ORGANIC FARMING: FOOD FOR THOUGHT

The principles, history, soil and weed management, livestock, standards, and world trends

Edited by

Mohamed Abdel-Raheem

Muna Ibrahim Jassem

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Introduction

Organic agriculture is a farming method that prioritizes the preservation of soil and ecosystem vitality, biodiversity, and animal well-being by refraining from the use of artