for managing the American bollworm, as it attracts adult moths to lay eggs on its leaves. Additionally, maize plants can function as trap crops to lure fruit fly adults in vegetable cultivation, where fruit flies are a significant pest. Table 5.14. provides more examples of trap crops that can be planted with the main crop to attract and control pests mechanically.

Table 5.14. Examples of Trap Crops That Can be Planted Alongside the Main Crop to Attract Pests and Control them Mechanically.

Main Crop	Trap Crop	Method of Planting Trap Crop	Target Pest
Potato	Hot Radish	Among the plants of the main crop	Colorado potato beetle (*Leptinotarsa decemlinata*)
Garlic	Basil Marigold	Around the border of the field	Thrips
Brassicaceae	Radish	Rows between the plants of main crop	Flea beetle Root maggot
Sweet Corn	Black Mustard Brassica nigra	Among the plants of the main crop	Sting bug (*Nezara viridula*)
Tomato	Dill	Rows between the plants of main crop	Tomato hornworm (*Manduca quinquemaculata*)
Soybeans	Sespania	Rows between the plants of main crop	Sting bug (*Nezara viridula*)
Maize	Soybeans	Rows between the plants of main crop	*Heliotis* sp.

5.4 Biological Pest Control in Organic Agriculture

Interest in biological control for pest management, particularly through the use of predators and parasites, has persisted for over a century. However, in recent years, there has been a significant surge in attention for two key reasons. Firstly, the documented successes of this approach have captured the interest of pest control practitioners. Secondly, growing concerns over environmental degradation and pollution caused by the unregulated and intensive use of chemical pesticides in agriculture have highlighted the importance of exploring alternative methods.

Biological control, utilizing predators and parasites, is a cornerstone of pest management strategies in organic agriculture. This approach involves either encouraging the proliferation of natural enemies of pests within the same ecosystem or introducing beneficial organisms and acclimating them to local conditions to reduce pest populations.

Tawfiq (1997) defines parasitism and predation as follows:

Predation involves a symbiotic relationship in which a predator hunts one or more members of another species, referred to as prey, to sustain itself. The predator typically consumes its prey over a limited period, which is shorter than the prey's entire feeding phase.

Parasitism is a symbiotic relationship in which one participant, the parasite, resides and obtains nutrients from another participant, the host. The parasite may live and feed either within the host’s body or externally on its surface during one or both of its feeding phases, complete or incomplete.

According to some scientists, parasitic insects are more accurately classified as “parasitoids” rather than parasites. Parasitoids, like predators, complete their development by feeding on a single host organism, often killing the host in the process. However, despite this distinction, the term "parasites" is commonly used in conventional terminology.

Parasitic and predatory insects are integral to biological pest control. The practice of biological control dates back to pre-Islamic times, when Arabs relocated nests of predatory ants from deserts to control common ants infesting date palms.

The following outlines the different approaches to using parasites and predators in biological control.

5.4.1 Classical Biological Control

Classical biological control, also known as importation biological control, is a method used to manage pest populations by introducing natural enemies, such as predators, parasitoids, or pathogens, from the pest's native range into a new environment. The goal is to establish sustainable and self-perpetuating populations of these natural enemies, which will then help control the target pest population. The process of classical biological control typically involves several key steps:

» **Pest Identification:** The target pest species and its natural enemies are identified, usually within the pest's native habitat.

» **Exploration and Collection:** Natural enemies of the pest are identified and collected from its native range. This step often involves extensive fieldwork to find suitable natural enemies that are effective against the pest while posing minimal risk to non-target species.

» **Importation and Quarantine:** The collected natural enemies are transported to the area where the pest is causing damage. Before release, these organisms undergo rigorous testing and quarantine procedures to ensure they are free from pathogens and other potential risks.

» **Release and Establishment:** Once cleared, the natural enemies are released into the target area. The aim is for them to establish self-sustaining populations that can control the pest over the long term.

» **Monitoring and Evaluation:** The success of the biological control program is continually monitored to assess its impact on the pest population and the broader ecosystem. Adjustments to the program may be made based on ongoing evaluations.

Classical biological control has been successfully used to manage a wide range of pest species across various agricultural and natural ecosystems. Notable examples include the introduction of the vedalia beetle (*Rodolia cardinalis*) to control the cottony cushion scale (*Icerya purchasi*, Hemiptera: Monophlebidae) in California, and the use of parasitoid wasps (*Tetrastichus planipennisi*, *Spathius agrili*, and *Oobius agrili*) to manage invasive pests such as the emerald ash borer (*Agrilus planipennis*, Coleoptera: Buprestidae).

While classical biological control can be an effective and environmentally sustainable pest management strategy, it requires careful planning, extensive research, and collaboration among scientists, government agencies, and agricultural stakeholders to ensure its success. Additionally, there are inherent risks associated with introducing non-native species into new environments, making thorough risk assessments and continuous monitoring essential to minimize unintended consequences.

The following are examples of successful classical biological control in managing various insect pests worldwide, with many cases highlighting its effectiveness in organic agriculture.

- **Cottony Cushion Scale, *Icerya purchasi* Maskell**

(Hemiptera: Monophlebidae)

Classical biological control of Cottony Cushion Scale (*Icerya purchasi*) is one of the most well-known and successful examples of this approach. In the late 19th century, *Icerya purchasi* caused significant damage to citrus orchards in California, threatening the state's growing citrus industry. Native to Australia, the pest was accidentally introduced to California, where it quickly spread and devastated citrus crops.

In 1888, the United States implemented classical biological control by introducing the vedalia beetle (*Rodolia cardinalis*), a species of lady beetle (Coleoptera: Coccinellidae), from its native habitat in Australia. The vedalia beetle preyed effectively on the cottony cushion scale, leading to a rapid decline in the pest population. Within a few years, the beetle had successfully controlled the infestation, effectively saving California's citrus industry from collapse.

This biological control method has since been applied to various regions, including New Zealand, the Hawaiian Islands, Italy, and Peru, where the introduction of the vedalia beetle similarly controlled *Icerya purchasi* populations.

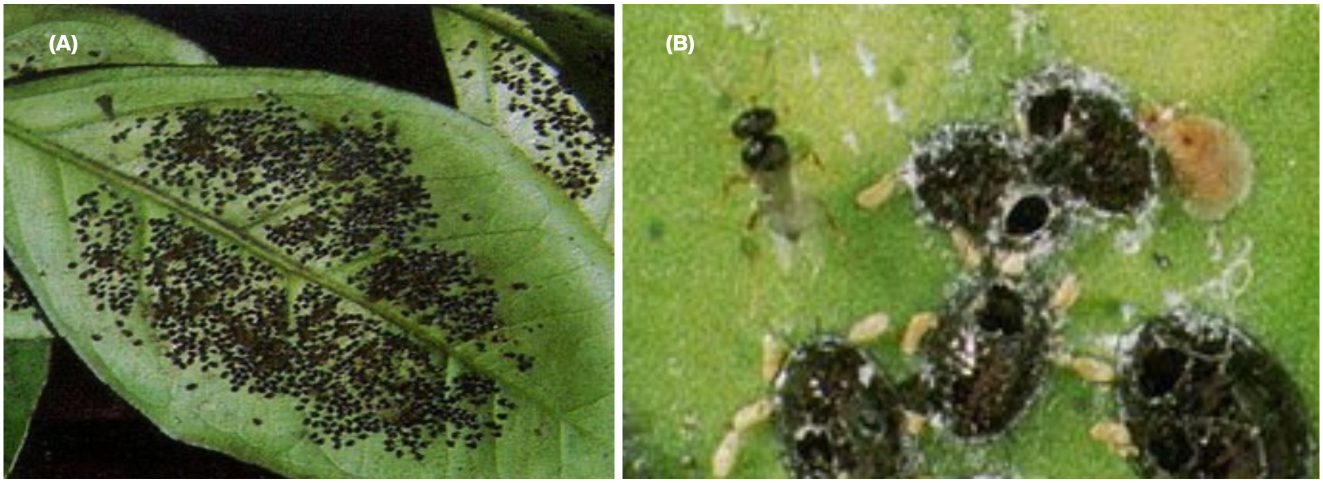
- **Citrus Black Fly, *Aleurocanthus woglumi* Ashby**

(Homoptera: Aleyrodidae)

The classical biological control of the Citrus Black Fly (*Aleurocanthus woglumi*), a significant pest of citrus and other crops, stands as a successful example of managing invasive species through natural enemies. Native to Southeast Asia, the citrus black fly was first detected in the Caribbean and later in parts of Central and South America in the early 20th century. By the mid-20th century, it had spread to southern Texas, Florida, and Mexico, posing a serious threat to citrus orchards due to its ability to cause leaf damage and reduce fruit yields.

In the 1970s, biological control programs were initiated to combat this pest. Several natural enemies of the citrus black fly were introduced into affected regions, including the parasitic wasps *Encarsia opulenta* and *Encarsia perplexa* (Hymenoptera: Aphelinidae). These parasitoid wasps, native to the pest's original habitat, were imported, bred in large numbers, and released into infested areas. The wasps effectively parasitize the immature stages of the citrus black fly, reducing the pest population by killing larvae and pupae.

Figure 5.12. A. Citrus Black Fly (*Aleurocanthus woglumi*) on the Lower Side of Citrus Leaves
B. The Parasitoid Wasp (*Encarsia* opulenta) and Its Round Exit Holes from Pupae.



The introduction of *Encarsia* species successfully reduced citrus black fly populations in many regions, including Mexico, the Caribbean, and parts of the southern United States. The long-term establishment of these parasitoids provided an ecologically sustainable solution, significantly reducing the damage caused by *A. woglumi* without the need for chemical pesticides.

Additionally, the parasitoid *Eretmocerus serius* (Hymenoptera: Aphelinidae) was introduced from India to combat citrus black fly in regions like Cuba and the Panama Islands. In Mexico, *Amitus hesperidum* and other parasitoids were imported from India and Malaysia to control the pest. In Oman, Kinawy (1987) reported successful control of the citrus black fly in both the northern and southern regions of the country through the establishment of *Encarsia opulenta*, imported from India, Figure 5.12.

In organic citrus-growing regions worldwide, these biological control programs remain among the most notable successes in managing *Aleurocanthus woglumi* and continue to be an integral part of integrated pest management (IPM) strategies.

- **Sugarcane Leafhopper,**
  ***Perkinsiella saccharicida* Kirkaldy**
  (Hemiptera: Delphacidae)

Figure 5.13. Sugarcane Leafhopper, *Perkinsiella saccharicida* Kirkaldy

Biological control of the sugarcane leafhopper (*Perkinsiella saccharicida*), as illustrated in Figure 5.13., has been successfully achieved through various methods, including the introduction and establishment of natural enemies such as parasitoids and predators. One notable success involves the use of the egg parasitoid *Anagrus optabilis* (Hymenoptera: Mymaridae) to control sugarcane leafhopper populations in sugarcane fields. *A. optabilis* are tiny wasps that parasitize the eggs of leafhoppers, including *P. saccharicida*. These parasitoids lay their eggs inside the leafhopper eggs, and the developing larvae consume the contents of the host eggs, ultimately killing the leafhopper embryos. This biological control approach has been implemented in sugarcane-growing regions to effectively manage sugarcane leafhopper populations and reduce crop damage.

The key predators and parasitoids of *P. saccharicida* in sugarcane agroecosystems generally belong to hymenopteran insects, including the genera *Anagrus* (Mymaridae), *Haplogonatopus* (Dryinidae), *Pseudogonatopus* (Dryinidae), and *Aprostocetus* (Eulophidae), as well as the mirid bug *Tytthus* (Hemiptera: Miridae) and the fly *Pipunculus* (Diptera: Pipunculidae).

The most important natural enemy of *P. saccharicida* in sugarcane fields in Hawaii, USA, is the mirid bug *Tytthus mundulus* Breddin, an egg predator (Nguyen *et al*., 1984). *T. mundulus* was introduced to Hawaii in 1920 from Australia and Fiji for the control of the sugarcane leafhopper *P. saccharicida*. It became well established in the cane fields and was later also found feeding on the eggs of the corn leafhopper. Dryinids are particularly valued as parasitoids of nymphs and adults due to their dual role as both parasitoids and predators (Dupo & Barrion, 2009). Additionally, entomopathogenic fungi (*Metarhizium* sp. and *Beauveria* sp.) have proven effective against *P. saccharicida* nymphs and adults (Badilla *et al*., 2004).

- **Woolly Apple Aphid,**
  ***Eriosoma lanigerum* (Hausmann)**
  (Hymenoptera: Aphelinidae)

In the United States, New Zealand, and Australia, the woolly apple aphid (*Eriosoma lanigerum*) has been effectively managed through the introduction of the parasitoid wasp *Aphelinus mali* (Haldeman), (Hymenoptera: Aphelinidae), originally from the eastern United States. In Oman, Kinawy (2012) reported that *Aphelinus mali* was imported from the Atlas Mountains in Morocco and released on organic farms in Al-Jabal Al-Akhdar area and successfully control the woolly apple aphid infestations, which consider important pest attacking apples, Figure 5.14.

Aphelinus mali is widely recognized as the primary biological control agent against the woolly apple aphid. However, research conducted in Washington State has highlighted the significant contribution of a diverse group of generalist predators in managing this pest. These predators include lady beetles, syrphid fly larvae (*Sphaerophoria philanthus* Meigen), green lacewings, the predatory plant bug (*Deraeocoris brevis* Uhler) from the family Miridae, and European earwigs (*Forficula auricularia* Linnaeus).

While *Aphelinus mali* leaves behind evidence of parasitism in the form of mummified aphids, the role of predators is often underestimated because they consume entire aphid colonies or parts of them, leaving no visible evidence of their presence. Among these predators, syrphid fly larvae are easily noticeable within aphid colonies due to their sedentary behavior, while more mobile predators also contribute to aphid control. Nocturnal predators, such as the European earwig (*Forficula* auricularia), play a particularly important role in controlling woolly apple aphid populations in Washington and elsewhere, although their activity often goes unnoticed.

Figure 5.14. *Aphelinus mali* Parasitizing the Woolly Apple Aphid. The Exit Hole of the Parasitoid is Visible in the Upper Left.

- **Coconut Scale Insect,** ***Aspidiotus destructor*** **Signoret**

(Hemiptera: Diaspididae)

The coconut scale insect (*Aspidiotus destructor* Signoret), a serious pest of coconut palms and other tropical crops, feeds on the sap of leaves, stems, and fruits, causing yellowing, tissue distortion, and potentially leading to plant death. Over the years, biological control has been an essential strategy for managing *A. destructor* populations in various regions, with the introduction of natural enemies playing a significant role in successful pest control efforts.

One of the most successful biological control agents against the coconut scale insect is the coccinellid beetle *Chilocorus nigritus* (Fabricius) (Coleoptera: Coccinellidae). This predatory beetle has been widely used in tropical regions to manage *A. destructor* populations. Native to Southeast Asia, C. nigritus has been introduced in biological control programs in Hawaii and many other regions, including parts of Europe. It is one of the key predators of diaspid scale insects.

Kinawy (1991) documented that *Chilocorus nigritus*, shown in Figure 5.15., was introduced to the southern region of Oman in 1985 from India via the Commonwealth Institute of Biological Control to combat *A. destructor* infestations on coconut palms. The beetle proved to be highly effective, significantly reducing scale populations and preventing widespread damage to coconut plantations.

In addition to predatory beetles, parasitoid wasps like *Aphytis lingnanensis* Compere (Hymenoptera: Aphelinidae) have been successfully used in some countries to control *A. destructor* populations. These wasps lay their eggs inside the coconut scale, and their larvae consume the host, effectively controlling the pest. In the Philippines and Pakistan, *Aphytis lingnanensis* and other parasitoids such as *Aphytis melinus* DeBach and *Anagyrus* spp. (Hymenoptera: Encyrtidae) have been introduced to provide effective long-term control of *A. destructor* (Vargas, 1985; Abul-Nasr & Kalimullah, 1998).

Figure 5.15. The Coccinellid Beetle, *Chilocorus nigritus*.

- **Mealybug, *Pseudococcus* spp.**

(Homoptera: Diaspididae)

Classical biological control of *Pseudococcus* spp. has been successfully implemented in various countries, including citrus orchards, vineyards, and ornamental plants. For example, in the United States, control of mealybugs (*Pseudococcus* spp.) was effectively achieved through the introduction of two parasitoids imported from Japan: *Allotropa burrelli* (Hymenoptera: Platygastridae) and *Acerophagus* (= *Pseudaphycus*) *malinus* (Hymenoptera: Encyrtidae). Parasitoids, particularly those from the family Encyrtidae, have proven highly successful in controlling various pseudococcid pests, providing comprehensive control of several major mealybug species.

Additionally, in California, the release of *Cryptolaemus montrouzieri* (the mealybug destroyer), a voracious predator of mealybugs, has been a long-standing method for controlling *Pseudococcus* spp. in citrus orchards and vineyards. This predator beetle feeds on all life stages of mealybugs, providing an effective biological control strategy in these agricultural systems (Flaherty *et al*., 1992).

In South Africa, the introduction of the parasitoid *Anagyrus pseudococci* was a major success in the classical biological control of *Pseudococcus viburni* (obscure mealybug) in vineyards. The parasitoid wasp significantly reduced mealybug populations in grapevine systems, lowering the pest burden and enhancing grape yield and quality (Walton & Pringle, 2004).

In Australia, *Leptomastix dactylopii* was introduced to control *Pseudococcus longispinus* (longtailed mealybug) in ornamental plants and citrus crops. This parasitoid has been highly effective in managing mealybug infestations, reducing the need for chemical interventions (Smith *et al*., 2008). Similarly, in Brazil, the parasitoid wasp *Anagyrus lopezi* was introduced to control the cassava mealybug, *Phenacoccus manihoti*, a close relative of *Pseudococcus* spp. This program dramatically reduced mealybug infestations in cassava fields, safeguarding crop yields (Bellotti *et al*., 1999).

The previous examples highlight the global success of classical biological control in managing *Pseudococcus* spp., significantly reducing the reliance on chemical pesticides, and promoting sustainable pest management practices, particularly in organic agriculture.

- **Woolly Whitefly *Aleurothrixus floccosus* (Maskell)**

(Hemiptera: Aleyrodidae)

Woolly whiteflies (*Aleurothrixus floccosus*) are known pests of various citrus varieties, certain types of guava (*Psidium* spp.), and sea grape (*Coccoloba uvifera*). They have also occasionally been reported on yellow trumpet flower (*Tecoma stans*). Among citrus fruits, grapefruit, tangelos, and tangerines are most heavily colonized, followed by oranges and lemons, although significant populations can develop on any citrus type.

In the classical biological control of the woolly whitefly (*Aleurothrixus floccosus*), the parasitoid wasp *Cales noacki* (Hymenoptera: Aphelinidae) is recognized as one of the most effective biological control agents. Native to South America, *Cales noacki* has been introduced to many regions around the world, including the Mediterranean, California, and parts of the Middle East, to control woolly whitefly populations in citrus groves. This wasp is a solitary endoparasitoid, meaning it lays its eggs inside the immature stages of the woolly whitefly. The developing larva consumes the whitefly from the inside, eventually killing it. Once the larva has fully developed, the adult wasp emerges, leaving behind a characteristic exit hole in the dead whitefly.

In the 1970s, *Cales noacki* was introduced in Spain (Mediterranean Region) as part of a biological control program aimed at reducing woolly whitefly infestations in citrus groves. The introduction was highly effective, leading to a significant reduction in woolly whitefly populations and a drastic decrease in the use of chemical insecticides in affected areas (Arzone and Vidano, 1980; Viggiani, 1985). Similarly, in California, *Cales noacki* was introduced to control *A. floccosus* in citrus orchards, where it quickly established and provided long-term control, reducing the need for chemical treatments in many citrus-growing regions (Bellows *et al*., 1985).

In addition to Spain and California, *Cales noacki* was introduced in Italy, where it rapidly established in citrus orchards and significantly reduced woolly whitefly populations, contributing to sustainable pest management (Viggiani & Battaglia, 1987). In Syria, *Cales noacki* was imported from Italy to control the woolly whitefly on citrus trees, where it achieved significant control of the pest and further supported sustainable pest management practices (Al-Ali and Afiuni, 1992).

In conclusion, the introduction of *Cales noacki* as a classical biological control agent has been highly successful in managing the woolly whitefly, Aleurothrixus floccosus, in several countries. This approach has significantly reduced the reliance on chemical pesticides and promoted sustainable pest management practices in citrus production systems.

- **Biological Control of Plant Mites, thrips and whiteflies on Avocado Trees**

Biological control is a crucial strategy for managing plant mites, thrips, and whiteflies on avocado trees, promoting sustainable and environmentally friendly pest management. Several natural enemies, including predatory mites, parasitoids, and generalist predators, are effectively used to control these pests.

Common mite pests on avocado trees include the avocado brown mite (*Oligonychus punicae*), the six-spotted spider mite (*Eotetranychus sexmaculatus*), and the Persea mite (*Oligonychus perseae*). Biological control of these mites involves the release of predatory mites such as *Phytoseiulus persimilis* and *Euseius hibisci*, which feed on pest mites, reducing their populations and minimizing damage to avocado trees (Hoddle, 1999).

Additionally, the predatory mite *Galendromus helveolus* Chant (Mesostigmata: Phytoseiidae), also known as *Typhlodromus helveolus*, has been successfully used in Florida, USA, to control various plant mites, thrips, and whiteflies, particularly on avocado trees. *G. helveolus* is a specialist predator of spider mites and plays a crucial role in reducing mite populations in subtropical fruit crops in Florida (Peña & Osborne, 1996). Originally introduced in Florida, *G. helveolus* is now present in California, Texas, Mexico, and Central America. This predator exhibits a female-biased sex ratio and feeds on all stages of spider mites, with a preference for eggs and protonymphs. Its life cycle lasts approximately 11 days, and females can lay around 41 eggs during their lifespan of about 25 days (Castillo & Peña, 2008).

Thrips, such as *Scirtothrips perseae* (avocado thrips), can cause significant damage to avocado trees by feeding on leaves and fruits. Biological control agents like the predatory bug *Orius* spp., lacewings, and six-spotted thrips (*Scolothrips sexmaculatus*) are commonly used to manage thrip populations. These predators effectively reduce thrip numbers, especially when combined with proper orchard management practices (Hoddle, 2005).

Whiteflies, such as the woolly whitefly (*Aleurothrixus floccosus*), can also infest avocado trees. Parasitoid wasps like *Cales noacki* are highly effective in controlling whitefly populations. *C. noacki* parasitizes the immature stages of whiteflies, killing them and preventing further infestations (Viggiani & Battaglia, 1987). Predators such as *Cryptolaemus montrouzieri* (the mealybug destroyer) may also help control whitefly populations in avocado orchards (Bellows *et al*., 1985).

- **Biological Control of Various Plant Mites and Thrips Using the Predatory Mite**

Euseius hibisci (Chant)
(Mesostigmata: Phytoseiidae)

Euseius hibisci, Figure 5.16., is a highly effective predatory mite used in the biological control of various plant mites and thrips, particularly in subtropical and tropical agricultural systems. As a generalist predator, *E. hibisci* feeds on a wide range of mite and thrip species, making it a valuable tool for sustainable pest management.

Like other predatory mites, *E. hibisci* feeds on multiple stages of pest mites, including eggs, nymphs, and adults. In the absence of mite prey, *E. hibisci* can survive and reproduce using alternative food sources such as pollen, aphid honeydew, mildew, lantania scale crawlers (*Hemiberlesa lataniae*), and leaf exudates. This adaptability enhances its potential for long-term establishment in orchard environments.

E. hibisci is commonly released to control several economically important mite species. It targets pest mites such as the two-spotted spider mite (*Tetranychus urticae*), avocado brown mite (*Oligonychus punicae*), Pacific spider mite (*Tetranychus pacificus*), European red spider mite (*Panonychus ulmi*), broad mite (*Polyphagotarsonemus latus*), and citrus red mite (*Panonychus citri*) (McMurtry & Croft, 1997). By feeding on these pest mites, *E. hibisci* significantly reduces their populations and minimizes damage to crops like avocado, citrus, and ornamentals.

Research conducted by McMurtry and Croft (1997) highlights that *E. hibisci* is well-adapted to high-temperature environments, allowing it to thrive where other predatory mites may be less effective. Its rapid reproduction in the presence of prey makes it an excellent biocontrol agent in orchards and greenhouses.

In addition to controlling mites, *E. hibisci* is an effective predator of thrips, including key pests like the western flower thrips (*Frankliniella occidentalis*) and avocado thrips (*Scirtothrips perseae*) (Hoddle, 2005). *E. hibisci* feeds on thrips eggs and larvae, providing substantial control of these pests. Studies have shown that using *E. hibisci* in combination with other natural enemies, such as lacewings or predatory bugs (*Orius* spp.), enhances its efficacy in controlling thrips populations. This integrative approach is essential for reducing reliance on chemical pesticides and promoting more sustainable practices in organic agriculture.

- **Biological Control of Various Plant Mites Using the Predatory Mite**

Neoseiulus californicus McGregor
(Mesostigmata: Phytoseiidae)

Neoseiulus californicus is distributed across arid and humid regions of semi-tropical and temperate South America, as well as arid areas of southern California and Europe. This predatory mite specializes in preying on spider mites and has been successfully employed to control spider mite populations on various crops, including strawberries, corn, soybeans, apples, peaches, and ornamental plants.

N. californicus also consumes pollen and can survive winter in the adult stage. As temperatures rise, this predator migrates from ground cover to tree canopies in search of prey. With a short life cycle of approximately 6 days, female *N. californicus* can lay about 60 eggs during their 23-day lifespan. This species is commercially produced and, like other predatory mites, is effectively utilized to reduce populations of various plant-damaging spider mites on the mentioned crops.

Flint and Dreistadt (1998) illustrated several species of predatory mites commonly used in biological control strategies, as depicted in Figure 5.16.

Figure 5.16. A. *Galendromus annectens* (De Leon), **B.** *Galendromus helveolus*, **C.** *Neoseiulus californicus* Mc Gregor and **D.** *Euseius hibisci*.

In addition to the previous examples, Kinawy *et al*. (2008) highlighted several significant classical biological control projects successfully implemented in both organic and conventional farms in Oman, as follows:

» **1984:** The parasitoid wasp *Encarsia opulenta* Silvestri was imported from (Florida) USA and released to combat the citrus black fly, *Aleurocanthus woglumi* (Hymenoptera: Aphelinidae). This effort resulted in the successful control and eventual eradication of the pest from citrus orchards in both the northern and southern regions of Oman.

» **1985:** The coccinellid beetle *Chilocorus nigritus* (Fabricius), a species of lady beetle, was imported from India through the Commonwealth Institute of Biological Control to control the coconut scale insect, *Aspidiotus destructor*. This beetle effectively managed the coconut scale insect that was attacking coconut plantations in the southern region of Oman.

» **1989:** A project successfully utilized the specialized virus *Rhabdionvirus oryctes* to control the coconut rhinoceros beetle, *Oryctes rhinoceros* (Coleoptera: Scarabaeidae), which was prevalent in southern Oman. Kinawy (2004) reported that three years after the virus introduction, the damage caused by *O. rhinoceros* was dramatically reduced to about half. In the fourth, fifth, and sixth years following the introduction, the damage continued to decrease, with the lowest levels of damage recorded in the fifth and sixth years.

» **1997:** The mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae), was imported from the UK for deployment in Oman. In April 1997, 3,500 adult beetles were released and successfully established themselves. *C. montrouzieri* is now highly effective against various species of mealybugs, including the citrus mealybug (*Planococcus citri*) and the hibiscus mealybug (*Maconellicoccus hirsutus*), which were significant pests affecting various fruit trees and date palms.

» **2002:** Three natural enemies were imported and released in Oman: the lady beetles *Hippodamia convergens* and *Harmonia axyridis*, along with the parasitoid wasp *Aphidius colemani*. These biological control agents successfully managed two widespread aphid species, the pomegranate aphid (*Aphis punicae*) and the melon aphid (*Aphis gossypii*), which attack pomegranate, apple, and pear trees in Al-Jabal Al-Akhdar, Oman.

» **Since 2003:** *Trichogramma* spp., egg parasitoids, have been regularly released in organic farms in Al-Jabal Al-Akhdar, Oman, to successfully combat the pomegranate butterfly (*Virachola livia*), a significant pest of pomegranate fruits.

These successful biological control programs have been implemented in organic farms across Al-Jabal Al-Akhdar and Salalah plain regions of Oman, contributing to effective pest management strategies, as shown in Table 5.15.

Table 5.15. Biological Control Programs for Fruit Tree Pests in Organic Farms in the Al-Jabal Al-Akhdar and Salalah Plain Regions of the Sultanate of Oman.

Target Pest	Crop	Biological Control Agent	Rate of Application
Pomegranate Butterfly ***Virachola livia*** **(Lepidoptera: Lycanidae)**	Pomegranate	Egg Parasitoids: (1) *Trichogramma brassicae* (2) *Trichogramma evanescens* (Hymenoptera:Trichogrammatidae)	100,000/acre
Codling Moth ***Cydia pomonella*** **Linnaeus** **(Lepidoptera: Tortricidae)**	Apples Pears Walnuts	Egg and Larval Parasitoid: *Ascogaster quadridentatus* (Hymenoptera: Braconidae)	6000/acre
		Egg Parasitoid: *Trichogramma evanescens* (Hymenoptera:Trichogrammatidae)	400 - 9000/acre (4-6 times)
		Granulovirus: *Cydia pomonella* (Lefavirales: Baculoviridae)	Spraying
Cottony Cushion Scale ***Icerya purcashi*** **Maskell** **(Homoptera: Monophlebidae)**	Pomegranate Stone fruits	Vedalia beetle: *Rodolia cardinalis* (Coleoptera: Coccinellidae)	10 - 50/tree
		Cottony-cushion Scale Parasitoid: *Cryptochaetum iceryae* (Diptera: Cryptochetidae)	10 - 50/tree
The Mealybug ***Paracoccus marginatus*** **(Hemiptera: Pseudococcidae)**	Papaya Avocado Pineapple	Parasitoid wasps: (1) *Acerophagus papaya* (2) *Anagyrus loecki* (3) *Pseudleptomastix mexicana* (Hymenoptera: Encyrtidae)	100 - 200 Per row of tree
The Coconut Mite ***Aceria guerreronis*** **Keifer** **(Acari: Eriophyidae)**	Coconut Palm	The Predatory Mite: (1) *Neoseiulus paspalivorus* (2) *Neoseiulus baraki* (3) *Cydnoseius negevi* (Acari: Phytoseiidae)	600 - 900 Per Palm

5.4.2 Conservation and Augmentation in Biological Pest Control

Conservation and augmentation are two essential strategies used in biological pest control to manage populations of natural enemies, such as predators, parasitoids, and pathogens, thereby controlling pest populations when they reach damaging levels. Below is an explanation of each strategy:

- **Conservation Biological Control**

Conservation biological control aims to preserve and enhance the effectiveness of naturally occurring biocontrol agents by minimizing disruptions to ecosystem functions. This strategy involves modifying the environment or agricultural practices to protect and bolster natural enemies, resulting in a reduction of pest populations. Conservation is a key component of any biological control effort, as it focuses on reducing factors that interfere with natural enemies while providing the necessary resources to support their populations.

This approach leverages natural enemies that are already well-adapted to the local environment, making it a vital and accessible method for growers, from backyard gardens to commercial fields. Conservation biological control is typically straightforward and cost-effective.

To implement conservation biological control, it is important to maintain habitats that sustain beneficial organisms both on the farm and at a regional level. This involves cultivating suitable host plants and protecting existing natural enemies from disruption, rather than relying on the direct introduction of biological control agents.

Conservation efforts often include comprehensive planning at the farm level, incorporating non-farmed areas to enhance biodiversity and landscape features. Strategies may involve establishing and maintaining networks of hedges, ditches, field margins, beetle banks, and conservation headlands to provide habitats for beneficial species. Additionally, leaving a diversity of broad-leaved weed species within crops can serve as food sources for birds and insects, provided that aggressive, crop-damaging weeds are controlled. Planting flowering species such as marigolds, alyssum, or buckwheat among crop rows can attract pollinators and predatory insects that contribute to pest control. Furthermore, creating and improving habitats for parasitoids and predators of crop pests can help regulate pest populations by enhancing natural levels of biocontrol.

One of the best examples of conservation biological control is strip-harvesting hay alfalfa in California. When an entire field of alfalfa is harvested during hot weather, the native western tarnished plant bug, *Lygus hesperus*, migrates within 24 hours, often to cotton fields where it becomes a key pest. However, when fields are harvested in alternating strips up to 120 meters wide, *Lygus* bugs move from the cut strips to the remaining strips, rather than migrating to cotton. This practice also preserves natural enemies, such as predators and parasitoids, within the alfalfa fields.

- **Augmentation Biological Control**

Augmentation biological control involves the periodic release of natural enemies, usually endemic species, that are already present but do not naturally reach sufficient population levels to effectively control the target pest. This method aims to boost the population of natural enemies that prey on or parasitize the pest species. The process typically involves mass-rearing the natural enemies under laboratory conditions and subsequently releasing them into the field to target pest populations.

In summary, conservation and augmentation are two key approaches in biological pest control. These strategies work by maintaining and enhancing populations of local natural enemies, thereby providing sustainable and effective management of pest populations in agricultural and natural ecosystems.

5.4.3 Inoculative and Inundative Releases

The periodic release of natural enemies to suppress pest populations can be achieved through two main methods: inoculative release and inundative release. Both strategies have specific benefits and are employed based on the pest management goals and ecological considerations of a given agricultural system.

- **Inoculative Release**

Inoculative biological control involves the periodic release and reestablishment of a biological control agent that may not survive year-round but can rapidly expand its population when conditions become favorable. An example is the use of the parasitoid wasp *Pediobius foveolatus*, native to tropical India, which was imported to control the Mexican bean beetle on soybeans in temperate zones of North America. *P. foveolatus* is effective during the summer growing season but cannot survive winter conditions. To maintain control, overwintering cultures are kept in laboratories, and the wasps are re-released annually in small nursery plots where they multiply and naturally disperse into soybean fields. Once released, these natural enemies continue to reproduce and establish themselves within the ecosystem, providing long-term pest control.

Inoculative biological control programs are typically regional and administered by local government agencies or task forces. Individual growers may not usually perform inoculative releases on their own, though they may participate in specific programs, such as those involving the release of predatory mites.

Inoculative release relies on the ongoing interaction between released natural enemies and the target pest population. The goal is to establish a balance between pest and natural enemy populations, leading to sustainable pest management outcomes over time.

- **Inundative Release**

Inundative release involves breeding natural enemies in large numbers and releasing them in substantial quantities. This method, often referred to as "mass release," is used when a biological control agent cannot reproduce or attain an adequate population size without human intervention. The goal is to rapidly suppress or eliminate the target pest population over a short period of time.

Unlike inoculative release, inundative release does not depend on the reproduction and establishment of the released natural enemies but instead focuses on achieving rapid, short-term pest control. This approach is similar to using chemical pesticides, as the released organisms act swiftly to reduce pest numbers. Natural enemies used in inundative release are sometimes referred to as "biotic insecticides" due to their immediate and intensive impact on pest populations.

An example of this approach is the mass release of the egg parasitoid *Trichogramma* spp. to control lepidopterous pests in crops such as corn and cotton. In some programs, hundreds of thousands of these wasps are released per acre to achieve the desired level of control, treating the biological control agent similarly to a biotic pesticide.

Inundative release is particularly well-suited for greenhouse environments due to the controlled conditions and the relatively high costs associated with mass releases. The most successful agent in this category is the bacterium *Bacillus thuringiensis* (*Bt*), which is used to control pests such as lepidopteran, dipteran, and coleopteran species. Other entomopathogens based on fungi and viruses have also been successfully used in this approach.

Inundative tactics can be implemented at a regional level by government agencies or at the individual crop level by pest managers. In both cases, the biological control agent must be artificially reared or mass-produced, making this strategy viable for commercial applications.

In summary, inundative releases aim for immediate pest control through mass releases, while inoculative releases focus on establishing self-sustaining populations of natural enemies for long-term pest management. Both approaches are integral to integrated pest management (IPM) strategies, depending on the specific pest and environmental conditions.

However, several challenges can impede the widespread use or importation of parasites and predators for biological control. These challenges include:

» **Specialized Expertise:** Implementing biological control programs requires skilled experts who understand the ecology of both pests and their natural enemies. Without proper knowledge, it can be difficult to deploy these strategies effectively.

» **Time Requirements:** Biological control often takes time to yield noticeable results. Unlike chemical pesticides, which may provide immediate pest suppression, biological control methods may require several seasons to establish and maintain effective control.

» **Multiplicity of Natural Enemies:** Successful biological control often involves introducing multiple natural enemies of the target pest to ensure effectiveness. Coordinating the importation and release of several species adds complexity to the process.

» **Local Environmental Conditions:** The success of introduced natural enemies can be influenced by local environmental factors, such as temperature, humidity, and habitat availability. These conditions may not always be optimal for the establishment and activity of imported predators or parasites.

» **Host Dependence:** Some natural enemies are highly specialized and depend on specific hosts for survival. If these hosts are not present in sufficient numbers, the effectiveness of the natural enemy may be limited.

» **Predation and Parasitism:** Introduced natural enemies may themselves become preyed upon or parasitized by other insects in the new environment, reducing their effectiveness in controlling the target pest population.

Addressing these challenges requires careful planning, ongoing research, and collaboration between scientists, farmers, and policymakers to develop and implement effective biological control strategies tailored to specific pest and environmental conditions. This collaboration ensures that biological control programs are not only ecologically sound but also economically viable and sustainable. Researchers provide critical insights into the biology and ecology of both pests and their natural enemies, while farmers contribute practical knowledge from field experiences. Policymakers play a key role by shaping regulations and supporting initiatives that promote the safe importation, testing, and release of biological control agents. Effective communication and cooperation between these stakeholders are essential to overcoming the challenges posed by biological control, such as environmental variability and the complexities of introducing multiple natural enemies.

5.4.4 The Use of Egg Parasitoid in Organic Agriculture

The family *Trichogramma*tidae, belonging to the order Hymenoptera, encompasses a diverse group of egg parasitoids, with approximately 620 species across 80 genera. This family plays a crucial role in biological control programs worldwide, particularly in organic agriculture. Among these genera, *Trichogramma* is one of the most widely used due to its effectiveness in pest management.

Trichogramma species are internal parasitoids of insect eggs, particularly those of order: Lepidoptera (moths and butterflies). Upon parasitization, *Trichogramma* larvae develop within the host egg, consuming its contents. As the parasitoid develops, the host egg darkens or turns black, a distinct indicator of successful parasitism, as shown in Figure 5.17. This colouration results from the growth and metamorphosis of the *Trichogramma* larvae within the host egg.

According to Queiroz *et al*. (2020), there are more than 200 known species within the genus *Trichogramma*, distributed across six biogeographic regions globally. Wajnberg and Hassan (1994) noted that the taxonomic classification of these species primarily relies on the characteristics of male genitalia, offering a precise method for distinguishing between different species.

Figure 5.17. Parasitized Eggs by *Trichogramma* spp., are Typically Darken or Turn Black.

5.4.4.1 The Egg Parasitoids of Genus *Trichogramma* spp.

The adult stage of the egg parasitoid *Trichogramma* spp. is characterized by its minute size, often barely visible to the naked eye, as shown in Figure 5.18. Typically measuring around 1 mm or less in length, these wasps are waxy yellow with red eyes. They possess two pairs of membranous wings, with the hind pair being smaller than the front. Most *Trichogramma* species have fringed wings adorned with regular rows of hairs, and their antennae are equipped with thick hairs.

Figure 5.18. Female of *T. pertiosum* Parasitoid on Egg of Bollworm.

Many species of *Trichogramma* are commercially produced for pest control purposes. In various countries, these egg parasitoids are mass-produced in quantities reaching millions and are subsequently released into agricultural and forest ecosystems to combat pests.

Trichogramma species have been effectively employed in controlling forest insect pests, as documented by Bai *et al*. (1995), and in managing field crop pests, as noted by Smith (1996) and Wajnberg and Hassan (1994). Additionally, they have been used to combat fruit tree pests such as the western avocado leafroller moth (*Amorbia cuneana*) on avocado trees (Oatman & Platner, 1985) and the olive kernel borer (*Prays oleae*) on olive trees (Hegazi *et al*., 2004). Moreover, *Trichogramma* species have shown efficacy against certain insect pests of date palms, as indicated by Mohammad *et al*. (2004).

Kinawy (2012) reported the extensive use of the egg parasitoid *Trichogramma brassicae* in the Sultanate of Oman since 2003 for controlling the pomegranate butterfly (*Virachola livia*), a major pest of pomegranate fruits. This egg parasitoid was mass-produced and integrated into pest management systems in organic farms in the Al-Jabal Al-Akhdar area of Oman. The approach proved effective in significantly reducing the pomegranate butterfly population, thus protecting the pomegranate crop, as illustrated in Figure 5.19.

Figure 5.19. Release of *T. brassicae* on Pomegranate Trees in Oman.

The integration of *Trichogramma* spp. into organic farming systems underscores the potential of biological control as a sustainable alternative to chemical pesticides in pest management.

According to Li (1984), the genus *Trichogramma* comprises over 70 species that are used for controlling insect pests across various regions globally. However, successful mass-production has been achieved for only about 20 species. Mass-production facilities for different *Trichogramma* species are operating in over 30 countries, where these egg parasitoids are employed with notable success in controlling insect pests infesting a wide range of crops, such as cotton, corn, sugarcane, sugar beet, fruits, and vegetables.

Below are some of the well-known species of *Trichogramma* that have been widely utilized in controlling various insect pests:

Trichogramma evanescens (Westwood).

Trichogramma maidis Pintureau & voegelè (= *T. brassicae* Bezdenko)

Trichogramma deion Pinto & Oatman

Trichogramma exiguum Pinto & Platner

Trichogramma brevicapillum Pinto & Platner

Trichogramma atopovirilia Oatman & Platner

Trichogramma minutum Riley

Trichogramma semblidis (Aurivillius)

Trichogramma cacoeciae Marchal

Trichogramma platneri Nagarkatti

Trichogramma oleae voegelè & pointel

Trichogramma ostriniae Pang & Chan

Trichogramma pretiosum Riley

Trichogramma dendrolimi Matsumura

Trichogramma chilonis Ishii (= *T. confusum* Viggiani)

Trichogramma japonicum Ashmead

Trichogramma nubilale Ertle & Davis

It is important to note that the presence of biological strains and individual variations in shape, colour, and growth rates within a single species of *Trichogramma* can sometimes lead to synonymy, complicating the classification of the species used for release.

This variability can present challenges in identifying and optimizing specific species for pest control programs.

5.4.4.2 The Most Important Features of *Trichogramma* spp.

Trichogramma species are highly valued for their effectiveness in biological pest control, especially in organic agriculture. Below is a summary of their key features:

» Tiny Size: Adult *Trichogramma* wasps are extremely small, usually less than 1 mm in length, making them difficult to detect with the naked eye.

» Parasitic Behavior: *Trichogramma* species are egg parasitoids, laying their eggs inside the eggs of various insect pests, particularly Lepidoptera (moths and butterflies). The parasitoid's life cycle occurs entirely within the host egg, where it consumes the egg's contents, effectively destroying it and preventing damage from the pest.

» Host Specificity: Different species of *Trichogramma* exhibit varying degrees of host specificity, targeting particular pest species or groups. This reduces non-target effects, enhancing their effectiveness in targeted pest management.

» High Reproductive Rate: Female *Trichogramma* can lay multiple eggs inside host eggs, rapidly increasing their population under favourable conditions.

» Short Life Cycle: *Trichogramma* can complete their life cycle quickly. In laboratory settings, they are prepared as parasitized host eggs (with adult *Trichogramma* ready to emerge). These parasitized eggs are adhered to paper cards, which can be easily deployed in fields or orchards.

» Versatility: *Trichogramma* can be mass-produced in laboratories and are compatible with various release methods, including aerial and ground releases, making them suitable for large-scale pest control programs.

» Ease of Ground Release: *Trichogramma* can be easily prepared and deployed in the field using adhesive-backed paper cards holding parasitized host eggs. These cards can be hung in crop fields or on trees, where the adults will emerge and parasitize pest eggs.

» Effectiveness: *Trichogramma* species are known for their efficiency in controlling a wide range of agricultural pests, particularly moths and butterflies that infest crops such as corn, cotton, tomatoes,soybeans, and others.

» Reduction of Target Pests: In biological control programs, *Trichogramma* significantly reduce the incidence of target pests, often achieving control rates exceeding 80 % to 90 %.

» Environmentally Friendly: As natural enemies, *Trichogramma* species pose minimal risk to non-target organisms and the environment. They are ideal for integrated pest management (IPM) programs and organic farming. Their ability to fly and effectively locate host eggs makes them adaptable to various agricultural environments.

» Adaptability: *Trichogramma* species can thrive in diverse environmental conditions and can establish and persist in various ecosystems.

» Commercial Availability: Many *Trichogramma* species are commercially available, providing farmers and growers with easy access to these beneficial insects for pest control purposes.

5.4.4.3 Mass-Production of the Egg Parasitoid *Trichogramma* spp.

The mass production of many species within the genus *Trichogramma* has been successfully achieved in various regions worldwide. Currently, three insects serve as alternative hosts for the mass production of *Trichogramma* spp. These are:

* *Sitotroga cerealella* (Olivier), the Angoumois grain moth.
* *Ephestia kuehniella* (Zeller), the Mediterranean flour moth.
* *Corcyra cephalonica* (Stainton), the rice meal moth.

These alternative hosts were chosen due to their suitability for the successful mass production of both the host and the egg parasitoid. The key characteristic of these host species is their high reproductive efficiency. Additionally, the adult stages of these moths have vestigial mouthparts, meaning they do not require a specialized food supply. Most of the females' eggs are laid within the first week of their adult life, resulting in a short, productive cycle.

Breeding techniques for both the host species and the egg parasitoid have been developed using semi-mechanical methods, making mass production feasible on a large scale. These alternative hosts pose no threat to crops when used for the field release of the egg parasitoid, as they are pests confined to stored grains. Additionally, before being exposed to *Trichogramma* adults, the eggs of these alternative hosts are sterilized to remove the embryo, ensuring optimal conditions for the successful rearing of the egg parasitoid.

5.4.4.4 Uses of the Egg Parasitoids *Trichogramma* spp. in Organic Agriculture

The egg parasitoid genus *Trichogramma* is widely utilized in both conventional and organic agriculture to control various pests across different crops. *Trichogramma* spp. are among the most important egg parasitoids used for pest management worldwide.

Before 1998, areas treated with *Trichogramma* spp. were estimated as follows: approximately 65 million feddans in Russia and China, between 350,000 and 850,000 feddans in the United States, the Philippines, and Colombia, and between 25,000 and 100,000 feddans in countries such as Iran, Egypt, India, and France. In other regions like Thailand, Canada, Portugal, Germany, Switzerland, Australia, Tunisia, and the Netherlands, application areas were estimated at less than 20,000 feddans.

As of recent estimates, the application of *Trichogramma* spp. in pest control spans over 32 million hectares globally each year, primarily in crops like corn, cotton, and sugarcane. Countries such as Russia, China, and parts of Europe and Latin America have particularly extensive *Trichogramma* programs, reflecting its global importance in both conventional and organic agriculture.

One of the primary uses of *Trichogramma* spp. in organic agriculture is the control of Lepidoptera pests that infest crops such as corn, cotton, and soybeans. *Trichogramma* species parasitize the eggs of major pests like the European corn borer (*Ostrinia nubilalis*), the cotton bollworm (*Helicoverpa armigera*), and the soybean looper (*Chrysodeixis includens*). In organic farming systems, where synthetic chemical pesticides are restricted, *Trichogramma* releases offer an effective and environmentally friendly solution (Hassan, 1993; Smith, 1996).

Trichogramma spp. are also widely used in organic orchards and vegetable farms to control pests such as the codling moth (*Cydia pomonella*) in apple orchards, the tomato fruit worm (*Helicoverpa zea*), and the diamondback moth (*Plutella xylostella*) in brassica crops. Mass releases of *Trichogramma* species, such as *T. evanescens*, help manage these pest populations effectively without harmful chemicals (Li, 1984; Oatman & Platner, 1985). Additionally, *Trichogramma* spp. are used in controlling Lepidoptera pests in olive and avocado orchards. For example, *Trichogramma oleae* has been used to parasitize the eggs of the olive kernel borer (*Prays oleae*) in Mediterranean olive groves, while *Trichogramma* species have been effective against the avocado leafroller (*Amorbia cuneana*) in avocado orchards (Hegazi *et al*., 2004; Oatman & Platner, 1985).

A notable application of *Trichogramma* in organic farming is its use in controlling the pomegranate butterfly (*Virachola livia*), a significant pest in pomegranate orchards. Since 2003, *Trichogramma brassicae* has been mass-produced and released in organic farms in the Al-Jabal Al-Akhdar region of Oman, where it has successfully reduced the pomegranate butterfly population (Kinawy, 2008).

According to Mohammad *et al*. (2004), *Trichogramma* spp. have also been employed to control key pests in date palm cultivation. The reduction in infestation rates depended on the timing and frequency of *Trichogramma* releases, as well as the density of the parasitoid population. The study highlighted the effectiveness of *Trichogramma* evanescens in reducing the incidence of key pests affecting date palms, as outlined in Table 5.16.

In general, *Trichogramma* spp. are often integrated into broader organic pest management strategies. They are compatible with other biological control agents, such as predatory insects and microbial pesticides, and can be combined with cultural practices like crop rotation and habitat manipulation to provide a comprehensive Integrated Pest Management (IPM) approach. The use of *Trichogramma* in organic agriculture not only reduces pest populations but also supports biodiversity and sustainability within the ecosystem (Wajnberg & Hassan, 1994).

Table 5.17 provides examples of significant pests targeted by *Trichogramma* spp. on various crops in organic agriculture.

Table 5.16. Infestation Reduction Rates for Key Pests in Date Palms Using the Egg Parasitoid *Trichogramma evanescens*.

Target Pest	Reduction of Infestation (%)
Greater date moth, *Arenipses sabella* Hampson	35.6 - 62.4
Lesser date moth, *Batrachedra amydraula Meyer*	44.0 - 58.2
Date stone beetle, *Coccotrypes dactyliperda* (F.)	49.5 - 53.1
Pomegranate butterfly, *Virachola livia* Klug	80.0
Currant moth, *Cadra* (*Ephestia*) *calidella* (Guenee)	41.7 - 47.3

Table 5.17. Key Pests on Various Crops Controlled by the Egg Parasitoid (*Trichogramma* spp.) in Organic Agriculture.

Crop	Target Pest	
	Common Name	Scientific Name
Maize - Sugarcane - Rice	Oriental corn borer	*Chilo agamemnon* Bleszynski (Lepidoptera: Crambidae)
Corn	European corn borer	*Ostrinia nubilalis* Hübner (Lepidoptera: Crambidae)
Alfalfa	Pea blue butterfly	*Lampides boeticus* (Linnaeus) (Lepidoptera: Lycaenidae)
Date Palm	Greater date moth	*Arenipses sabella* Hampson (Lepidoptera: Pyralidae)
	Lesser date moth	*Batrachedra amydraula Meyer* (Lepidoptera: Batrachedridae)
	Date stone beetle	*Coccotrypes dactyliperda* (F.) (Cleoptera: Curculionidae)
	Currant moth	*Ephestia calidella* (Guenee) (Lepidoptera: Pyralidae)

Crop	Target Pest	
	Common Name	Scientific Name
Grapes	European grapevine moth	*Lobesia botrana* (Den. & Schiff.) (Lepidoptera: Tortricidae)
	Honeydew moth	*Cryptoblabes gnidiella* Millière (Lepidoptera: Pyralidae)
Pomegranate	Pomegranate butterfly	*Virachola livia* Klug (Lepidoptera: Lycaenidae)
Fig	Fig tree defoliator	*Ocnerogyia amanda* Staud. (Lepidoptera: Lymantriidae)
Citrus	Citrus blossom moth	*Prays citri* (Millière) (Lepidoptera: Plutellidae)
Peaches - apricots Plums - almonds	Peach twig borer	*Anarsia lineatella* Zeller (Lepidoptera: Gelechiidae)
Apples - pears - Walnuts - Loquat	Codling moth	*Cydia pomonella* L. (Lepidoptera: Tortricidae)
Olive	Jasmine moth	*Palpita vitrealis* (Rossi) (Lepidoptera: Crambidae)
Tomato	Cotton bollworm	*Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)
	Lesser armyworm	*Spodoptera exigua* (Hubn) (Lepidoptera: Noctuidae)
Potato	Potato tuber moth	*Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae)
Tomato - Potato	Tomato leafminer or borer	*Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)

5.4.4.5 The Egg Parasitoid *Pseudoligosita babylonica* Viggiani

The The egg parasitoid *Pseudoligosita babylonica* Viggiani (Hymenoptera: *Trichogramma*tidae), illustrated in Figure 5.20., is known for parasitizing the eggs of the Dubas Bug (*Ommatissus lybicus* Bergevin), a major pest of date palms worldwide. Initially recorded as Oligosita sp. by The Natural History Museum (2002), this species was later identified as *Pseudoligosita babylonica* by Viggiani (2008). The first formal identification of this parasitoid under the name *Pseudoligosita babylonica* was made by Hassan *et al*. (2004) in Iraq.

Research by Al-Khatri (2018) in the Sultanate of Oman revealed that in certain locations, the parasitism rate on Dubas Bug eggs by *P. babylonica* exceeded 70 %. This high parasitism rate highlights the significant potential of *P. babylonica* as a crucial biological control agent for managing Dubas Bug populations on date palms. Despite its potential, the widespread successful breeding of this parasitoid has not yet been achieved. If effective mass production and release techniques can be developed, *P. babylonica* could play a vital role in controlling Dubas Bug infestations in organic date palm farms, especially in areas where the parasitoid is not naturally present.

Figure 5.20. The Egg Parasitoid, *Pseudoligosita babylonica.*

5.4.5 Biological Pest Control of Organic Crops in Greenhouses

In organic greenhouses, many natural enemies, including parasitoids and predators, can be effectively employed in biological control programs to manage pest populations. Below are definitions of some of the most important parasitoids and predators commonly used in biological control programs for greenhouse pests in organic agriculture.

5.4.5.1 The Main Parasitoids Used in Biological Pest Control

- **The Parasitoid Wasp, *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae)**

Encarsia formosa is a tiny parasitoid wasp widely used in biological control programs to manage whitefly populations in greenhouses. The adult female measures approximately 0.6 mm in length, with a dark brown to black head and thorax, and a yellow abdomen. The male, which constitutes only 1-2 % of the population, is entirely black. The adult wasp emerges from a round exit hole in the whitefly pupa, Figure 5.21. *E. formosa* prefers parasitizing the greenhouse whitefly (*Trialeurodes vaporariorum*) but can also attack the tobacco whitefly (*Bemisia tabaci*).

Female *E. formosa* produce only females through unfertilized eggs, resulting in a predominantly female population. Each female can lay around 150 eggs during her lifetime, at a rate of 5-15 eggs per day. The wasp is most effective at temperatures between 20-25°C, although it remains functional at lower temperatures. At higher temperatures (around 30°C), adults have a lifespan of only a few days.

The development of *E. formosa* proceeds through six stages: egg, three larval instars, pupal instar, and adult. Except for the adult stage, all life stages occur inside the host (whitefly larvae and pupae), making *E. formosa* an "endoparasite."

Females prefer to lay eggs in third and early fourth larval instars but avoid parasitizing larvae that have already been parasitized. After the eggs hatch, the developing larvae feed internally on the whitefly, eventually killing it. During the parasite's development, the host pupa turns black (in the case of *T. vaporariorum*), making parasitized pupae easy to identify. When *B. tabaci* is parasitized, the pupa remains transparent to brown, facilitating species identification.

Encarsia formosa is highly effective in reducing greenhouse whitefly populations as part of an integrated pest management (IPM) strategy. It is often released at regular intervals in greenhouses, depending on infestation severity. The wasps are supplied as parasitized whitefly pupae, either loose or attached to cards that can be hung on plants.

While *E. formosa* is particularly effective in controlling whiteflies on tomato plants, its movement can be hindered by the dense hairs and veins found on cucumber plants, reducing its efficacy. Nevertheless, *E. formosa* remains a valuable tool in greenhouse pest management, providing an environmentally friendly alternative to chemical pesticides and supporting sustainable crop production.

- **The Parasitoid Wasp, *Eretmocerus eremicus* Rose & Zolnerowich (Hymenoptera: Aphelinidae)**

Eretmocerus eremicus is a tiny parasitic wasp that primarily targets whiteflies, especially the greenhouse whitefly (*Trialeurodes vaporariorum*) and the tobacco whitefly (*Bemisia tabaci*). It is widely used in biological control programs to manage these pests in various greenhouse crops. The female *E. eremicus* has a lemon-yellow body, green compound eyes, and three red ocelli, Figure 5.22. It measures approximately 0.75 mm in length. Males are slightly smaller, with a dark yellow to brown body, green compound eyes, and red ocelli, making them less frequently observed.

Figure 5.21. The Parasitoid Wasp, *Encarsia formosa.*

After emerging, female *E. eremicus* can begin parasitizing new hosts almost immediately, but mating is necessary for producing female offspring. Unmated females produce only males. This species shows a preference for *T. vaporariorum* over *B. tabaci* and is particularly effective against the immature stages of both whitefly species.

Figure 5.22. The Parasitoid Wasp, *Eretmocerus eremicus.*

Female *E. eremicus* lay their eggs underneath the 2nd through 4th larval stages of whiteflies, with a preference for the 2nd instar stage. Each female can lay between 50 and 200 eggs during her lifespan. Once the eggs hatch, the larvae feed internally on the tissues of the whitefly larvae, eventually killing the host. A key advantage of *E. eremicus* over other parasitoids, such as *Encarsia formosa*, is its ability to remain active at higher temperatures, ranging from 30°C to 40°C. This makes it particularly effective in warmer greenhouse environments, where other parasitoids may become less efficient.

The life cycle of *E. eremicus* takes approximately 16-20 days under optimal conditions, maintaining a balanced sex ratio of 1:1. Development from egg to adult occurs entirely within the host whitefly larva or pupa. The larvae of *E. eremicus* feed on the body fluids and tissues of the whitefly larvae, ultimately resulting in the parasitization and death of the host. Parasitized larvae often exhibit characteristic changes in colour, such as turning black, making it easy to identify the affected whitefly.

E. eremicus is a valuable component of integrated pest management (IPM) programs targeting greenhouse whiteflies. Its regular release in greenhouses, depending on the severity of the infestation, helps reduce whitefly populations and prevent crop damage. The parasitoid is typically supplied as parasitized whitefly pupae, either loose or on cards that are strategically placed on plants within the greenhouse.

This parasitoid is effective in controlling whitefly populations in various crops, including tomatoes, cucumbers, eggplant, sweet peppers, and ornamental plants. However, its effectiveness can vary based on environmental conditions such as temperature, humidity, and the presence of other biological control agents.

- **The Parasitoid Wasp, *Eretmocerus mundus* (Mercet)**
  (Hymenoptera: Aphelinidae)

Eretmocerus mundus, Figure 5.23., is a parasitoid wasp from the family Aphelinidae, used in biological control programs to manage whitefly populations. Naturally occurring in Mediterranean regions, *E. mundus* often appears spontaneously when the tobacco whitefly (*Bemisia tabaci*) is present. Unlike other parasitoids, *E. mundus* exclusively targets *B. tabaci* and does not parasitize the greenhouse whitefly (*Trialeurodes vaporariorum*) or other whitefly species. Since 2002, *E. mundus* has been employed as an effective biological control agent against *B. tabaci*.

Adult female *E. mundus* lay between 80 and 250 eggs during their lifespan. The female selects second or early third instar whitefly larvae for parasitization. Once the eggs hatch, the developing larvae of *E. mundus* feed internally on the whitefly larvae, ultimately causing their death. Parasitized larvae often show characteristic colour changes, such as turning black as the *Eretmocerus* larvae grow inside. The life cycle of *E. mundus* typically takes 2 to 3 weeks, depending on temperature and the developmental stage of the whitefly larvae. However, under suboptimal conditions, development can take up to a month or more.

E. mundus typically exhibits a sex ratio of about 60 % females to 40 % males, ensuring that most of the population consists of egg-laying females. However, its effectiveness may be reduced on cucumber plants due to physical traits such as dense leaf hairs and veins, which can hinder the movement of the parasitoid. These barriers may limit the parasitoid's ability to locate and parasitize whitefly larvae on cucumber plants as efficiently as on other crops.

Eretmocerus mundus is commonly released at regular intervals in greenhouses, depending on the level of whitefly infestation. It plays a critical role in Integrated Pest Management (IPM) programs, often working alongside other natural enemies to control pest populations. Overall, *E. mundus* significantly contributes to the biological control of whiteflies, helping manage pest populations in both agricultural and horticultural systems.

- **The Parasitoid Wasp, *Aphidius* spp.**
  (Hymenoptera: Braconidae)

The braconid wasps of the *Aphidius* genus are widely used in biological control programs to manage aphid populations in agricultural crops. These small wasps, typically measuring 2-3 millimeters in length, play a vital role in regulating aphid numbers by parasitizing aphid nymphs. Adult *Aphidius* wasps have slender bodies with narrow waists and are usually black or dark brown in colour.

As solitary endoparasitoids, *Aphidius* wasps lay their eggs inside aphid bodies. Female wasps use their ovipositors to inject eggs into aphid nymphs, Figure 5.24. After the eggs hatch, the larvae feed on the aphids' internal tissues. Different species of *Aphidius* exhibit varying degrees of host specificity, targeting specific aphid species or groups. This host specificity helps to minimize non-target effects and ensures effective control of target aphid populations. For example:

* *Aphidius colemani* Viereck is primarily used to control small aphid species, such as the melon aphid (*Aphis gossypii*) and the green peach aphid (*Myzus persicae*).
* *Aphidius ervi* Haliday is effective against larger aphid species, including the potato aphid (*Macrosiphum euphorbiae*) and the foxglove aphid (*Aulacorthum solani*).

Despite their host specificity, both *A. colemani* and *A. ervi* can parasitize over 40 different species of aphids, making them highly versatile in biological control programs targeting aphid infestations in agricultural crops.

The life cycle of *Aphidius* spp. includes four stages: egg, larva, pupa, and adult. After the larval wasp hatches, it consumes the internal contents of the aphid nymph, killing it. The larva then pupates inside the aphid's exoskeleton and emerges as an adult wasp. Female *Aphidius* wasps can lay multiple eggs within aphid nymphs, parasitizing numerous aphids throughout their lifespan. This high reproductive rate allows *Aphidius* populations to grow rapidly under favorable conditions.

Aphidius spp. are environmentally friendly and pose minimal risk to non-target organisms. They are compatible with Integrated Pest Management (IPM) strategies and are often used in organic farming practices. *Aphidius* wasps are released in greenhouse and field environments by introducing parasitized aphids or releasing adult wasps directly into the crop canopy.

Overall, *Aphidius* spp. provide effective and sustainable control of aphid pests in agricultural systems, helping reduce reliance on chemical pesticides while promoting a healthy and balanced ecosystem.

Figure 5.23. The Parasitoid Wasp, *Eretmocerus mundus.*

Figure 5.24. The Parasitoid Wasp, *Aphidius colemani.*

5.4.5.2 The Main Predators Used for Biological Pest Control

- **The Predatory Bug, *Macrolophus caliginosus* Wagner (Heteroptera: Miridae)**

Macrolophus caliginosus is an omnivorous predatory bug, Figure 5.25., widely used in biological control programs, particularly within greenhouse environments.. It preys on a wide variety of pests, including aphids, thrips, whiteflies, and small caterpillars, making it an effective natural enemy against various pest species. *M. caliginosus* also feeds on the eggs of certain insect pests, , further contributing to the suppression of their populations.

The adult *M. caliginosus* is particularly effective against whiteflies, consuming approximately 30-40 eggs, 15-20 pupae, or 2-5 adult whiteflies per day. Females lay their eggs individually on plant stems or thick leaves, with an average of about 120 eggs per female at 25°C. The generation time of this predator can extend up to 42 days, depending on environmental conditions.

When incorporating *Macrolophus caliginosus* into pest management programs, several considerations are important. Early release on tomato and eggplant crops is recommended to control whitefly populations effectively. Pairing *M. caliginosus* with the parasitoid *Encarsia formosa* can enhance pest control results.

However, caution is necessary when using *M. caliginosus* on certain tomato varieties, such as Cherry Tomato and Vine Ripened, as it may cause damage to leaves and fruits. Its use on cucumber and pepper plants may also be less effective due to its longer generation time and weaker establishment on these crops. Additionally, high temperatures above 40°C can be fatal for *M. caliginosus* nymphs, so temperature control is critical. Despite these challenges, *M. caliginosus* thrives when feeding on whiteflies, which boosts its fertility. This predator also feeds on Lepidoptera eggs and can derive nutrients from plant material.

In Integrated Pest Management (IPM) programs, *Macrolophus caliginosus* plays a vital role due to its adaptability and voracious appetite for pest insects. To ensure success, maintaining optimal environmental conditions, such as suitable temperature and humidity levels, promotes the predator's establishment and activity.

Figure 5.25. The Predatory Bug, *Macrolophus caliginosus.*

Additionally, providing alternative food sources, such as pollen or supplemental prey, can be beneficial, especially when pest populations are low. This practice ensures the continued presence and effectiveness of *M. caliginosus* in sustainably controlling pests.

Overall, *Macrolophus caliginosus* significantly contributes to sustainable pest management by reducing reliance on chemical pesticides and promoting environmentally friendly practices in greenhouse crops.

- **The Predatory Mite, *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae)**

The predatory mite *Amblyseius swirskii*, Figure 5.26., is a highly versatile and effective predator, widely used in biological control programs, particularly in greenhouse environments. This mite preys on various soft-bodied insect pests, including whiteflies, thrips, and to a lesser extent, spider mites. In addition to its primary prey, *A. swirskii* can also feed on pollen, honeydew, and fungal spores, making it a valuable agent not only for pest suppression but also for reducing certain plant pathogens.

A. swirskii is known for its voracious appetite, rapid reproductive rate, and adaptability to a wide range of environmental conditions. These traits allow it to establish and maintain long-term populations in greenhouses, providing effective pest control. Native to the coastal areas of the Middle East and North Africa, this species thrives in warm and humid conditions.

Commercially, *A. swirskii* is typically available in small envelopes containing approximately 300 mites, which can be attached directly to plants like tomatoes, cucumbers, peppers, or eggplants. Alternatively, it can be supplied in packages with vermiculite, which can be easily scattered over the plants' leaves. This gradual release method ensures the mites disperse evenly throughout the crop, leading to effective and sustained pest control.

This predatory mite is particularly effective against whiteflies and thrips, which are major greenhouse pests capable of causing significant crop damage. *A. swirskii* is also compatible with other biological control agents, making it a valuable part of Integrated Pest Management (IPM) strategies. To maximize the effectiveness of *A. swirskii* in biological control programs, it is important to maintain optimal environmental conditions, such as proper temperature and humidity levels, to promote its establishment and activity. Additionally, providing alternative food sources, such as pollen, can help sustain *A. swirskii* populations when pest levels are low.

- **The Predatory Mite, *Neoseiulus (Amblyseius) cucumeris* (Oudemans) (Acari: Phytoseiidae)**

Neoseiulus cucumeris, Figure 5.27., is a widely used predatory mite in the Phytoseiidae family, particularly effective in biological control programs for managing thrips, such as the western flower thrips (*Frankliniella occidentalis*), and small pests like spider mites. This mite preys on thrips' eggs and larvae, contributing significantly to pest control in various crops.

The adult female *N. cucumeris* lays 1-3 eggs per day, with an average of 47 eggs over its lifespan, which lasts around three weeks. Female *N. cucumeris* outnumber males, making up approximately 64 % of the population.

Figure 5.26. The Predatory Mite, *Amblyseius swirskii.*

Figure 5.27. The Predatory Mite, *Neoseiulus cucumeris.*

While *N. cucumeris* primarily preys on the first instar of western flower thrips, it is less effective against older thrips nymphs or adults. Older thrips can defend themselves by striking the predatory mites with their abdomens or secreting a wet substance that forces the mites to spend time cleaning themselves rather than attacking the thrips.

For effective pest management, *N. cucumeris* should be released as soon as the first signs of thrips are observed, particularly in crops like cucumbers. In peppers, these mites can be released even before thrips are detected, as they can survive on pollen until thrips become available. This preemptive release strategy allows *N. cucumeris* to establish and control the thrips population before it becomes problematic.

N. cucumeris is known for its voracious appetite and ability to reproduce rapidly under favorable conditions. It thrives in warm and humid environments, making it ideal for greenhouse cultivation. These mites can establish sustainable populations, providing long-term pest control without the need for frequent reintroduction.

Commercially, *N. cucumeris* is available in containers or sachets mixed with vermiculite, which are strategically placed throughout the crop to target pest hotspots. Regular monitoring of both pest and predator populations, as well as environmental conditions, is essential for maintaining effective pest control and ensuring crop health. With its rapid life cycle, high reproductive capacity, and adaptability to greenhouse environments, *Neoseiulus cucumeris* is a valuable component of Integrated Pest Management (IPM) strategies, offering sustainable and long-term pest control.

- **The Minute Pirate Bug, *Orius laevigatus* (Fieber)** (Hemiptera: Anthocoridae)

Figure 5.28. The Adult and Nymph of the Minute Pirate Bug, *Orius laevigatus*.

Orius laevigatus, commonly known as the minute pirate bug, is a highly active predator from the family Anthocoridae. These insects are renowned for their voracious appetite, primarily preying on a wide range of small insect pests, such as thrips, aphids, spider mites, and other soft-bodied insects. Thrips are their preferred prey, though adult *O. laevigatus* are also attracted to flowers and can feed on pollen.

Widely used in biological control programs, especially in greenhouses, *O. laevigatus* plays a critical role in managing pest populations. These bugs attack the eggs and nymphs of pests, piercing them with their piercing-sucking mouthparts and consuming their body fluids. They are particularly effective against thrips during their larval and pupal stages, making them an essential tool for controlling thrips infestations.

The adult *O. laevigatus* measures about 2.5-3 mm in length and has a dark, flattened body with distinctive whitish wings. Nymphs display an orange-yellow soft body, and as they mature, they develop yellow colourations with orange spots, Figure 5.28. Both nymphs and adults are highly active, searching for prey even in hidden areas within the plant canopy and flowers.

At 25°C, the development of *Orius laevigatus* from egg to adult takes approximately 15 days. Female *O. laevigatus* have an average lifespan of 20 days, during which they lay around 125 eggs. One key characteristic of *O. laevigatus* is their ability to fly, allowing them to swiftly locate and attack pest populations throughout the greenhouse. When prey is scarce, *O. laevigatus* can sustain itself on pollen and nectar, helping to maintain population levels even during periods of low pest activity. Sufficient daylight length is essential for successful establishment and reproduction. Since this predator tends to lay its eggs on lateral growths, it is crucial to release *O. laevigatus* immediately after removing these lateral growths.

Orius laevigatus is typically introduced into greenhouses at regular intervals, depending on pest pressure and crop conditions. These predatory bugs are available in various forms, including adults, nymphs, and eggs, and are often distributed using release cards or sachets strategically placed throughout the crop canopy. It is recommended to release *O. laevigatus* early in the morning or at sunset when temperatures and light levels are lower, as this encourages the predators to settle directly on the plants rather than flying toward the greenhouse roof. *O. laevigatus* is commonly packaged in packs containing 500 adults and nymphs, mixed with buckwheat seed husks and vermiculite, facilitating easy and effective distribution within the greenhouse.

To optimize the efficacy of *Orius laevigatus* in biological control programs, regular monitoring and adjustments to release schedules based on pest pressure and crop conditions are essential. Maintaining suitable environmental conditions, such as optimal temperature and humidity levels, is crucial for supporting the predator's activity and reproduction. These factors influence *O. laevigatus*' ability to locate and consume pests, as well as its overall reproductive success. By maintaining these conditions, robust populations of *O. laevigatus* can be established within the greenhouse, providing effective and sustained pest control.

- **The Green Lacewing, *Chrysoperla carnea* Stephens**
  (Neuroptera: Chrysopidae)

The Green Lacewing, *Chrysoperla carnea*, is a predatory insect in the family Chrysopidae, belonging to the order Neuroptera. This order includes 91 families of predatory insects, with some significant members being Corydalidae (Dobsonflies), Sialidae (Alderflies), and Myrmeleontidae (Antlions). The Chrysopidae family, commonly referred to as green lacewings, is especially important in biological control due to the predatory behavior of their larvae, often called "Aphid Lions" because of their effectiveness in preying on aphids, mites, and small pests such as whiteflies, mealybugs, leafhoppers, and small larvae.

Figure 5.29. The Four Stages of the Green Lacewing, *Chrysoperla carnea* Stephens.

While the larvae of all species in this family are predatory, the adult behavior varies between species. Adults of the genus *Chrysopa* are predatory, feeding on insects as well as honeydew, pollen, and nectar. On the other hand, adults of the genus *Chrysoperla* generally feed on pollen and nectar but are not predatory. The larvae of *C. carnea* are gray to brown and have an alligator-like appearance. They are equipped with large, sickle-shaped jaws that they use to pierce their prey and suck out body fluids, making them particularly effective at controlling aphids and other soft-bodied pests in gardens, landscapes, and crop fields.

The green lacewing (*Chrysoperla carnea*) is a well-known insect predator, distinguished by its golden eyes and delicate, lacey wings. Adults have long, slender bodies and an attractive yellowish-green color, with two pairs of thin membranous wings that are longer than their bodies. Their long antennae and net-veined wings, which fold over the body in a truss-like formation when at rest, give them a characteristic appearance.

The larvae of *C. carnea*, often called "Aphid Lions," are highly efficient predators with large, piercing mandibles. These voracious larvae can subdue and suck dry a wide range of soft-bodied prey, including aphids, mites, whiteflies, mealybugs, and leafhoppers, making them indispensable in pest control for gardens, landscapes, and crop fields.

The eggs of the green lacewing are easy to recognize. Females lay each egg on a delicate stalk attached to the plant surface. These white eggs are visible to the naked eye. The larvae, which are flat and gray with reddish-brown spots, have elongated, fusiform bodies well-suited for predation.

Notably, the larvae of *C. carnea* do not defecate during their active stage because their digestive tract is closed at one end. Solid waste from consumed prey accumulates in the stomach until they transition to the pupal stage. The larvae undergo three molting instars over a 10-15 day period. When fully grown, the larvae secrete silk from the Malpighian tubules, forming a spherical cocoon. Inside the cocoon, metamorphosis into the pupal stage occurs, and the accumulated waste, resembling a small seed, is expelled. The pupal stage lasts between 6 and 10 days.

Adult green lacewings feed on flower nectar and pollen. The adult lifespan is 20 to 30 days, during which a female lays around 300 eggs. A single larva can consume approximately 350 aphids or 300 Lepidoptera eggs or newly hatched larvae during its development.

To promote the presence of green lacewings, maintaining diverse plantings of flowering species and reducing the use of insecticides is beneficial. This practice fosters a balanced ecosystem, supporting their predatory activities and contributing to natural pest management.

- **The Mealybug Destroyer, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae)**

The Mealybug Destroyer (*Cryptolaemus montrouzieri*) is a species of lady beetle in the family Coccinellidae, widely recognized for its predatory behavior on mealybugs. Mealybugs are serious pests that infest a broad range of plants, including ornamentals, fruits, vegetables, and field crops. Young *Cryptolaemus* larvae primarily target mealybug eggs and juvenile stages, although when mealybugs are scarce, they will feed on aphids, scale insects, mites, thrips, whiteflies, and other soft-bodied pests. Both larvae and adults feed aggressively on mealybug eggs, nymphs, and adults, making this species a crucial agent in biological control programs in organic agriculture.

Figure 5.30. The Mealybug Destroyer, *Cryptolaemus montrouzieri* Mulsant

The adult *Cryptolaemus montrouzieri* measures approximately 3 to 5 millimeters in length and has a distinctive black or dark brown body with a reddish-orange head and thorax. A single female can lay up to 500 eggs during her lifetime.

The larvae, which are larger than the adults at 7 to 10 millimeters in length, are elongated and covered in waxy white filaments that resemble the mealybugs they prey on, as illustrated in Figure 5.30.

One unique adaptation of the Mealybug Destroyer is its waxy secretion, which covers the larvae and mimics the appearance of mealybugs. This camouflage allows the larvae to blend in with their prey, providing an effective ambush strategy that enables them to feed on mealybugs undetected.

Mealybug Destroyers can be released in mealybug-infested areas or introduced into greenhouses to establish populations that provide long-term pest control. This species is widely valued for its role in reducing mealybug infestations in a sustainable manner without the need for chemical insecticides, making it a staple in both organic agriculture and horticultural pest management systems.

Table 5.18. outlines the most important parasitoids and predators used in the biological control of greenhouse pests in organic agriculture, along with their recommended release rates for optimal effectiveness.

Table 5.18. Biological Control Agents (Parasitoids and Predators) for Managing Greenhouse Pests in Organic Agriculture.

Target Pest	Biological Control Agent	Type	Releasing Rate (m^2)		
			Preventive	Light Curative	Heavy Curative
Whiteflies	*Encarsia formosa* (Hymenoptera: Aphelinidae)	Parasitoid Wasp	1.5 - 3	3 - 6	9
	Eretmocerus eremicus (Hymenoptera: Aphelinidae)	Parasitoid Wasp	1.5 - 3	3 - 6	9
	Eretmocerus mundus (Hymenoptera: Aphelinidae)	Parasitoid Wasp	1.5 - 3	3 - 6	9
	Macrolophus caliginosus (Hemiptera: Miridae)	Predatory Bug	--	10	50
Aphids	*Aphelinus abdominalis* (Hymenoptera: Aphelinidae)	Parasitoid Wasp	0.25	2	4
	Aphidius colemani (Hymenoptera: Braconidae)	Parasitoid Wasp	0.25	1	2
	Aphidius ervi (Hymenoptera: Braconidae)	Parasitoid Wasp	0.25	1	2
	Chrysoperla carnea (Neuroptera: Chrysopidae)	The Green Lacewings	--	10	50
	Aphidoletes aphidimyza (Diptera: Cecidomyiidae)	Predatory Midge	--	1	10
	Episyrphus balteatus (Diptera: Syrphidae)	Predatory Hoverfly	--	50/ha	100/ha
	Adalia bipunctata (Coleoptera: Coccinelidae)	Two Spotted Ladybird	--	10	50

Target Pest	Biological Control Agent	Type	Releasing Rate (m^2)		
			Preventive	Light Curative	Heavy Curative
Thrips	*Amblyseius swirskii* (Acarina: Phytoseiidae)	Predatory Mite	25	50	100 - 300
	Neoseiulus cucumeris (Acarina: Phytoseiidae)	Predatory Mite	50	100	100
	Orius laevigatus (Hemiptera: Anthocoridae)	Predatory Bug	0.5	1	10
	Orius insidiosus (Hemiptera: Anthocoridae)	Predatory Bug	0.5	1	10
Spider Mites	*Phytoseiulus persimilis* (Acarina: Phytoseiidae)	Predatory Mite	2 - 4	6 - 10	20 - 50
	Neoseiulus californicus (Acarina: Phytoseiidae)	Predatory Mite	25	100	200
	Feltiella acarisuga (Diptera: Cecidomyiidae)	Predatory Gall Midge	--	0.25	10
Leafminers	*Dacnusa sibirica* (Hymenoptera: Braconidae)	Parasitoid Wasp	--	0.25	--
	Diglyphus isaea (Hymenoptera: Eulophidae)	Parasitoid wasp	--	0.1	0.25
Mealybugs	*Cryptolaemus montrouzieri* (Coleoptera: Coccinelidae)	Mealybug destroyer	5	10 - 20	20 - 40

- **The Use of the Entomopathogenic Fungi *Verticillium lecanii* to Control Whitefly**

Verticillium lecanii is a naturally occurring entomopathogenic fungus first observed affecting whitefly in 1915, originally named *Cephalosporium lefroyi* and later reclassified as *Cephalosporium lecanii*. According to Malais and Ravensberg (2003), *V. lecanii* consists of a complex of strains, primarily targeting arthropods. These strains, once thought to be separate species, are now recognized as variations with distinct host ranges, though they share minimal external differences.

Since the 1980s, the "whitefly strain" of *V. lecanii* has been employed for the biological control of whiteflies, as well as for thrips management. The different strains, such as the "whitefly" and "aphid" strains, exhibit slight morphological differences, including spore size, and are selective in their host targets.

Following the application of *Verticillium* lecanii, the first signs of infection on whiteflies typically appear within 7 to 10 days, with more pronounced effects becoming visible after about two weeks. Infected whiteflies develop a cottony white appearance caused by the fungal hyphae. Under magnification, these hyphae show characteristic perpendicular branching, Figure 5.31. The side branches, known as phialides, produce globules that contain one or more conidiospores, which are surrounded by a slimy substance. The spores themselves are cylindrical or elliptical in shape with rounded tips.

V. lecanii primarily affects whitefly larvae but, under optimal humidity conditions, can also infect pupae and adults, though the eggs remain unaffected. For thrips, the fungus mostly targets larvae, although adults and pupae may also be infected. The eggs, embedded in leaf tissue, are rarely affected.

V. lecanii spores germinate on insect surfaces, often taking advantage of the honeydew secreted by whiteflies, or grow on carbohydrates added to commercial formulations. The fungus may penetrate the insect directly, bypassing the external growth phase, leading to the insect's death as the fungus develops internally.

The optimal conditions for the growth of *V. lecanii* are temperatures between 15°C and 28°C and humidity levels above 80 %. These conditions maximize the effectiveness of fungal applications in controlling whitefly populations. *V. lecanii* can continue to grow on live insect hosts and produce spores, which are mechanically transmitted through water or by contact with infected hosts.

Commercially, *V. lecanii* is marketed under the product name Mycotal and is typically available as spores for use in greenhouse whitefly control programs. These spores can spread through water or by contact with infected insects, providing an environmentally sustainable method of pest management.

Figure 5.31. Whitefly Adult and Pupa Infected with *Verticillium lecanii*

5.5 Crop Rotation in Organic Agriculture

Crop rotation is a fundamental practice in organic agriculture with significant benefits for pest control, soil health, and crop productivity. This method systematically rotates different crops in a specific sequence within the same field over time. Its importance lies in its ability to manage pests and diseases naturally, essential in organic farming where synthetic pesticides are prohibited. Additionally, crop rotation plays a key role in replenishing soil nutrients, particularly nitrogen, and promoting soil vitality. By alternating crops with different nutrient needs and root structures, it helps prevent soil depletion and promotes healthier, more resilient soils. Furthermore, crop rotation disrupts the life cycles of insect pests, plant diseases, and weeds, reducing their prevalence.

5.5.1 The Importance of Crop Rotation

To design an effective crop rotation system in organic agriculture, several key considerations must be taken into account:

» **Soil Type, Fertility, and Climate:** Understanding the soil's fertility, texture, drainage, and the local climate is critical in tailoring the rotation to meet the specific needs of the land. Different crops have varying nutrient and growth requirements, so selecting crops that suit the soil and climate conditions is essential.

» **Alternation of Root Structures:** Deep-rooted crops, like legumes or tap-rooted vegetables, can help break up compacted soil and access deep nutrients. Rotating these with shallow-rooted crops ensures soil structure is maintained and topsoil nutrients are not depleted.

» **Nitrogen Fixation and Nitrogen Demand:** Rotating nitrogen-fixing crops, such as legumes (e.g., peas, beans, clover), with nitrogen-demanding crops replenishes soil nitrogen levels. Legumes form symbiotic relationships with nitrogen-fixing bacteria, converting atmospheric nitrogen into a form usable by plants.

» **Cover Crops and Green Manures:** Incorporating cover crops and green manures into crop rotations is essential for protecting soil, reducing erosion, suppressing weeds, and improving soil fertility. For example, cover crops like clover and vetch act as living mulches, adding organic matter to the soil when tilled under, and increasing natural nitrogen levels.

Leguminous cover crops, which function as green manures, fix atmospheric nitrogen through symbiotic relationships with soil bacteria, providing valuable nutrients as they decompose.

- Alternation of Crop Types: Varying the crop types in rotation helps break pest and disease cycles. For instance, alternating leafy greens with grain crops can disrupt the life cycles of pests specializing in specific plant families. Rotating crops with different growth habits also helps manage weeds and optimize space.
- Pest and Disease Tolerance: Choosing tolerant crop varieties and alternating susceptible crops with less susceptible ones can mitigate the risk of outbreaks. By reducing the continuous presence of host plants for specific pests and pathogens, crop rotation can help suppress populations without the need for chemical interventions.

Organic farming systems emphasize practices that promote the sustainability of soil structure and long-term soil health through thoughtful crop rotation and organic inputs. The soil ecosystem consists of a dynamic balance of biological organisms, minerals, organic matter, air, and water, all of which interact to support plant growth and ecosystem health. However, certain agricultural practices, like excessive tilling or overuse of synthetic chemicals, can leave the soil prone to erosion and nutrient depletion, gradually weakening its structural integrity.

To address these challenges, organic farming focuses on effective soil management strategies that improve soil aggregation, enhance organic matter content, and maintain a favorable environment for beneficial soil organisms. These strategies ensure the soil remains fertile and vital, capable of supporting diverse crops while minimizing the need for external inputs. The integration of organic residues, minimal tillage, and the use of cover crops are some of the core principles employed to safeguard and enhance soil structure in organic farming systems.

To implement soil management practices effectively in organic farming, the following key points should be considered:

- Continuous Addition of Organic Residues: Regularly incorporating organic materials, such as compost, manure, and crop residues, into the soil helps maintain high levels of organic matter (humus). This organic matter not only provides essential nutrients for plant growth but also improves soil structure, water retention, and microbial activity, all of which are vital for sustaining soil health and fertility.
- Maintain Adequate Microbial Activity: Promoting conditions favorable for soil microorganisms is crucial. These microorganisms play an essential role in breaking down organic matter, releasing nutrients in forms that plants can absorb, and maintaining overall soil fertility. Practices such as applying compost, reducing soil disturbance, and avoiding harmful chemical inputs support microbial life.
- Support Soil Organisms: Earthworms, beneficial insects, and other soil organisms contribute to soil aeration, organic matter decomposition, and nutrient cycling. Creating a favorable environment for these organisms enhances soil health. This can be achieved through minimal tillage, using cover crops, and maintaining organic residues in the soil.
- Improve and Stabilize Soil Structure: Practices such as shallow plowing, using organic amendments, and incorporating cover crops can enhance soil aggregation, which stabilizes soil structure. Good soil structure promotes better water infiltration, root penetration, and overall plant growth, while minimizing erosion.
- Employ Soil Cover Techniques: Techniques like mulching, cover cropping, and intercropping can help prevent soil erosion, retain moisture, suppress weeds, and protect soil organisms. These practices maintain a protective layer on the soil surface, which enhances soil fertility and resilience to environmental stressors, particularly in organic farming systems.

By considering the previous factors and principles when designing a crop rotation plan, organic farmers can optimize soil health, nutrient management, pest control, and overall crop productivity in a sustainable and environmentally friendly manner. Crop rotation serves as a cornerstone of organic agriculture, promoting resilience, biodiversity, and long-term agricultural sustainability.

5.5.2 General Principles for Designing Crop Rotations

Effective crop rotation design is essential for optimizing soil health, nutrient cycling, and pest management in organic agriculture systems. The following are key principles to consider when planning a crop rotation:

» **Incorporate Leguminous Crops First:** Start the rotation with leguminous crops such as peas, beans, or clover. These crops fix atmospheric nitrogen into the soil through a symbiotic relationship with rhizobia bacteria, enriching soil fertility for subsequent crops.

» **Follow with Nitrogen-Demanding Crops:** After legumes, plant crops with high nitrogen requirements (e.g., corn, leafy greens) to capitalize on the nitrogen added to the soil. This ensures efficient nutrient use and maximizes crop yields.

» **Avoid Consecutive Plantings of Related Crops:** Prevent the buildup of diseases and pests by rotating crops from different plant families. For example, avoid planting brassicas (e.g., cabbage, broccoli) consecutively to reduce the risk of pathogen buildup in the soil.

» **Promote Crop Health:** Design rotations to enhance crop health by balancing nutrient inputs and outputs. Rotate crops that use different nutrients to prevent soil depletion and create favorable conditions for robust plant growth.

» **Weed Control:** Use crop succession strategically to suppress weed growth. Crops that grow quickly or have dense canopies can outcompete weeds, while certain crops may release allelopathic compounds that inhibit weed germination.

» **Incorporate Deep-Rooted Crops:** Plant deep-rooted crops (e.g., carrots, alfalfa) in the rotation to improve soil structure and nutrient cycling. These crops access deeper soil layers, breaking up compaction and bringing up nutrients that shallow-rooted crops cannot reach.

» **Residue Management:** Choose crops that leave behind significant organic residue, like corn or cover crops, to increase soil organic matter content. These residues improve soil structure, water retention, and microbial activity.

» **Diversify Crop Types:** Diversify crops in rotation based on factors like plant family, planting time, crop type (root, leafy, fruiting), and agricultural practices. This diversity helps reduce pest and disease pressure, ensures efficient nutrient use, and promotes overall soil health.

By adhering to these principles, organic farmers can develop successful crop rotations that promote long-term soil health, improve crop productivity, and maintain ecological balance within their farming systems. This holistic approach significantly enhances the sustainability and resilience of organic farming operations, ensuring both environmental and economic benefits.

5.5.3 Crop Rotation and Pest Control

Crop rotation plays a vital role in protecting crops from insect pests and diseases by leveraging an understanding of their life cycles and behaviors. By systematically alternating crops, farmers can disrupt pest life cycles and reduce their populations. Different crops exhibit varying levels of susceptibility to specific pests and diseases, so alternating crop families can effectively break these cycles. For instance, planting a non-host crop can reduce the population of pests that are specific to certain crops.

Moreover, crop rotation helps in weed suppression. Some crops exhibit allelopathic properties, releasing biochemicals that inhibit weed growth. Others allow for strategic practices, like intercropping or cover cropping, which suppress or reduce the emergence of weeds by creating a more competitive environment.

Additionally, crop rotation fosters biodiversity, attracting beneficial organisms such as predatory insects, birds, and microbes, all of which contribute to natural pest control through predation or competition. A diverse ecosystem is more resilient to pest outbreaks, as the variety of organisms helps maintain natural checks and balances.

In the long term, crop rotation promotes sustainable agricultural systems. By preserving soil fertility, reducing pest pressure, and preventing yield declines, it helps ensure the long-term viability of farming operations and the conservation of natural resources for future generations.

The following are key considerations for understanding the relationship between crop rotation and pest control:

» **Knowledge of Pest and Disease Biology:** Successful crop rotation requires a deep understanding of the pests and diseases affecting crops. This includes knowing their preferred hosts, life cycles, and habitats. With this knowledge, farmers can implement crop rotations that disrupt the life cycles of pests and diseases, making it harder for them to establish and proliferate.

» **Utilizing Integrated Pest Management (IPM):** Crop rotation can be one component of a broader pest and disease management strategy. Depending on the nature of the pests and diseases, additional measures such as the use of bio-pesticides, biological control agents, or cultural practices like sanitation and trap cropping may also be necessary to achieve effective control.

» **Managing Soil-Borne Pathogens:** While crop rotation can help reduce certain soil-borne pathogens, it may not be effective against all pathogens. Some may persist in the soil despite crop rotation. In such cases, using resistant crop varieties, practicing good sanitation, and avoiding the introduction of contaminated materials can help manage these diseases more effectively.

» **Understanding Pest Life Cycles:** The timing of crop rotation is crucial for its effectiveness in pest control. Ideally, the rotation should coincide with vulnerable stages of the pest's life cycle, such as egg-laying or pupation. By disrupting these stages, farmers can reduce pest populations and minimize their impact on crops.

» **Challenges with Highly Mobile Pests:** Some pests, like corn earworms and cabbage loopers, have highly mobile adult stages that can easily migrate between fields. In such cases, crop rotation may have limited effectiveness, and supplementary control measures such as environmentally friendly pesticide applications or physical barriers may be necessary to manage these pests effectively.

Generally, crop rotation is an effective strategy for pest control in organic agriculture. For example, rotating brassica crops (such as cabbage, broccoli, and kale) with non-brassica crops reduces the buildup of brassica-specific pests, such as cabbage worms and flea beetles, as these pests cannot survive without their host plants. Similarly, rotating corn with soybeans or small grains disrupts the life cycle of corn rootworms, which thrive in continuous corn cultivation. For nematode control, alternating susceptible crops like tomatoes and carrots with nematode-resistant or non-host crops, such as marigolds, grains, or legumes, helps reduce nematode populations. In the case of the Colorado potato beetle, rotating solanaceous crops (potato family) with non-solanaceous crops like beans or corn deprives the beetles of their food source, thereby reducing their population.

In conclusion, while crop rotation is a valuable tool for pest and disease management in organic agriculture, its success depends on a combination of factors, including knowledge of pest biology, timing of rotations, and integration with other pest control measures. By carefully planning and implementing crop rotations tailored to specific pest and disease challenges, farmers can mitigate risks and protect their crops more effectively.

5.6 Grafting Vegetable Crops in Organic Agriculture

Vegetable grafting is an ancient technique, originating in Asia, that significantly enhances plant production, increases resistance to diseases, and boosts plant vigour. By grafting, the shoot (scion) of one plant is fused with the root system (rootstock) of another, creating a single composite plant. Typically, the scion is chosen for its desirable fruit quality, taste, or yield, while the rootstock is selected for traits such as disease resistance, drought tolerance, or adaptability to challenging soil conditions.

The grafting procedure begins by making precise cuts on both the scion and rootstock, ensuring that they are properly aligned. Once aligned, the scion and rootstock are securely bound together to facilitate the healing process, during which the two plants form a stable union. After the graft has successfully healed, the newly fused plant is ready for transplantation into open fields or greenhouses, where it will continue to grow and develop.

Grafting gained prominence in Japan and Korea in the late 1920s, initially applied to watermelon plants to combat disease and increase yield. Over time, the technique expanded globally, becoming particularly valuable in regions with limited agricultural space, such as the Mediterranean and Europe, where soil-borne pathogens tend to concentrate due to intensive land use. Grafting became essential for managing these pathogens, as it offered a practical solution to soil-borne diseases that would otherwise affect crop yields. Today, Japan remains at the forefront of grafting technology, especially in the cultivation of watermelons, cucumbers, and eggplants. This is particularly relevant in areas where crop rotation is less feasible, making grafting an indispensable method for maintaining crop health and productivity.

In Arab countries, including the UAE, Oman, Egypt, Syria, Jordan, Lebanon, and Morocco, vegetable grafting has increasingly gained popularity. This growth is primarily driven by the need to combat soil-borne fungal diseases and plant-parasitic nematodes. In these regions, where chemical alternatives are often restricted due to environmental and health regulations, grafting has become a crucial, sustainable solution for pest management.

The surge of interest in vegetable grafting in the Western world began in 2005 following the Montreal Protocol, which banned the use of methyl bromide, a common soil fumigant. The ban led farmers, especially organic growers, to seek alternatives, and grafting emerged as a highly effective method for managing pests without relying on synthetic chemicals. This technique has since gained traction, particularly in organic farming, where the focus is on sustainable and environmentally friendly practices.

Commonly grafted vegetable crops include tomatoes, eggplants, and peppers (Family: Solanaceae), as well as watermelon, melon, cucumber, and zucchini (Family: Cucurbitaceae). Though grafting requires higher initial investment and labour, its benefits in enhancing disease resistance, improving yields, and promoting environmental sustainability make it an increasingly popular method in organic agriculture.

5.6.1 Objectives of Using Vegetabl Grafting in Organic Agriculture

The use of vegetable grafting in organic agriculture serves multiple objectives aimed at addressing various challenges and optimizing crop production sustainably. These objectives are summarized as follows:

- **Resistance to Soil-Borne Pathogens:** One of the key objectives of vegetable grafting is to impart resistance to soil-borne pathogens like fungi and nematodes. Grafting susceptible scion varieties onto resistant rootstocks can protect plants from diseases such as *Fusarium* wilt, *Verticillium*, and *Pseudomonas*, reducing the need for chemical interventions. For example, grafting tomatoes onto *Fusarium*-resistant rootstocks helps prevent yield losses from this destructive disease.
- **Enhanced Temperature Tolerance:** Grafting increases a plant's ability to withstand extreme soil temperatures. Certain rootstocks, such as pumpkin (*Lagenaria siceraria*) and fig-leaf gourd (*Cucurbita ficifolia*), are well known for their capacity to tolerate temperature fluctuations, allowing crops like cucumbers to thrive even in environments with challenging temperature variations.
- **Resistance to Soil Salinity:** Vegetable grafting also enhances resistance to soil salinity. Some rootstock varieties, such as those from the Cucurbitaceae family, are more tolerant of saline conditions. When crops are grafted onto these rootstocks, it allows them to grow in saline soils where non-grafted plants would otherwise struggle to survive.
- **Modification of Vegetative-to-Root Ratio:** Grafting modifies the "Top-to-Root ratio", often favoring stronger root development. This enhances the plant's ability to absorb water and nutrients from the soil, leading to more vigorous vegetative growth and, subsequently, higher-quality fruit production.
- **Enhanced Plant Strength and Fruit Quality:** Grafted plants tend to exhibit greater vigour and resilience. This translates to stronger, more robust plants that can produce fruit of superior quality. Grafting also allows for the selection of rootstocks that improve specific fruit characteristics, such as size, shape, colour, and sugar content, resulting in better overall crop performance.

Overall, vegetable grafting in organic agriculture is a valuable technique for managing soil-borne diseases, optimizing plant performance in challenging environmental conditions, and improving the quality and yield of organic crops. By carefully selecting appropriate rootstocks and scion varieties, growers can adapt grafting strategies to align with specific production goals and environmental factors. This adaptability supports the creation of sustainable and resilient agricultural systems that are better equipped to handle the challenges of organic farming.

5.6.2 Benefits of Vegetable Grafting in Organic Agriculture

The benefits of vegetable grafting in organic agriculture offer significant advantages for crop production and sustainability. Below are some of the key advantages:

- **Disease Control:** Grafting onto resistant rootstocks effectively controls soil-borne fungal diseases and nematodes, minimizing the need for chemical pesticides. This leads to healthier plants and reduces crop losses due to diseases.
- **Improved Fruit Quality and Quantity:** Grafted plants often produce higher-quality fruits in greater quantities. For example, cucumber plants grafted onto disease-resistant rootstocks tend to yield more fruits per

node, which leads to increased production and earlier harvests.

» **Tolerance to Environmental Stress:** Grafted plants are better able to withstand environmental stresses such as soil acidity, salinity, and nutrient deficiencies. Their strong root systems allow them to access essential nutrients and water even in challenging conditions, ensuring consistent yields.

» **Resource Efficiency:** Grafted vegetable plants demonstrate enhanced efficiency in absorbing water and nutrients from the soil, which reduces the need for both irrigation and fertilizers. This contributes to sustainability by lowering production costs and minimizing resource inputs, ultimately reducing the environmental impact. By requiring fewer inputs, grafted plants help farmers conserve water and reduce fertilizer usage, aligning with the goals of organic agriculture to foster more eco-friendly farming systems.

» **Optimized Planting Density:** Grafted plants typically require less space, enabling growers to plant more densely and maximize land use efficiency. This results in higher yields with fewer seedlings per unit area. Additionally, grafted plants are more resilient to adverse environmental conditions, further improving their performance in high-density planting systems.

» **Compatibility with IPM:** Grafting complements integrated pest management (IPM) practices by reducing reliance on chemical controls. This aligns with the goals of organic agriculture, promoting a healthier ecosystem and more sustainable pest management strategies.

5.6.3 The Most Important Methods of Vegetable Grafting

Vegetable grafting is a technique that involves joining the scion (the upper part of the plant) with the rootstock (the root system) to combine desirable traits from both plants. The following outlines the key methods and processes involved in vegetable grafting:

» **Selection of Scion and Rootstock:** The process begins with selecting a scion known for its superior traits (such as fruit quality or yield) and a rootstock chosen for its disease resistance, drought tolerance, or soil adaptability. Both plants should be healthy and free from disease to ensure successful grafting.

» **Preparation for Grafting:** Once selected, the scion and rootstock are prepared by cutting healthy sections of similar diameter. Ensuring that the plant cuttings are clean and free from pests is crucial for a successful union.

» **Making Precise Cuts:** Clean, precise cuts are made on both the scion and rootstock to create matching surfaces for the graft. Typically, a diagonal cut is made near the base of each plant, ensuring that the surfaces align properly. Achieving clean, accurate cuts is crucial for promoting successful healing and union between the scion and rootstock.

» **Grafting Techniques:** After the cuts are made, the scion and rootstock are carefully aligned and joined together. Depending on the plant species and desired outcome, various grafting techniques can be applied. Common methods include:

* **Cleft Grafting:** A straightforward method where the scion is inserted into a cleft or split made in the rootstock.
* **Side Grafting:** Involves attaching the scion to the side of the rootstock, allowing for easier alignment of the tissues.
* **Tube or Splice Grafting:** The scion and rootstock are joined at matching diagonal cuts, then secured with grafting clips, rubber bands, or grafting tape to stabilize the union while it heals.

» **Healing and Union Formation:** After grafting, the plants require an optimal environment with controlled moisture and temperature to heal and form a strong union. This healing process can take several days to weeks, depending on the grafting method and plant species.

» **Transplanting and Care:** Once the graft has healed, the plant is transplanted to the field or greenhouse. Care must be taken during transplanting to avoid damaging the graft union. Grafted plants also require ongoing care, including proper irrigation, fertilization, and pest management to ensure healthy growth and maximize yields.

The vegetable grafting process requires meticulous attention to detail and the application of precise techniques to achieve successful graft unions, resulting in high-quality, resilient plants. With proper care and management, grafted vegetable plants provide numerous benefits, including enhanced disease resistance, improved yield and quality, and overall increased productivity for growers.

The following are detailed descriptions of various grafting techniques used in vegetable production, as outlined by Sacha *et al*. (2011). The choice of technique depends on the plant species and desired outcomes, allowing growers to tailor their grafting practices to specific agricultural objectives. By paying careful attention to these methods, vegetable grafting can significantly enhance plant health, increase yield, and improve resilience, making it an invaluable tool in organic agriculture.

5.6.3.1 Cleft Grafting

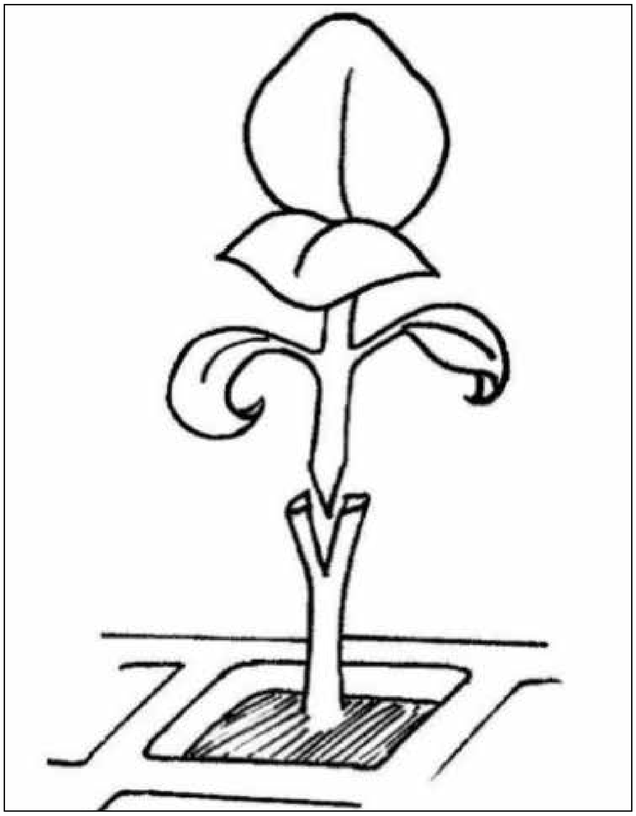
Cleft grafting, also known as apical or wedge grafting, is a widely employed technique for grafting cucurbits, tomatoes, and eggplants. This method requires precision during the grafting process and careful maintenance of optimal air humidity to ensure success, as illustrated in Figure 5.32.

The process typically begins by planting rootstock seeds on the first day, followed by scion seeds on the fourth day. After about 18 days, grafting is performed by removing the top portion of the rootstock plant horizontally, just above the grafting area. A vertical incision, approximately 0.5 cm long, is made in the stem of the rootstock. The scion is then prepared by removing its true leaves and creating a wedge-shaped cut of about 0.5 cm at its base. The scion is inserted into the vertical incision on the rootstock, ensuring the cut surfaces of both plants are in close contact. A plastic clamping clip or parafilm is used to secure the union tightly.

The grafted plants are then placed under a plastic enclosure to promote fusion between the scion and rootstock. After 15-20 days, the plants begin to acclimate, and after another week, they can be gradually exposed before being transplanted into the permanent growing area or greenhouse.

One of the main advantages of cleft grafting is the secure fit of the scion within the rootstock's vertical incision, which provides a firmer attachment than other methods, such as splice grafting. This secure fit allows for the use of parafilm instead of plastic clips to bind the graft, reducing material costs and improving ease of handling. However, cleft grafting typically requires more time to perform than other techniques, and care must be taken to avoid making the scion wedge too wide, as this can split the rootstock stem and result in graft failure.

Figure 5.32. Cleft Grafting.



5.6.3.2 Side Grafting

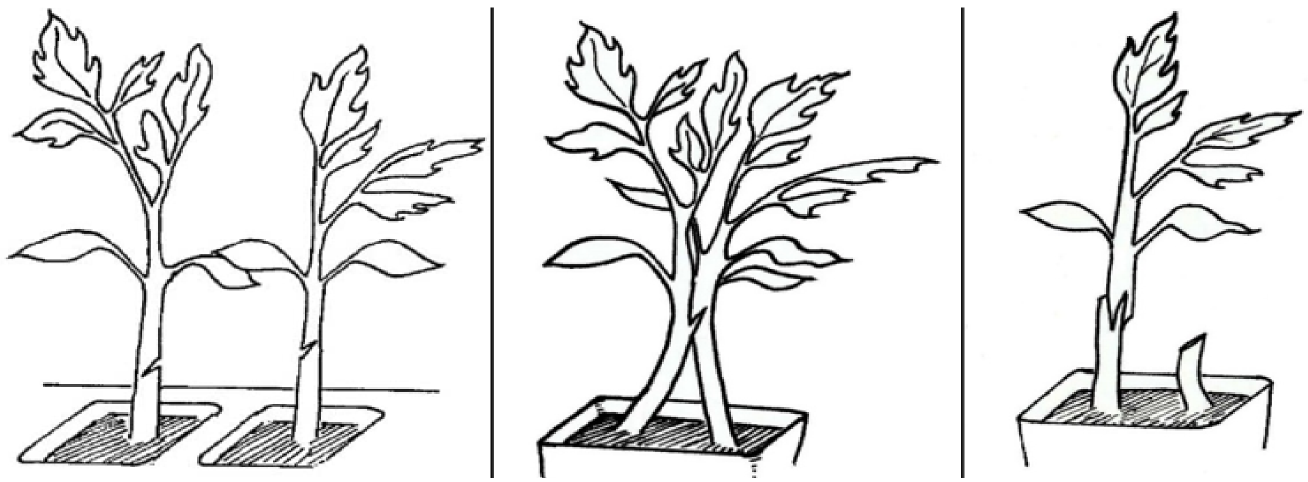
Side grafting, also known as tongue grafting or side-by-side grafting, is a common technique used for vegetables like tomatoes, cucumbers, and cantaloupes, as illustrated in Figure 5.33. It is considered one of the safest grafting methods due to its high success rate, as both the rootstock and scion retain their roots and leaves during the healing period. This retention ensures graft stability and allows for easy re-grafting if needed.

In side grafting, rootstock seeds are sown four days before the grafting process to ensure they are slightly more mature than the scion. After two weeks, the rootstock and scion are selected and prepared, with particular attention to ensuring that their stem thicknesses are similar. A 45-degree oblique cut is made on the rootstock stem to form a tongue-shaped protrusion about 1 cm deep. A similar cut is made on the scion's stem, and the two are carefully aligned, with the tongues inserted into each other to create a snug, secure fit. The graft union is then secured using a plastic clamping clip to hold the scion and rootstock in place during the healing process.

After the grafting process, seedlings are placed in an incubator room maintained at a minimum of 25°C. They are lightly watered once or twice a day, and organic fungal disinfectants are applied with irrigation if needed. Nutrients are provided if the seedlings show signs of nutrient deficiencies. Acclimatization starts a week after grafting, gradually exposing the plants to external conditions. The final step occurs 25 days after grafting, where the rootstock's vegetative portion is removed above the graft union, and the scion's root portion is cut below. After about a month, the plants are ready for transplantation into their permanent growing environment.

One of the main advantages of side grafting is its high success rate, as the scion can continue absorbing water through its roots during the healing process. However, it requires more space since both rootstock and scion must be transferred together, which can be challenging in greenhouse settings. Side grafting is also a slightly slower and more complex technique compared to other methods. Proper labeling of the rootstock and scion is essential to avoid confusion, especially if the seedlings look similar.

Figure 5.33. Side or Tongue Grafting.



5.6.3.3 Splice Grafting

Splice grafting, also known as tube grafting, top grafting, or slant-cut grafting, is a widely used horticultural technique for vegetables such as tomatoes, peppers, and eggplants, as illustrated in Figure 5.34. This method involves connecting the stem of the scion plant with the stem of the rootstock plant by making diagonal cuts, aligning them carefully, and securing the graft.

Both the scion and rootstock are grown separately until they are ready for grafting. The rootstock is typically chosen for its strong root system or disease resistance, while the scion is selected for its desirable fruit characteristics. It is important that the stem diameters of both plants match to ensure a successful graft union. Only healthy, disease-free plants should be selected for this procedure.

A sharp knife is used to make diagonal cuts on both the scion and rootstock, usually at a 45-degree angle, creating matching surfaces that fit together. The vascular cambium layers (responsible for nutrient and water transport) of both the scion and rootstock must be in close contact to ensure a successful graft union. The stems are then secured using silicone grafting clips, rubber bands, or grafting tape, as shown in Figure 5.35. This ensures proper alignment and promotes the formation of a strong union.

Post-grafting, the plants are placed in a high-humidity, temperature-controlled environment, such as a greenhouse or propagation chamber. Proper moisture and temperature management are essential to promote healing and union formation. Once the grafts have healed, the plants are gradually acclimatized to outdoor conditions by slowly increasing exposure to sunlight and reducing humidity. This prepares them for transplanting into a field or garden.

Splice grafting is simple to learn and an efficient way to graft large numbers of plants. However, it requires grafting clips to ensure firm contact between the scion and rootstock. This technique allows growers to combine desirable traits, such as disease resistance and fruit quality, making splice grafting a valuable tool in horticultural production. With proper care, splice-grafted plants can produce high-quality yields, enhancing overall crop performance.

Figure 5.34. Splice Grafting of Tomato Plants.

Source: Washington State University extension fact sheet (FS052E).

Figure 5.35. Silicon Grafting Clip.

5.6.4 Factors Affecting the Success of Vegetable Grafting

The success of vegetable grafting is influenced by several key factors, ranging from environmental conditions to the specific techniques employed. Below are the most important factors that impact the grafting process:

» **Selecting the Appropriate Rootstock:** It is essential to choose a rootstock capable of withstanding local environmental conditions and resistant to soil-borne fungi and nematodes. Mechanical and physiological compatibility between the rootstock and scion is critical for the graft to take hold successfully.

» **Choosing the Right Scion Variety:** The scion should possess desirable traits, such as superior yield, quality, or pest resistance. It's important to synchronize the planting times of the rootstock and scion to ensure that both are at an ideal stage for grafting.

» **Availability of Skilled Labour:** Grafting is a delicate process that requires well-trained personnel. Success largely depends on the precision of cuts, proper alignment, and the overall technique used.

» **Pre-Grafting Preparation:** Limit sunlight exposure to both rootstock and scion for 2-3 days before grafting to slow growth. Reduce irrigation during this period to prevent new growths, which could interfere with the grafting process.

» **Grafting Environment:** Grafting should take place in an environment with controlled heat, humidity, and lighting. Ideally, a plastic tunnel covered with shading nets is used to create these optimal conditions. The grafting area must also be sterile to reduce the risk of disease transmission.

» **Sanitation:** Proper cleanliness during the grafting process is crucial. All tools must be sterilized, and disease-free plant material should be used. Working in a clean and sanitized environment helps prevent contamination.

» **Grafting Techniques:** The choice of grafting method, such as cleft grafting, splice grafting, or side grafting, depends on the specific plant species being grafted. Precision is key to ensuring a proper union between the scion and rootstock.

» **Nutrient Management:** Adequate nutrition, especially nitrogen, phosphorus, and potassium, is essential to support the growth of grafted plants. Supplemental fertilizers may be needed depending on soil conditions and plant requirements.

» **Water Management:** Maintaining optimal soil moisture is vital for the success of grafted plants. Care should be taken to avoid waterlogging, which can lead to root rot, while ensuring that sufficient moisture is available to prevent drought stress.

» **Proper Docking Conditions:** Ensure that the docking of the rootstock and scion provides sufficient contact area for vascular bundles to fuse. Prevent the docking surfaces from drying out to encourage successful bonding.

» **Monitoring Graft Success:** A successful graft is indicated by the efficient transfer of water and nutrients from the rootstock to the scion, as well as the movement of photosynthetic products from the scion to the rootstock.

» **Planting Grafted Seedlings:** Grafted seedlings should be planted with the graft union above the soil surface to prevent infection. The planting distance may vary from traditional methods, and original growths should be removed as necessary.

» **Post-Grafting Care:** After grafting, place the plants under a plastic tunnel with temperatures maintained between 27-30°C and humidity levels kept above 95 % for the first three days. This helps facilitate the healing process and supports successful grafting.

5.6.5 Problems that can Affect the Process of Vegetable Grafting

While vegetable grafting offers numerous benefits, several challenges can impact its success. Common issues include:

» **Incompatibility:** Compatibility between the scion and rootstock is critical for successful grafting. If the plants are not closely related or their vascular systems are incompatible, the graft union may fail to form, or the resulting plant may lack the strength to support growth.

» **Graft Failure:** Poor alignment, insufficient contact between the scion and rootstock's vascular tissues, or mechanical damage to the graft union can result in graft failure. This can lead to reduced vigour, stunted growth, or even plant death.

» **Disease Transmission:** Grafting can transfer diseases between the rootstock and scion if either plant is infected. To minimize this risk, proper sanitation is essential, including disinfecting tools and using disease-free plant material.

» **Environmental Factors:** Environmental conditions such as temperature, humidity, and light intensity significantly affect the success of grafting. Extreme temperatures or rapid fluctuations can stress plants and hinder the vegetable grafting process. Low humidity levels, for instance, can dry out the graft union, leading to graft failure.

» **Handling and Transplanting:** Rough handling during transplanting can damage the delicate graft union, compromising the success of the graft. Grafted plants should be handled gently, ensuring no damage to the graft union or root system.

» **Nutritional Imbalance:** Imbalanced nutrient levels, especially nitrogen, phosphorus, and potassium, can hinder the development of grafted plants. It's crucial to tailor fertilization practices to the specific needs of the grafted plants for optimal growth and productivity.

» **Pest Pressure:** Pests, such as insects and rodents, pose a threat to grafted plants, particularly during the early stages. Using integrated pest management strategies and ensuring protection from pests can help mitigate this risk.

» **Rootstock Vigour:** The vigour and health of the rootstock are key to the success of the graft. Weak or diseased rootstocks may fail to support the scion, leading to poor performance and reduced productivity.

To overcome these challenges, careful attention to grafting techniques, optimal environmental control, and sound plant health management practices is essential. By following these steps, many potential issues can be minimized, resulting in successful vegetable grafting and enhanced crop productivity.

5.6.6 Examples of Rootstocks Used for Grafting in the Cucurbitaceae

In the Cucurbitaceae family, a variety of rootstocks are employed for grafting to enhance disease resistance, environmental tolerance, and improve overall yield. Below are some prominent examples:

- ***Cucurbita maxima:*** Commonly known as winter squash or pumpkin, is frequently used as a rootstock for grafting cucurbits, including watermelon, cucumber, and melon. This rootstock offers robust resistance to soil-borne diseases, particularly *Fusarium* wilt (*Fusarium oxysporum*) and root-knot nematodes (*Meloidogyne* spp.). The resistance provided by *C. maxima* stems from its origins in wild squash species, which are naturally adapted to withstand these pathogens.
- ***Cucurbita moschata:*** Another species of squash, *C. moschata* is preferred for its resilience against various soil-borne pathogens and pests. It's commonly employed for grafting crops like watermelons and cucumbers, promoting stronger disease resistance and overall plant vigour.
- ***Cucurbita ficifolia:*** Known as fig-leaf gourd, it is favoured as a rootstock for cucumbers and melons due to its resistance to soil-borne diseases and tolerance to adverse environmental conditions like high salinity and elevated temperatures.
- ***Lagenaria siceraria:*** Also known as bottle gourd or calabash, it is prized for its vigorous root system and tolerance to saline soils. It is often used as a rootstock for cucumbers and watermelons, particularly in regions with saline soils, enhancing overall plant health and productivity.
- ***Cucumis metuliferus:*** Commonly referred to as African horned cucumber or kiwano, this species resists various soil-borne diseases and is used as a rootstock for cucumbers and melons in areas with high disease pressure.
- ***Benincasa hispida:*** Known as winter melon or wax gourd, it serves as a rootstock for cucumbers and melons. It provides strong resistance to soil-borne diseases and thrives in difficult soil conditions, making it a reliable option for improving crop resilience.

These rootstocks allow growers to enhance the disease resistance, vigour, and environmental tolerance of their crops. The selection of a suitable rootstock is tailored to the crop's specific needs, disease pressures, and soil conditions of the region. Continuous research and trials help identify the most effective rootstocks for different circumstances, ensuring the health and productivity of the grafted plants.

5.6.7 Examples of Rootstocks Used for Grafting in the Solanaceae

In the Solanaceae family, several rootstocks are frequently used in vegetable grafting to improve resistance to diseases, enhance environmental adaptability, and boost yield in crops like tomatoes, eggplants, and peppers. Here are some of the most common rootstocks used in grafting for Solanaceous crops:

- ***Solanum torvum:*** Also known as wild eggplant or turkey berry, it is widely used for grafting tomatoes and eggplants. This rootstock is known for its resistance to soil-borne diseases, including *Fusarium* wilt and root-knot nematodes, offering enhanced plant vigour and protection from pathogens, which improves the growth and yield of grafted plants.
- ***Solanum melongena:*** Certain eggplant cultivars, such as Black Beauty, are used as rootstocks for grafting other eggplant varieties. These rootstocks resist soil-borne pathogens and pests, resulting in enhanced plant health and productivity.
- ***Solanum habrochaites:*** This wild tomato species is commonly used as a rootstock for commercial tomato varieties. It resists several soil-borne diseases, such as *Fusarium* wilt and bacterial wilt, as well as tolerance to environmental stressors like drought and salinity.
- ***Solanum lycopersicum:*** Certain tomato cultivars are used as rootstocks for grafting other susceptible tomato varieties. These cultivars often exhibit resistance to *Fusarium* and *Verticillium* wilt, making them an effective solution for improving plant health, yield, and disease resistance.
- ***Solanum muricatum:*** Also known as pepino melon or sweet cucumber, it is used as a rootstock for grafting both tomatoes and eggplants. This rootstock resists soil-borne diseases and adaptability to environmental stressors, enhancing the overall health and productivity of the grafted plants.

Each of these rootstock varieties in the Solanaceae family offers unique characteristics that contribute to improved plant resilience and productivity, making them valuable in the field of vegetable grafting.

Lee (1994) offers an extensive analysis of rootstock species commonly employed in the grafting of various vegetable crops in South Korea. Table 5.19. highlights key examples, illustrating the range of strategies used to enhance resistance to diseases, increase plant vigour, and improve crop yields across different environmental conditions. This resource is particularly valuable for understanding how specific grafting methods can optimize crop production, showcasing successful applications in South Korean agriculture, where grafting is integrated to achieve sustainability and efficiency.

Table 5.19. Rootstocks, Major Grafting Methods, and Purposes of Grafting for Some Vegetables in South Korea.

Vegetables	Popular Rootstock Species	Grafting Methods	Purpose of Grafting
Watermelon	Gourd (*Lagernaria siceraria* var. *hispida*)	Cleft Grafting Tongue Grafting	Fusarium Wilt Control. Growth Promotion.
	Wax gourd (*Benincasa hispida* Cogn.)	Cleft Grafting Tongue Grafting	Fusarium Wilt Control. Growth Promotion.
	Pumpkin (*Cucurbita pepo* L.)	Cleft Grafting Tongue Grafting	Fusarium Wilt Control. Growth Promotion. Low-Temperature Tolerance.
	Squash (*Cucurbita moschata* L.)	Cleft Grafting Tongue Grafting	Fusarium Wilt Control. Growth Promotion. Low-Temperature Tolerance.
	Sicyos angulatus	Tongue Grafting	Nematode Resistance.
Cucumber	Figleaf gourd (*Cucurbita ficifolia*)	Tongue Grafting	Fusarium Wilt Control. Growth Promotion. Low-Temperature Tolerance.
	Cucumber (*Cucumis sativus*)	Tongue Grafting	Fusarium Wilt Control. Growth Promotion.
	Sicyos angulatus	Tongue Grafting	Fusarium Wilt Control. Growth Promotion.
Sweetmelon	*Cucumis melo*	Tongue Grafting	Fusarium Wilt Control.
Tomato	*Lycopersicon pimpinellifolium* (L.)	Cleft Grafting	Nematode Resistance.
	Lycopersicon hirsutum Humb. & Bonpl.	Cleft Grafting	Nematode Resistance.
	Lycopersicon esculentum	Cleft Grafting	Nematode Resistance. Growth Promotion.
Eggplant	*Solanum integrifolium* Poir	Tongue Grafting Cleft Grafting	Bacterial Wilt Control.
	Solanum torvum Sw.	Tongue Grafting Cleft Grafting	Virus Infection Reduction.

Source: Lee (1994).

Chapter 6

6. weed control Strategies in Organic Agriculture

Weeds are indeed a significant challenge in organic crop production due to their ability to compete with crops for water, nutrients, light, and space, ultimately reducing yields. Effective weed management in organic agriculture is critical because chemical herbicides are not permitted, making preventive and mechanical methods key components of control.

Weeds are commonly categorized based on their life cycle, leaf shape, and duration of existence. These categories help farmers and agronomists understand the growth patterns and management strategies for various weed species:

- **Broadleaf Annual Weeds:**
  - » Winter Varieties:

1. *Bidens pilosa*: Also known as "beggar-ticks," this weed is common in tropical and subtropical regions, competing with crops for nutrients.
2. *Euphorbia helioscopia*: Known as "sun spurge," it thrives in disturbed soils and can be toxic to livestock.
3. Sonchus oleraceus: Often referred to as "sow thistle," this weed is widespread in fields and can crowd out crops.
4. *Chenopodium album*: Commonly called "lamb's quarters," it is a prolific seed producer that can reduce crop yields significantly.

   » Summer Varieties:

1. *Hibiscus trionum*: Also called "flower-of-an-hour," this weed is prevalent in warm regions and can quickly spread through fields.
2. *Portulaca oleracea*: Known as "purslane," it is a succulent weed that can thrive in hot, dry conditions, often outcompeting crops.
3. *Xanthium strumarium*: Commonly referred to as "cocklebur," it grows in moist soils and can be toxic to livestock.
4. *Amaranthus* spp.: Amaranths, or "pigweeds," are notorious for their rapid growth and herbicide resistance, making them major agricultural pests.

- **Narrow-leaf Annual Weeds:**
  - » Winter Varieties:

1. *Avena fatua*: Also known as "wild oats," this weed competes heavily with cereal crops, reducing yields.
2. *Avena sterilis*: Another species of wild oats, problematic in dry regions and often resistant to control methods.
3. *Avena sativa*: While cultivated as a crop, volunteer oats can act as weeds in other cereal crops.
4. *Polypogon monspeliensis*: Known as "annual beard grass," this weed grows in moist areas and can compete with crops like rice.

   » Summer Varieties:

1. *Echinochloa colonum*: Known as "jungle rice," this weed thrives in wet conditions and is a common problem in rice paddies.
2. *Digitaria sanguinalis*: Commonly called "crabgrass," it competes with row crops and is difficult to control.
3. *Echinochloa crus-galli*: Also called "barnyard grass," this weed competes directly with rice and other crops, often lowering yields.
4. *Oryza spontanea*: This wild relative of cultivated rice can act as a weed in rice fields, reducing crop uniformity.

- **Perennial Weeds:**
   » Broadleaf Varieties:

1. *Convolvulus arvensis*: Known as "field bindweed," this weed is particularly difficult to control due to its deep, extensive root system.
2. *Conyza dioscoridis*: Also called "fleabane," this weed can grow in disturbed soils and is resistant to some herbicides.
3. *Alhagi maurorum*: Known as "camelthorn," it is highly drought-resistant and spreads aggressively in arid regions.
4. *Lippia nodiflora*: A creeping perennial that forms dense mats, competing with crops for space and resources.

   » Narrow-leaf Varieties:

1. *Imperata cylindrica*: Known as "cogon grass," this invasive species is highly competitive and can dominate agricultural fields, reducing yields.
2. *Phragmites australis*: Also known as the "common reed," it is often found in wetlands and can outcompete native plants and crops.
3. *Cyperus rotundus*: Called "nutsedge," this weed spreads via tubers and is one of the most difficult weeds to manage in agriculture.
4. *Cynodon dactylon*: Known as "Bermuda grass," it is commonly found in pastures and lawns but can become invasive in crop fields.

The difference between broadleaf and narrow-leaf weeds lies in their classification:

* Broadleaf weeds (Dicotyledonous plants): Produce two cotyledons (seed leaves) upon germination and have broader leaves with net-like veins.
* Narrow-leaf weeds (Monocotyledonous plants): Produce a single cotyledon and have grass-like leaves with parallel veins.

This classification helps farmers and agronomists devise effective weed management strategies tailored to the types of weeds affecting their fields.

Effective weed control in organic agriculture emphasizes preventive and mechanical methods, as chemical herbicides are prohibited. Strategies such as crop rotation, cover cropping, mulching, and strategic tillage not only help reduce weed pressure but also enhance soil health and crop yields. Below are key strategies for weed control in organic agriculture.

6.1 Crop Rotation

Crop rotation is an effective strategy for managing weeds in organic agriculture. This practice involves alternating crops with different growth habits, root systems, and life cycles, disrupting the life cycles of weeds and reducing their overall population. Here are keyways crop rotation helps with weed control:

» **Disrupting Weed Life Cycles:** Many weed species are adapted to specific crop environments. Rotating crops, particularly between those with different planting and harvesting schedules (e.g., alternating annual and perennial crops or cool-season and warm-season crops), can interrupt weed germination and growth. For example, rotating a summer crop like corn with a winter crop like wheat can break the lifecycle of weeds that thrive in only one season.

» **Changing Soil Conditions:** Different crops have varying nutrient requirements and root structures, which can alter soil conditions. Some crops deplete specific nutrients favoured by certain weeds, making the environment less conducive to weed growth.

» **Altering Weed Emergence Patterns:** Certain weeds thrive under specific environmental conditions. Rotating crops allows growers to modify soil moisture levels, light exposure, and other factors that influence weed emergence patterns, thereby reducing weed pressure.

» **Breaking Weed-Host Relationships:** Some weeds form specific relationships with host plants. Crop rotation disrupts these relationships, making it harder for weeds to access essential resources and reducing their ability to proliferate.

» **Varying Soil Disturbance:** Different crops require different cultivation techniques, resulting in varying levels of soil disturbance. Some weeds thrive under constant tillage, while others prefer minimal disturbance. Rotating crops with different tillage needs helps limit the establishment of specific weed species.

» **Smothering Weeds:** Dense-growing cover crops, such as legumes, rye, or clover, can be incorporated into the rotation to act as "smother crops," shading out and outcompeting weeds. Fast-growing crops like buckwheat can provide quick ground cover, reducing weed seed germination.

» **Rotating Deep-Rooted and Shallow-Rooted Crops:** Deep-rooted crops like alfalfa or sunflowers can target perennial weeds that grow deep in the soil, while shallow-rooted crops help control surface-level weeds. This rotation balances weed pressure across soil layers.

» **Improving Soil Health:** Crop rotation improves soil health by increasing organic matter, enhancing microbial diversity, and improving nutrient cycling. Healthy soils favour crop growth over weeds, reducing weed establishment.

» **Including Allelopathic Crops:** Some crops, like rye or sorghum, release natural compounds into the soil that inhibit weed germination. Rotating allelopathic crops can provide an additional natural method for weed control.

» **Reducing the Weed Seed Bank:** Continuous cropping of the same plants allows specific weeds to build up a seed bank in the soil. Rotating crops can reduce the ability of specific weed species to dominate, gradually depleting the weed seed bank over time.

When implementing crop rotation for weed control in organic agriculture, careful planning is essential. Factors such as crop compatibility, nutrient cycling, pest and disease management, and market demand should be considered. By integrating diverse crop sequences and cultural practices, organic growers can effectively manage weeds while promoting sustainable agricultural systems.

6.2 Cover Crops

Cover crops are an excellent tool for weed control in organic farming. By growing these crops between main crop cycles or alongside cash crops, farmers can effectively suppress weed growth, improve soil health, and increase biodiversity. The following points explain how cover crops help in weed control:

» **Outcompeting Weeds for Resources:** Cover crops compete with weeds for essential resources such as water, nutrients, and space. By planting fast-growing, high-biomass-producing cover crops like crimson clover, hairy vetch, or barley, weeds are starved of these resources, reducing their ability to thrive.

» **Allelopathy (Natural Weed Suppression):** Certain cover crops, like cereal rye, sorghum-Sudan grass, and mustard, release chemicals into the soil that inhibit the germination and growth of weed seeds. This allelopathic effect provides a natural form of weed control that lasts even after the cover crop is terminated.

» **Smothering Weeds:** Cover crops with vigorous growth and dense foliage can physically smother weeds, preventing them from accessing the light and resources necessary for growth. This suffocates weeds and reduces their competitiveness.

» **Enhanced Soil Structure:** Cover crops improve soil structure and tilth, creating a more favourable environment for desirable plants while making it challenging for weeds to establish. Their extensive root systems help bind soil particles together, reducing soil erosion and weed germination.

» **Nutrient Cycling:** Cover crops capture and recycle nutrients from deeper soil layers, making them available to subsequent cash crops. By efficiently utilizing nutrients, cover crops reduce the availability of resources for weed growth, thereby limiting weed proliferation.

» **Weed Suppression during Cover Crop Establishment:** Fast-growing cover crops can suppress weeds during their establishment phase, occupying space and resources that weeds would otherwise utilize. This initial weed suppression helps create a weed-free environment for subsequent cash crops.

» **Reducing Weed Seed Germination:** By keeping the soil covered, cover crops can prevent fluctuations in soil temperature and moisture, which are often triggers for weed seed germination. For example, planting winter cover crops like rye or vetch can stop early-season weeds by keeping the soil cooler in the spring.

» **Preventing Soil Disturbance:** Cover crops protect the soil from erosion and compaction, reducing the need for tillage, which can disturb weed seeds and promote weed growth. Minimizing soil disturbance helps maintain weed seed dormancy and prevents the emergence of new weed populations.

» **Interrupting Weed Life Cycles:** Planting cover crops at different times of the year (e.g., winter covers or summer covers) disrupts the life cycles of both annual and perennial weeds. For example, planting winter rye can outcompete cool-season weeds, while buckwheat is highly effective against warm-season weeds.

» **Mulching Effect After Termination:** Once cover crops are mowed or terminated, their residue can act as a natural mulch, suppressing weed emergence by physically blocking light and forming a protective layer on the soil. Crops like cereal rye and wheat provide a thick residue that can last throughout a cropping season.

» **Attracting Beneficial Organisms:** Cover crops provide habitat and food sources for beneficial insects, birds, and microorganisms that contribute to natural weed control. Predatory insects and birds feed on weed seeds and herbivorous insects, helping to keep weed populations in check.

- **Examples of Effective Cover Crops for Weed Control:**

» **Cereal Rye (*Secale cereale*):** Known for its quick growth, dense canopy, and allelopathic properties. It is often used in fall to provide a weed-suppressing mulch for spring planting.

» **Buckwheat** (*Fagopyrum esculentum*): A fast-growing summer cover crop that suppresses weeds by forming a thick canopy within a few weeks.

» **Crimson Clover** (*Trifolium incarnatum*): A winter legume that smothers weeds and improves soil fertility through nitrogen fixation.

» **Hairy Vetch** (*Vicia villosa*): This legume grows vigorously in cool seasons and creates a dense mat that outcompetes weeds.

» **Sorghum-Sudangrass** (*Sorghum bicolor x S. bicolor* var. *sudanense*): Produces high biomass and has strong allelopathic properties, making it effective at weed suppression during the summer.

In conclusion, cover crops are a sustainable and highly effective tool for weed control, significantly reducing the need for herbicides and fostering a healthier agro-ecosystem. By smothering weeds, competing for essential resources like water and nutrients, and providing natural mulching effects, cover crops not only suppress weed growth but also improve soil health, enhance biodiversity, and boost the long-term productivity of organic farming systems. Their use aligns with sustainable agricultural practices, promoting resilience and environmental stewardship in organic agriculture.

6.3 Organic Mulch

Organic mulch is an effective strategy for controlling weeds in organic agriculture. By applying natural materials to the soil surface, organic mulch suppresses weed growth, conserves moisture, improves soil health, and enhances crop productivity in a sustainable manner. Various natural materials can serve as organic mulch, including straw, hay, grass clippings, wood chips, bark mulch, cardboard, newspaper, and compost.

Non-living plant residues (dry residues) make an excellent organic mulch for weed control in organic agriculture. These materials include a variety of plant byproducts like straw, dry leaves, corn stalks, coconut husk, banana leaves, and sugarcane trash. By forming a protective layer over the soil, these residues create a physical barrier that blocks sunlight, preventing weed seeds from germinating. They also help retain soil moisture, moderate soil temperatures, and add organic matter as they decompose, contributing to improved soil fertility. Figures 6.1., 6.2., and 6.3. illustrate various types of organic mulch materials used in organic agriculture. The slow decomposition rate of dry residues like coconut husk ensures prolonged weed suppression, while faster-decomposing materials like dry leaves may require periodic replenishment to maintain their effectiveness. These mulches also reduce soil erosion, suppress soil-borne diseases, and encourage beneficial microbial activity. Here's how organic mulching effectively controls weeds:

» **Suppressing Weed Seed Germination:** Mulches maintain more stable soil temperatures and moisture levels, conditions that are less conducive to weed seed germination. Weed seeds, particularly those that require fluctuating temperatures or moisture levels to sprout, are suppressed when the soil is covered with mulch.

» **Moisture Retention:** Organic mulches help retain soil moisture by reducing evaporation. This creates a favourable environment for crop growth but can hinder weed growth, especially for weeds that thrive in dry, bare soil.

» **Regulating Soil Temperature:** Mulch acts as an insulating layer, moderating soil temperatures and creating a more stable environment for plant growth. Consistent soil temperatures discourage weed growth, as certain weeds thrive under specific temperature conditions.

» **Nutrient Retention:** Organic mulches like straw, hay, or compost gradually decompose, releasing nutrients into the soil. This nutrient enrichment benefits desirable plants while reducing the competitiveness of weeds, which may struggle to compete with well-nourished crops.

» **Blocking Sunlight:** Organic mulches like straw, grass clippings, or wood chips create a physical barrier that prevents sunlight from reaching the soil, which is essential for weed seed germination. Without light, most weed seeds remain dormant, reducing weed pressure. Mulch materials form a dense layer, making it difficult for weed seedlings to push through and grow.

» **Smothering Existing Weeds:** Applying mulch over weeds can smother them by cutting off their light and oxygen supply. This is especially effective for annual weeds that are shallow-rooted and unable to break through the mulch layer.

» **Preventing Weed Spread:** Mulching creates a physical barrier that reduces soil erosion and minimizes the movement of weed seeds by wind or water. This helps to prevent the spread of weed seeds to different areas of the field.

» **Improved Soil Structure:** Organic mulches contribute to soil health by promoting the development of soil aggregates and enhancing soil structure. Improved soil structure facilitates root growth and water infiltration while discouraging weed germination and growth.

» **Suppression of Perennial Weeds:** Thick layers of mulch can effectively smother perennial weeds by depriving them of light and resources. Over time, continuous mulching can weaken perennial weed populations and suppress their regrowth.

» **Enhancing Soil Microbial Activity:** Organic mulches decompose over time, promoting the growth of beneficial soil microorganisms. A healthy microbial population competes with weed roots for nutrients and space, making it harder for weeds to establish and thrive. Mulch decomposition also improves soil structure, which enhances the soil's ability to retain moisture and nutrients for crops, indirectly reducing competition from weeds.

» **Reduces Weed Seed Bank Over Time:** By continuously mulching, farmers can reduce the number of weed seeds in the soil over time. As fewer weeds can grow and set seeds, the weed seed bank diminishes, leading to reduced weed pressure in subsequent growing seasons.

Figure 6.1. Coconut Husk Used as Organic Mulch Under Papaya and Citrus Trees for Weed Control.

Figure 6.2. Banana Leaves Used as Organic Mulch Under Papaya and Banana Trees for Weed Control.

Organic mulches made from dry plant residues that retain some moisture are particularly beneficial for covering the soil surface. These mulches allow rainwater to quickly infiltrate the soil beneath, contributing to better water management. Using plant residues or organic crop residues for mulching is preferable, as they enhance soil health and fertility.

Studies have shown that coconut husk peels can remain in the soil for extended periods, often lasting up to three years or more, providing long-term weed suppression. In contrast, mulches made from dry tree leaves typically decompose more quickly, lasting around six months. Therefore, it is essential to periodically replenish the mulch layer to maintain effective weed control.

By using organic mulches, farmers can create a weed-free environment while promoting soil health and sustainability in organic farming practices. When applying plant residues as organic mulches, consider the following key points:

» Ensure Dryness and Pest-Free Material: It is essential to use plant residues for mulching that are completely dry and free from all stages of insects, as well as pathogens such as fungi and bacteria, to prevent introducing pests and diseases to the soil.

» Proper Coverage Around Trees: When applying mulch around fruit trees, ensure full coverage around the tree base, especially over areas where the feeding roots are spread, while keeping the mulch a safe distance from the trunk to prevent rot and other issues.

» Optimal Thickness: The layer of dry plant residues used for mulching should be at least 15-20 cm thick to ensure effective weed suppression, moisture retention, and temperature regulation.

» Avoid Trunk Contact: When applying mulch around trees, be sure to avoid direct contact with the tree trunks. Maintain a gap of at least 20-25 cm between the mulch layer and the trunk to prevent potential issues like trunk rot, disease, or pest infestations.

» Prevent Mould and Termite Growth: Take precautions to avoid conditions that encourage mould formation or termite activity. This may involve selecting materials that are less prone to mould growth and avoiding those that attract termites.

By following these guidelines, farmers can effectively use plant residues as organic mulches to control weeds while simultaneously promoting soil health and enhancing sustainable organic farming practices.

6.4 Mulching with Plastic Sheets

Mulching with plastic sheets involves covering the soil surface with black plastic, as illustrated in Figure 6.4. It is a highly effective method for weed control in agriculture. Unlike organic mulches, plastic mulch creates a physical barrier that completely blocks weed growth while also offering additional benefits such as improved soil moisture retention and temperature regulation. Here's how plastic mulching works for weed control and the key aspects to consider when using it:

Figure 6.3. Date Palm Fronds Used as Organic Mulch Under Date Palm for Weed Control. The Absence of Weed Growth is Evident on the Right Side.

- Complete Weed Suppression: Plastic mulch creates a solid barrier that blocks sunlight from reaching the soil. Without light, weeds cannot germinate or grow, which provides excellent weed suppression throughout the growing season.
- Moisture Conservation: Plastic mulch retains soil moisture by reducing evaporation. This consistent moisture level benefits crops, but it can also hinder weed growth, especially for weeds that thrive in dry, disturbed soils. The prevention of direct water contact with weeds (outside the planting holes) further limits weed establishment.
- Soil Temperature Control: Plastic mulch helps to regulate soil temperature by trapping heat. Black plastic mulch warms the soil early in the season, making it ideal for crops like tomatoes, peppers, and melons that thrive in warmer soils. Warmer soil can suppress cool season weeds while promoting faster crop growth, giving the crops an advantage over potential weeds.
- Reduction of Weed Seed Germination: Weeds that require fluctuating temperatures to germinate are less likely to emerge under plastic mulch. The consistent soil temperature maintained under the plastic creates an unfavourable environment for many weed seeds. It also prevents weed seeds from being exposed to light, further inhibiting their germination.
- Long-term Weed Suppression: Plastic mulch provides long-lasting weed control, especially for annual weeds. It remains effective as long as it is intact, making it suitable for crops that require longer growing seasons.
- Customization for Planting: Holes are cut into the plastic where the crops are planted. This targeted approach ensures that weeds are suppressed everywhere except in the immediate area of the crop, reducing overall weed pressure. To minimize weed growth in the planting holes, smaller holes are preferred, and crop planting should be done promptly after laying the plastic.
- Enhanced Microbial Activity: Plastic mulch can increase soil microbial activity while reducing fertilizer leaching by minimizing excess irrigation.
- Reduced Fruit Spoilage: Plastic mulch prevents fruits from coming into direct contact with the soil, reducing the risk of spoilage and rotting, especially for crops like strawberries.

The following are some best practices and considerations for using plastic mulch for weed control in organic agriculture:

- Prepare the Soil: Ensure the soil is completely free of weeds before applying plastic mulch. This maximizes the mulch's effectiveness by preventing weed regrowth beneath the plastic.

» **Apply Early:** Lay down plastic mulch early in the season, ideally before weeds have a chance to germinate. This early application prevents the establishment of weeds from the start of the growing season.

» **Use Drip Irrigation:** When applying plastic mulch, it is advisable to install drip irrigation systems beneath the mulch. This ensures that crops receive adequate water while preventing waterlogging, which can occur if water accumulates around plant roots without proper drainage. Drip irrigation also helps conserve water by delivering it directly to the root zone, minimizing evaporation and runoff.

» **Ensure Proper Installation:** Secure the edges of the plastic mulch using soil, stones, or staples to prevent it from being lifted by wind, which could allow weeds to grow along the edges.

» **Monitor the Planting Holes:** Keep an eye on the planting holes for emerging weeds and manage them promptly to prevent competition with the crops. Weed control in these areas is critical to avoid undermining the benefits of the mulch.

However, there are some disadvantages to using plastic mulch, which can be summarized as follows:

» **Risk of Root Rot:** Without proper irrigation management, plastic mulch can trap moisture, leading to increased risk of root rot. This issue is more common if the plastic mulch is overused in humid or poorly drained soils.

» **Salt Accumulation:** Salt buildup can occur in the planting holes where crops grow, especially in regions with poor irrigation management or high salinity.

This can be reduced by placing materials like sawdust beneath the planting holes to absorb some of the salts.

Figure 6.4. Black Plastic Mulch Covering the Soil Surface for Weed Control in Both Open Fields and Greenhouses.

» **Seedling Damage:** High temperatures can be a concern for seedlings as heat may become trapped under the mulch, particularly around the planting holes. Hot air entering these holes can damage young seedlings.

» **Reduced Soil Aeration:** Plastic mulch can restrict air exchange in the soil, particularly in heavy soils or in areas with poor drainage. Reduced soil aeration may negatively affect root health and crop growth over time.

Plastic mulching is a highly effective method for controlling weeds in both organic and conventional agriculture. It blocks sunlight, conserves soil moisture, and regulates soil temperature, which helps suppress weed growth. However, farmers must manage potential risks, such as root rot and reduced soil aeration, through proper irrigation and management techniques. It's also important to note that plastic mulches are non-biodegradable, so their disposal can pose environmental challenges, especially in organic systems.

6.5 Mulching with Paper Lids

Mulching with paper lids (or paper mulch) is an effective and eco-friendly method for weed control in organic agriculture. This technique involves using biodegradable paper sheets or specially designed paper mulches to suppress weed growth while enhancing soil health. Paper mulch is typically made from plant residues and sold in rolls, which can be spread over the soil surface using specialized equipment, as shown in Figure 6.5. Although this method is effective, the relatively high cost of paper mulch makes it more suitable for high-value crops, such as strawberries. Paper mulch offers several advantages, particularly for organic farming, where synthetic weed control methods are prohibited. Below are the key benefits of using paper mulch for weed control:

» **Weed Suppression:** Paper lids act as a physical barrier, blocking sunlight from reaching the soil surface, thereby preventing weed seeds from germinating. The thick layer of paper mulch effectively smothers existing weeds and inhibits the growth of new ones, reducing weed pressure throughout the growing season.

Figure 6.5. Spreading of Paper Mulch by Machine and Creating Holes at Suitable Dimensions to Plant Seedlings or Seeds Through It.

- **Biodegradable and Organic:** Paper mulch is made from natural fibers, such as recycled paper or wood pulp, and is fully biodegradable. As it breaks down naturally in the soil, it contributes organic matter without leaving harmful residues. This makes it a sustainable option that complies with organic farming standards.
- **Moisture Retention:** Paper lids help conserve soil moisture by reducing evaporation, which is especially beneficial in dry regions or during drought conditions. This moisture retention reduces the need for frequent irrigation and supports healthier crop growth.
- **Temperature Regulation:** Paper mulch provides insulation, helping to regulate soil temperatures by keeping the soil cooler in hot conditions and warmer during cooler periods. This temperature moderation can suppress weed growth and benefit crop development.
- **Soil Improvement:** As paper mulch decomposes, it adds organic matter to the soil, improving soil structure and promoting microbial activity. This enhances soil fertility, aeration, and water infiltration, creating a more favorable environment for crops.
- **Erosion Control:** Paper mulch helps reduce soil erosion by creating a protective layer over the soil. This is particularly beneficial on sloped fields or areas prone to wind or water erosion, as it stabilizes the soil and prevents the loss of valuable topsoil.
- **Cost-Effective and Easy to Apply:** Compared to other biodegradable mulching options, such as biodegradable plastic, paper mulch is relatively affordable and easy to install. It can be applied manually or mechanically, making it a viable option for large-scale organic farming operations.
- **Environmentally Friendly:** Since paper lids are made from natural materials, they do not harm beneficial soil organisms, such as earthworms and beneficial bacteria

Commercially available paper mulches are often treated with non-toxic substances to improve water resistance and durability for longer growing seasons. Recycled paper or cardboard sheets can also serve as a cost-effective and eco-friendly mulching option. Additionally, waxed paper mulch, which is coated with a biodegradable wax layer, improve water resistance, making them more durable for longer growing seasons. Waxed paper mulch is still biodegradable but can offer better weed suppression in wet conditions.

In conclusion, mulching with paper lids is an effective, sustainable, and environmentally friendly method for weed control in organic agriculture. Paper mulch not only provides excellent weed suppression but also conserves soil moisture and enhances soil health as it decomposes.

6.6 Mechanical Weed Control

Mechanical weed control involves using physical tools and machinery to suppress or remove weed growth. This method is crucial in organic farming, where chemical herbicides are prohibited. By relying on tools like hoes, cultivators, and tillers, farmers can effectively manage weeds while maintaining soil health. Some of the key benefits of mechanical weed control include:

- **Effective Weed Removal:** Mechanical tillage and cultivation physically uproot weeds, reducing competition for vital resources such as water, nutrients, and sunlight. This ensures that crops have better access to these resources, enhancing their growth and productivity.
- **Improved Soil Aeration:** Tillage aerates the soil by breaking up compacted layers, creating better conditions for root growth and nutrient uptake. This improves the overall health of the crops and helps boost yields.
- **Seedbed Preparation:** Mechanical cultivation loosens the soil and removes debris, providing optimal conditions for seed germination and crop establishment.
- **Incorporation of Organic Matter:** Tillage also helps integrate crop residues and green manures into the soil. This incorporation enhances soil fertility, microbial activity, and nutrient cycling, all of which are critical for sustainable farming.
- **Weed Seed Burial:** Tillage can bury weed seeds deep into the soil, limiting their exposure to light and reducing their ability to germinate. Over time, this process helps deplete the weed seed bank in the soil, leading to fewer weeds in future growing seasons.

While mechanical weed control offers several advantages, it also comes with certain drawbacks and considerations that need to be addressed to minimize negative impacts. These include:

» **Soil Erosion:** Intensive tillage, especially on sloped land or vulnerable soils, can increase the risk of soil erosion. This leads to the loss of topsoil, which is rich in nutrients, and contributes to long-term degradation of soil quality.

» **Soil Compaction:** Repeated use of heavy machinery in tillage can lead to soil compaction. Compacted soils have reduced porosity, which limits water infiltration and root penetration. This negatively impacts the ability of crops to access water and nutrients, leading to reduced growth and productivity.

» **Energy and Labor Intensive:** Mechanical weed control methods require considerable energy, labour, and machinery. This not only raises production costs but also increases the environmental footprint due to higher fuel consumption and resource use.

» **Disruption of Soil Microorganisms:** Regular tillage disturbs the soil's natural structure and disrupts soil microbial communities that are essential for nutrient cycling and maintaining overall soil health. Frequent disruption can reduce microbial diversity and the ecosystem services they provide, such as organic matter decomposition and nutrient availability to plants.

To mitigate these issues, organic farmers often adopt conservation tillage practices, such as reduced tillage or no-till farming, which minimize soil disturbance. Additionally, integrating mechanical cultivation with other weed control strategies like mulching, cover cropping, and crop rotation can improve overall weed management and promote sustainable farming.

Hand weeding, though labour-intensive, is a highly effective method of weed control in organic farming. It involves manually removing weeds using hands or tools like hoes, weeders, or forks. Despite its challenges, hand weeding offers several distinct advantages:

» **Precision and Selectivity:** Hand weeding allows for precise targeting and removal of individual weeds without damaging nearby crops. This precision enables selective weed management, reducing competition for resources such as water, nutrients, and sunlight.

» **Non-Chemical and Eco-Friendly:** Hand weeding is fully aligned with organic farming principles since it doesn’t rely on synthetic herbicides. This makes it an environmentally friendly option, ensuring that no harmful chemicals are introduced into the soil or surrounding ecosystem.

» **Environmentally Friendly:** By eliminating the use of chemicals, hand weeding preserves the health of beneficial soil organisms such as earthworms and bacteria, which are crucial for maintaining soil fertility and ecological balance.

» **Cultural Integration:** Hand weeding can be seamlessly integrated with other cultural practices like crop rotation, intercropping, and mulching. This integration enhances the overall weed management strategy and contributes to sustainable agricultural practices.

While hand weeding offers precision and eco-friendliness, it also comes with several limitations:

» **Labour-Intensive:** Hand weeding is time-consuming and requires significant manual labour, which makes it less practical for large-scale farming operations. The extensive labour needed can reduce its efficiency in managing larger fields.

» **Costly:** The labour costs associated with hand weeding can be high, especially in areas where labour is expensive or hard to find. This can raise the overall costs of production, making hand weeding less viable in certain regions.

» **Limited Coverage:** Hand weeding is often impractical for large-scale operations or areas with dense weed infestations. In such cases, mechanical or other methods may be more efficient at addressing widespread weed issues.

» **Weed Regrowth:** Hand weeding may not completely eradicate weeds, especially if roots or rhizomes are left in the soil. These remnants can lead to regrowth, necessitating repeated weeding efforts.

Despite these challenges, hand weeding remains an essential tool for managing weeds in organic farming, particularly where chemical herbicides are prohibited. By integrating hand weeding with mechanical and cultural methods such as crop rotation, mulching, and cover cropping, farmers can create an effective, integrated weed management strategy. This combination not only enhances crop productivity but also minimizes environmental impacts. Thoughtful incorporation of these practices allows organic farmers to develop sustainable weed management systems that preserve soil health, promote ecological balance, and reduce reliance on external inputs.

6.7 Prevention and Sanitation

Effective weed control in agriculture relies heavily on robust prevention and sanitation practices. By limiting the spread and persistence of weed seeds and propagules, farmers can significantly reduce weed pressure and promote crop health and productivity. The following are essential prevention and sanitation practices for managing weeds:

» Field Cleanliness: Keeping fields free of weeds is critical for preventing their establishment and spread. Regularly removing weeds before they produce seeds, helps lower the weed seed bank in the soil, preventing future weed population increases.

» Equipment Maintenance: Farm equipment, such as tractors and harvesting machinery, can unintentionally spread weed seeds between fields. Regular maintenance and thorough cleaning of machinery between uses help prevent the transportation of weed seeds from one area to another, minimizing the risk of new weed infestations.

» Contaminated Material Disposal: Proper disposal of weed-infested crop residues, harvested plants, and other organic materials is essential to prevent the spread of weed seeds and propagules. Composting or burning these weed-infested materials helps destroy the seeds, preventing them from germinating and establishing in new areas.

» Hygiene Practices: Maintaining good hygiene on the farm, such as cleaning boots, clothing, and tools before entering fields, helps prevent the introduction and spread of weed seeds. Contaminated equipment and clothing can inadvertently carry weed seeds, leading to new infestations in previously weed-free areas.

» Weed-Free Seed and Plant Material: Utilizing certified weed-free seed and plant materials is essential for preventing the introduction of new weed species. Carefully inspecting seed batches before planting ensures that no weed seeds are present, significantly reducing the risk of introducing weeds into fields.

» Monitoring and Early Detection: Consistent field monitoring for emerging weeds, followed by prompt removal, prevents weed establishment and spread. Early detection ensures that weeds do not compete with crops for vital resources like water, nutrients, and sunlight, reducing the need for more intensive and costly control measures later in the growing season.

By consistently and effectively implementing preventive measures and sanitation practices, farmers can significantly reduce weed infestations, maintain clean and productive fields, and decrease dependence on more expensive and labour-intensive weed control methods. In addition to weed management, these practices enhance overall farm hygiene and biosecurity, promoting the long-term health and sustainability of agricultural systems.

6.8 Soil Solarization

Soil solarization is an effective and cost-efficient method used in organic agriculture to control weeds by eradicating weed seeds and seedlings present in the soil. In addition to weed control, soil solarization helps eliminate pests, soil-borne diseases and nematodes, improves soil properties, and increases the availability of essential nutrients like nitrogen for plant growth. This technique offers a sustainable solution for weed and pest management without relying on synthetic chemicals, making it a valuable practice in organic agriculture.

One of the key advantages of soil solarization is its potential to replace chemical pesticides commonly used in conventional agriculture. By eliminating the need for such chemicals, soil solarization reduces the accumulation of toxic residues in the soil, thus minimizing environmental harm and supporting a healthier ecosystem.

Soil solarization is versatile and can be employed in various scales of organic farming, from small gardens to large farms. The process works by harnessing solar energy through a transparent plastic cover, usually made of polyethylene. This cover traps sunlight, raising soil temperatures to levels that are lethal to many pests, pathogens, and weed seeds.

The effectiveness of soil solarization depends on several factors, including the location, climate, timing, duration of the process, soil preparation, and post-solarization planting methods. This method can be applied in a wide range of organic plantations, including vegetable fields, orchards, greenhouse crops, and garden beds.

However, soil solarization is most effective in regions with high sunlight intensity and elevated temperatures during the summer months. Its reliance on sunlight means it is most successful in areas with prolonged sunlight exposure, which allows the plastic cover to trap solar energy and elevate soil temperatures to lethal levels for pests, pathogens, and weed seeds.

6.8.1 Type and Quality of Plastic Cover Used in Soil Solarization

Transparent plastic, or clear plastic, is the most effective material for soil solarization due to its superior ability to trap sunlight and increase soil temperatures. In contrast, black plastic is less efficient for this purpose, as it does not allow sunlight to penetrate and warm the soil. However, black plastic can be useful for surface mulching to suppress weed growth by blocking sunlight.

The thickness of the transparent plastic significantly affects the efficiency of the solarization process. Thinner plastic sheets generally store more heat, enhancing soil sterilization. Plastics with a thickness of one millimeter are sufficient and highly effective but may be more susceptible to damage from wind or other environmental factors. For better durability, transparent plastic with a thickness of 1.5-2 mm is typically recommended for successful soil solarization.

Plastic sheets can be reused multiple times if they are kept intact, free from holes, and thoroughly cleaned of dust and debris. Proper maintenance is essential for ensuring optimal performance and extending the lifespan of the plastic covers during the soil solarization process.

6.8.2 Steps to Perform Soil Solarization

- **Soil Preparation**

Before beginning soil solarization, ensure the soil surface is smooth and free of debris, clods, previous crop residues, or any growing weeds. Remove large weeds, rocks, and other debris to prevent tears in the plastic cover. Properly plowing and smoothing the soil helps avoid damage to the plastic during application.

- **Soil Irrigation**

Moist soil conducts heat more efficiently than dry soil, so irrigating the soil thoroughly before applying plastic is crucial. Moisture increases heat penetration and enhances sterilization by making weed seeds and soil-borne pathogens more vulnerable to high temperatures. Ensure the soil is moist to a depth of 60 cm, aiming for a field capacity of over 70 % beneath the plastic. In sandy soils, it may be necessary to re-irrigate under the plastic, though this can temporarily cool the soil. Eventually, the additional moisture will enhance heat accumulation under the plastic cover.

- **Covering the Soil with Transparent Plastic**

Use clear polyethylene plastic (25-60 microns thick) as it allows sunlight to pass through and trap heat efficiently. Thicker plastic lasts longer but may be more expensive. The plastic must be tightly secured over the soil surface, with the edges buried in soil to prevent air from escaping and heat from dissipating. Covering can be done manually by workers or mechanically with specialized equipment. Figure 6.6. illustrates full-field coverage, and Figure 6.7. depicts coverage of planting lines or terraces.

Figure 6.6. Soil Solarization, (Complete Coverage of the Field).

Figure 6.7. Soil Solarization, (Strip Coverage of the Field).

- **Duration of the Soil Solarization Process**

For effective soil solarization, keep the plastic in place for 4 to 6 weeks during the hottest part of the year, depending on climate and soil type. While 2 weeks may kill some pests, a minimum of 4 weeks ensures thorough sterilization. In regions with high summer temperatures, the process is most effective from mid-May to mid-August when soil temperatures can reach 45°C to 60°C (113°F to 140°F) at depths of 5-15 cm, which is sufficient to kill weed seeds and soilborne pathogens.

- **Removing the Plastic and Cultivating the Soil**

After solarization, remove the plastic or puncture it to plant seeds or seedlings. Ensure seeds are planted at a shallow depth (3-5 cm) to avoid disturbing untreated soil layers that may contain viable weed seeds. It is important to avoid deep tillage after solarization, as this may bring untreated weed seeds and pathogens from deeper soil layers to the surface.

- **Additional Considerations in Soil Solarization**

Soil solarization is suitable for various crops, including vegetables, fruit orchards, and greenhouse plantings. It is particularly effective at eradicating weed seeds and soil-borne pests. However, some smaller fruit trees may be susceptible to heat damage under transparent plastic, in which case black plastic can be used to absorb and retain heat more safely. This method has been successfully applied in crops such as pistachios in California to reduce wilt disease caused by Verticillium dahliae. It has also proven effective in managing soil-borne diseases in citrus orchards, grape vineyards, avocado groves, olive plantations, and stone fruit orchards.

It is important to consider the effects of soil solarization on young or small trees, as the high temperatures generated under transparent plastic can potentially damage them. To mitigate this risk, using thin black plastic instead of transparent plastic is recommended. Black plastic still effectively absorbs and retains heat, sterilizing the soil without reaching temperatures that might overheat or harm the trees. This approach helps reduce the chances of tree damage while maintaining the benefits of soil sterilization.

6.8.3 Effect of Soil Solarization on Weeds

Soil solarization is an environmentally friendly and effective method used in organic agriculture to control weeds by utilizing solar energy. By covering moist soil with transparent plastic during the hot months, solarization elevates soil temperatures to levels that are lethal to many weed species. Soil solarization, therefore, provides a non-chemical, environmentally friendly approach to long-term weed control that aligns well with organic agriculture principles. Table 6.1. summarizes some common weed species and their susceptibility to soil solarization.

The following are key effects of soil solarization on weeds:

» **Reduction in Weed Seed Viability:** The elevated temperatures during solarization kill weed seeds, especially those near the soil surface. Most weed seeds are vulnerable to temperatures between 45°C and 60°C, effectively reducing the weed population in the treated area.

» **Control of Annual Weeds:** Solarization is particularly effective against shallow-rooted annual weeds such as *Chenopodium album* (Lamb's Quarters) and *Amaranthus retroflexus* (Redroot Pigweed), which are easily killed by the heat treatment.

» **Reduced Growth of Perennial Weeds:** While less effective than against annual weeds, soil solarization can weaken perennial weeds like *Cyperus rotundus* (Purple Nutsedge) and *Cynodon dactylon* (Bermuda Grass), reducing their ability to propagate through underground tubers and rhizomes.

» **Weed Seedbank Depletion:** Soil solarization gradually depletes the weed seed bank by killing seeds in the upper layers of the soil. This reduces the availability of seeds for future germination, helping lower weed pressure in subsequent growing seasons.

» **Increased Weed Control Synergy:** Solarization enhances the effectiveness of biological weed control measures by increasing microbial activity in the soil. The heat-tolerant microorganisms help degrade weed seeds, further reducing the weed population over time.

» **Improved Soil Health:** In addition to controlling weeds, soil solarization helps eradicate soil-borne pathogens and pests, contributing to improved soil health and crop productivity.

Table 6.1. Weed Species and Their Susceptibility to Soil Solarization.

Weed Species		Response to Soil Solarization
Common Name	**Scientific Name**	
Lamb's Quarters	*Chenopodium album*	Highly Susceptible
Purslane	*Portulaca oleracea*	Highly Susceptible
Redroot Pigweed	*Amaranthus retroflexus*	Highly Susceptible
Common Cocklebur	*Xanthium strumarium*	Highly Susceptible
Crabgrass	*Digitaria sanguinalis*	Susceptible
Green Foxtail	*Setaria viridis*	Susceptible
Horseweed	*Conyza canadensis*	Susceptible
Barnyard Grass	*Echinochloa crus-galli*	Susceptible
Black Nightshade	*Solanum nigrum*	Susceptible
Annual Bluegrass	*Poa annua*	Susceptible
Johnson Grass	*Sorghum halepense*	Moderately Susceptible
Purple Nutsedge	*Cyperus rotundus*	Moderately Susceptible
Bermuda Grass	*Cynodon dactylon*	Moderately Susceptible
Yellow Nutsedge	*Cyperus esculentus*	Moderately Susceptible

In general, the mechanism of action of soil solarization for weed control can be attributed to several factors:

* Thermal Stress: High soil temperatures generated by solarization denature proteins and disrupt the cellular structures of weed seeds and seedlings. This leads to the death of seeds and the prevention of weed emergence, especially in the upper layers of the soil.

* Enhanced Microbial Activity: The heat from solarization stimulates the growth of heat-tolerant microorganisms. These microbes can compete with and degrade weed seeds, contributing to further weed suppression.

* Inhibition of Seed Germination: Solarization interferes with the dormancy and germination processes of weed seeds. The elevated temperatures disrupt germination signals, inhibiting the ability of seeds to sprout, thus reducing future weed growth.

6.8.4 Effect of Soil Solarization on Soil Pathogens

Soil solarization is a highly effective technique in organic agriculture for managing soil pathogens. By raising soil temperatures through the use of clear plastic covers, this method disrupts the life cycles of many harmful organisms, including pathogens, fungi, nematodes, and bacteria. The following outlines its key effects:

- **Direct Pathogen Elimination:** Soil solarization works by increasing soil temperatures to levels lethal for many soil-borne pathogens. These include fungi like Verticillium dahliae, *Fusarium* spp., and Phytophthora cinnamomi, as well as nematodes and other harmful microorganisms. Exposure to these temperatures, which can reach up to 60°C, effectively sterilizes the soil.

- **Weakening of Pathogens:** Even if soil solarization doesn't completely kill pathogens, it weakens them. Weakened pathogens become more susceptible to attack by heat-tolerant beneficial microorganisms, such as fungi and bacteria, which continue to thrive in the elevated temperatures. This combination helps control diseases while allowing beneficial organisms to outcompete harmful ones.

- **Chemical Changes in Soil Composition:** The heat generated by solarization induces chemical changes in the soil, further contributing to pathogen suppression. Changes in nutrient availability and microbial balance create an environment hostile to many soil-borne pathogens, preventing them from reestablishing themselves in the soil.

- **Control of Soil-Borne Diseases:** Numerous studies, such as those conducted by Katan (1980), Pullman *et al*. (1984), Stevens *et al*. (1990), Ristaino *et al*. (1991), and Fiume (1994), have shown that soil solarization can effectively control a broad range of soil-borne diseases. These studies demonstrate its efficacy in managing fungal diseases, such as Verticillium and *Fusarium* wilts, as well as bacterial diseases and nematodes that threaten crop productivity.

Overall, soil solarization offers a sustainable, non-chemical alternative to conventional soil treatments, contributing to organic farming by promoting healthier soils while controlling a wide array of pathogens. Table 6.2. provides a list of major fungal and bacterial diseases managed through solarization, and Table 6.3. outlines the soil-borne nematodes effectively controlled through this process. These examples emphasize the broad-spectrum impact of solarization on pathogens, making it an essential tool for sustainable agriculture.

Table 6.2. Key Diseases Caused by Soil-Borne Fungi and Bacteria Controlled by Soil Solarization.

Disease	Pathogen	Affected Crops
Didymella stem rot	*Didymella lycopersici*	Tomato
Fusarium wilt	*Fusarium oxysporum*	Tomatoes, cucurbits, Bananas, Strawberry
Clubroot	*Plasmodiophora brassicae*	Cruciferous
Pink root	*Phoma terrestris*	Onion
Phytophthora root rot	*Phytophthora cinnamomi*	Onion & Others
Corky root	*Pyrenochaeta lycopersici*	Tomato
Damping off	*Pythium ultimum*	Tomato
Leaf spot	*Paramyrothecium roridum*	Strawberry
Root and Stem Rot	*Rhizoctonia solani*	Beans, lettuce, tomatoes
White mold	*Sclerotinia minor*	Carrot, Tomatoe, Peanut and Lettuce
White rot	*Sclerotium cepivorum*	Onions, Garlic, Leeks
Southern blight	*Sclerotium rolfsii*	Beans, carrots, peppers
Black root rot	*Thielaviopsis basicola*	Different crops
Verticillium wilt	*Verticillium dahliae*	Tomatoes, peppers, strawberries
Crown gall	*Rhizobium radiobacter*	Different crops
Bacterial wilt and Canker of tomato	*Clavibacter michiganensis*	Tomato
Common scab of potato	*Streptomyces scabies*	Potato
Bacterial leaf spot	*Xanthomonas* spp.	Peppers, tomatoes, brassicas
Bacterial Wilt	*Ralstonia solanacearum*	Potatoes, tomatoes, eggplants

Table 6.3. Key Soil-Borne Nematode Species Controlled by Soil Solarization.

Nematode Species	
Common Name	**Scientific Name**
Ring nematode	*Criconemella xenoplax*
Stem and bulb nematode	*Ditylenchus dipsaci*
Potato cyst nematode	*Globodera rostochiensis oxysporum*
Spiral nematode	*Helicotylenchus digonicus*
Sugar beet cyst nematode	*Heterodera schachtii*
Northern root knot nematode	*Meliodogyne hapla*
Javanese root knot nematode	*Meliodogyne javanica*
Pin nematode	*Pratylenchus penetrans*
Lesion nematode	*Pratylenchus thornei*
Lesion nematode	*Pratylenchus vulnus*
Fig pin nematode	*Paratylenchus hamatus*
Citrus nematode	*Tylenchulus semipenetrans*
Dagger nematode	*Xiphinema* spp.

6.8.5 Effect of Soil Solarization on Beneficial Organisms

The effects of soil solarization on beneficial organisms are generally less harmful compared to its impact on plant pathogens and pests. Here's a detailed breakdown of its effects on key beneficial organisms in the soil ecosystem:

» **Resistance of Beneficial Organisms:** Many beneficial soil organisms display resilience to the elevated temperatures caused by solarization. Beneficial fungi, such as mycorrhizal fungi and certain parasitic fungi that target soil pathogens, can withstand the heat. Studies suggest that organisms like *Trichoderma* and *Aspergillus* species not only survive but may also proliferate during the solarization process due to reduced competition from pathogens.

» **Earthworms and Burrowing Behavior:** Earthworms, which contribute significantly to soil health through aeration and organic matter decomposition, generally survive solarization by burrowing deeper into the soil where temperatures remain lower. This deep burrowing allows them to avoid the lethal heat levels experienced closer to the surface, preserving their populations during and after the process.

» **Heat-Resistant Fungi:** Certain heat-tolerant fungi, including species from the *Trichoderma*, *Aspergillus*, and *Talaromyces* genera, thrive during solarization. These fungi have beneficial effects, including suppressing pathogens and enhancing soil health. They can survive the process and even expand in numbers as pathogen populations decline.

» **Beneficial Bacteria Recovery:** Populations of beneficial bacteria such as *Bacillus* spp. and *Pseudomonas* spp. may initially decline during soil solarization but usually rebound after the soil cools. These bacteria play critical roles in nutrient cycling and disease suppression. While *Rhizobium* spp., which facilitate nitrogen fixation in legumes, may be significantly impacted, reintroduction or natural recovery can help restore their populations.

» **Effect on Actinomycetes:** *Actinomycetes* spp., a group of beneficial bacteria known for their ability to produce antibiotics and suppress harmful pathogens, are generally unaffected by the heat from soil solarization. Their resilience allows them to continue playing a significant role in post-solarization soil health by inhibiting the growth of soil-borne fungi and bacteria. This natural disease suppression enhances crop disease resistance after solarization, contributing to overall soil health and productivity in organic farming systems.

Although soil solarization targets harmful soil pathogens and pests, many beneficial organisms either remain unharmed or recover quickly after the process. This helps restore the soil's microbial balance and maintain its overall health. As a result, soil solarization remains an environmentally friendly method of pest and pathogen control in organic agriculture while supporting a healthy soil ecosystem.

6.8.6 Effect of Soil Solarization on Soil Properties and Plant Growth

Soil solarization has numerous positive effects on both soil properties and plant growth, making it a valuable technique for organic farmers to enhance soil health and crop productivity. Below is a summary of the key impacts:

» **Improved Soil Properties:** Soil solarization enhances both the physical and chemical properties of soil by increasing the decomposition of organic matter. This process releases essential nutrients like nitrogen, potassium, calcium, and magnesium, all of which are critical for plant development. As these nutrients become more available, plants can access them more easily, leading to better soil fertility and overall plant health and vigour.

» **Enhanced Plant Growth:** Plants grown in solarized soil often exhibit faster and healthier growth due to multiple factors:

» **Pest and Disease Control:** By killing or reducing the populations of harmful soil-borne pests and pathogens, soil solarization creates a healthier environment for plants. With fewer diseases, plants can grow without the typical stresses caused by soil pathogens. Additionally, soil solarization may address previously undetected pests and diseases, further reducing threats to plant health.

» **Weed Suppression:** Soil solarization also effectively suppresses weed populations. Weeds compete with crops for critical resources like water, nutrients, and sunlight. By eliminating or significantly reducing weed pressure, soil solarization allows cultivated plants to grow without this competition.

» **Increased Nutrient Availability:** Solarization accelerates the breakdown of organic matter in the soil, making nutrients more available to plants. This increase in nutrient accessibility supports healthier plant growth and development, fostering stronger, more vigorous plants.

» **Beneficial Microorganisms:** Although solarization targets harmful pathogens, it may also promote the activity of heat-tolerant beneficial microorganisms. These organisms can help suppress harmful pathogens and contribute to improved soil structure, which further supports plant growth.

In conclusion, soil solarization leads to better soil health and enhanced plant growth through nutrient enrichment, pest and weed control, and the promotion of beneficial soil microorganisms. These combined benefits make it a highly effective strategy for improving soil fertility and crop productivity, particularly in organic farming systems.

6.9 Soil Sterilization Using Organic Pesticides

In organic agriculture, soil sterilization using organic pesticides combines effective weed control with adherence to organic farming principles, which prohibit synthetic chemicals. Methyl bromide, a widely used soil sterilant, was highly effective but had severe environmental consequences, particularly its contribution to ozone layer depletion. Following the 1987 Montreal Protocol, which mandated the global phase-out of methyl bromide, organic farmers have sought sustainable alternatives.

Traditional soil sterilization methods, such as solarization, steaming, and mechanical cultivation, are widely used, but some organic-certified substances also provide a way to manage weeds. These organic pesticides are derived from natural sources and are compliant with organic standards. Below is a summary of common organic pesticides used in soil sterilization for weed control:

- **Acetic Acid (Vinegar)**

Acetic acid, the primary component of vinegar, is widely used as a non-selective organic herbicide, especially in higher concentrations (typically 10-20 %). When applied to the foliage of weeds, it rapidly dries out and burns the plant tissues, causing dehydration and cell death. This makes acetic acid particularly effective for controlling young, shallow-rooted weeds. However, because it does not penetrate deeply into the soil, it is less effective against perennial or deep-rooted weeds, which may regrow after treatment.

Acetic acid is typically applied as a foliar spray, targeting the above-ground parts of the plant. The best results are observed when it's applied to small, actively growing weeds on warm, sunny days. Organic certification standards allow acetic acid derived from natural fermentation processes, making it an approved herbicide in organic farming. While it is useful for immediate, visible results, its lack of soil persistence means repeat applications are often necessary for complete weed control, especially for stubborn or well-established weeds.

- **Pelargonic Acid**

Pelargonic acid, a naturally occurring fatty acid, is used as a contact herbicide that effectively controls annual weeds by disrupting plant cell membranes. It is especially effective on small, newly emerged weeds when applied as a spray. One of its main advantages is its fast action, with visible results typically appearing within hours of application. This quick action makes it a popular choice for organic weed management. Pelargonic acid is approved for organic use in various regions due to its natural origin.

However, like acetic acid, it only affects the parts of the plant it meets (contact action), meaning that it doesn't kill the root system. As a result, regrowth may occur if the roots remain intact, which may necessitate repeat applications to maintain weed control.

Its use aligns well with organic farming principles, as it offers a non-synthetic solution for weed management, particularly for crops where chemical herbicides are prohibited. However, its efficacy is most pronounced in controlling young weeds, making timing an important factor in its application.

- **Clove Oil**

Clove oil, rich in eugenol, is a natural herbicide commonly used in organic farming for its ability to desiccate and damage weed cells. Eugenol disrupts the cellular structure of plants, leading to wilting and death of the treated area. Clove oil is typically used as a foliar spray and is most effective on young, small, shallow-rooted weeds, particularly broadleaf varieties.

To enhance its herbicidal action, clove oil is often combined with other organic herbicides, such as acetic acid, which increases its efficacy. This combination creates a stronger, more immediate impact on weed growth. However, while clove oil works well on emerging weeds, persistent or deep-rooted species may require repeated applications to fully control their regrowth.

Clove oil is generally recognized as safe and approved for organic use by most certification bodies, making it a suitable choice for organic weed management. However, since its effects are localized to the exposed parts of the plant, it may not be as effective on perennial weeds, which can regenerate from their root systems.

- **Corn Gluten Meal**

Corn gluten meal, a byproduct of corn milling, acts as a natural pre-emergent herbicide in organic agriculture. It inhibits seed germination by disrupting root formation in seedlings, making it particularly effective for controlling weeds before they emerge. Corn gluten meal is typically applied to the soil before weed seeds start to germinate, with early spring and fall being the most effective times for application. It is widely used in gardens, lawns, and crop areas to manage annual weeds such as crabgrass and dandelions.

As a pre-emergent herbicide, corn gluten meal does not affect established weeds or plants. Its effectiveness relies on precise timing, targeting the period before weed seeds begin to sprout. It is essential to water the area immediately after application to activate the herbicidal properties, followed by a dry period to inhibit weed growth. Corn gluten meal is recognized and approved for use in organic farming systems, making it a popular choice for natural weed management.

However, it's important to note that corn gluten meal is less effective against perennial weeds and can be costly if used in large quantities. Additionally, it may require repeated applications for continued weed suppression.

- **Hydrogen Peroxide (H_2O_2)**

Hydrogen peroxide is an effective soil disinfectant used in organic agriculture to control weed seeds, soil-borne pathogens, and pests. It works by releasing oxygen when applied in higher concentrations, which helps sterilize the soil surface. This makes hydrogen peroxide a valuable tool in organic farming, where synthetic chemicals are prohibited. It is typically diluted and applied to the soil as a drench or spray before planting, ensuring that the soil is treated without leaving harmful residues.

In organic systems, hydrogen peroxide is permitted for pest and disease control due to its environmentally friendly nature and rapid breakdown into water and oxygen. However, it has a limited residual effect, meaning that its effectiveness diminishes quickly. Because of this, repeated applications may be necessary to maintain weed and pathogen control. It is especially effective for surface-level sterilization but may require additional methods to target deeper-seated weed seeds or pathogens.

Overall, hydrogen peroxide is a versatile and approved tool in organic farming, offering benefits for pest and weed control without violating organic standards. However, it must be used carefully to ensure repeated applications are properly timed for maximum effect.

- **Essential Oils (Citrus, Pine, Cinnamon)**

Essential oils, such as citrus oil, pine oil, and cinnamon oil, are commonly used in organic herbicides due to their ability to degrade the protective waxy cuticle on weed leaves, which causes plant desiccation and eventual death. These oils are typically applied as foliar sprays targeting young weeds, as they are most effective when applied early in weed development. They often work best when combined with other organic agents, enhancing their herbicidal effect.

Essential oils are generally considered safe and are approved for use in organic agriculture. However, they are classified as contact herbicides, meaning they only affect the parts of the plant they come into contact with. This limits their ability to kill the entire weed, particularly the root systems, which can result in potential regrowth. Therefore, while essential oils are effective for short-term weed suppression, they may need to be reapplied to control persistent weed populations effectively. These oils offer a natural, environmentally friendly option for managing weeds in organic farming, promoting sustainability.

- **Dazitol**

Dazitol is an organic pesticide and soil treatment used as an alternative to the now-banned methyl bromide, known for its harmful environmental and health impacts, particularly its contribution to ozone depletion. Dazitol's active ingredients are cinnamon oil and mustard oil, both recognized for their natural bio-pesticidal properties. These oils work together to suppress soil-borne pests, nematodes, fungi, and some weed species by creating a hostile environment that disrupts pest feeding, breeding, and settlement.

Dazitol acts as a natural fumigant, penetrating the soil to target pests such as root-knot nematodes (*Meloidogyne* spp.) and other soil-borne pathogens. The strong chemical properties of mustard and cinnamon oils interfere with the biological processes of pests, reducing their populations. This makes Dazitol particularly effective in high-value crops like fruits, vegetables, and flowers, which are sensitive to soil-borne diseases.

Typically, Dazitol is applied as a pre-planting soil drench or mixed into the soil to sterilize the planting area, helping control nematodes such as *Tylenchus*, *Pratylenchus*, *Xiphinema*, and others. Because it is certified for use in organic agriculture, Dazitol adheres to organic farming standards, providing an environmentally sustainable solution for soil sterilization.

For instance, in Morocco, Dazitol is widely used in organic vineyards and strawberry fields to control soil-borne pests and weeds, Figure 6.8., offering an eco-friendly, biodegradable alternative to synthetic chemicals. It is particularly suited for crops that require stringent soil health management, replacing harmful chemical fumigants like methyl bromide while aligning with organic farming practices.

Generally, using organic pesticides for soil sterilization is a key strategy for controlling weeds in organic farming systems. These pesticides offer a sustainable, environmentally friendly alternative to synthetic chemical methods, helping preserve soil health and biodiversity. Each organic pesticide, such as acetic acid, pelargonic acid, clove oil, and products like Dazitol, has specific strengths in managing different weed species and pests. However, their effectiveness may vary depending on weed maturity, soil conditions, and the crops being grown.

Integrating organic pesticides with holistic practices like crop rotation, cover cropping, and mulching creates a more comprehensive weed management system. Crop rotation helps disrupt weed life cycles, cover crops smother weed growth, and mulching prevents weed seed germination, further enhancing soil fertility while reducing weed pressure naturally.

For optimal results, organic farmers should evaluate their specific weed control needs, soil types, and crop requirements before selecting a pesticide. This ensures that the chosen organic pesticide will align with both the farm's environmental conditions and organic standards, leading to better crop productivity and sustainability in the long run.

Figure 6.8. Organic Vineyards in the Atlas Mountains Region of Morocco, Free of Weeds Due to the Use of Dazitol for Soil Sterilization Before Planting.

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Organic Agriculture

Fertilization and Pest Control Strategies

Since its inception in 2007, the General Secretariat of Khalifa International Award for Date Palm and Agricultural Innovation, has been committed to translating the vision of the UAE's wise leadership, through a clear strategic plan, aimed at developing the date palm cultivation and production sector, strengthening the agricultural innovation system, and disseminating specialized scientific knowledge nationally, regionally, and internationally. Throughout its journey, the Award has been inspired by the spirit of giving and the humanitarian vision rooted in the legacy of the late Sheikh Zayed bin Sultan Al Nahyan, "May God bless his soul". As he set a pioneering model for sustainable development, and the advancement of both humanity and its surrounding environment.

This continued success and prestigious status achieved by the Award over the past sixteen years are a result of the unlimited support of the UAE's wise leadership, led by H.H. Sheikh Mohamed bin Zayed Al Nahyan, President of the United Arab Emirates, "May God protect him", and H.H. Sheikh Mansour bin Zayed Al Nahyan, UAE Vice President, Deputy Prime Minister, and Chairman of the Presidential Court, as well as the close follow-up of H.E. Sheikh Nahayan Mabarak Al Nahayan, Minister of Tolerance and Coexistence, Chairman of the Award's Board of Trustees, and the close supervision of H.H. Sheikh Theyab bin Mohamed bin Zayed Al Nahyan, Deputy Chairman of the Presidential Court for Development and Fallen Heroes' Affairs, Chairman of the Board of Trustees of the Erth Zayed Philanthropies foundation. This highlights the significant role of this sector as a strategic cornerstone in strengthening food security, supporting the national economy, and driving sustainable development.

Within the framework of this humanitarian and knowledge-based approach, the Award's General Secretariat continues its pioneering role in disseminating knowledge, and empowering stakeholders by publishing specialized scientific books, that contribute to the development of this vital sector. The "Organic Agriculture Fertilization and Pest Control Strategies" book serves an extension of such efforts, emphasizing the importance of promoting sustainable agricultural practices and improving the quality of agricultural production in line with Zayed's timeless vision to serve humanity and the environment.

Dr. Abdelouahhab Zaid, Prof.

Secretary General of Khalifa Intl. Award
for Date Palm and Agricultural Innovation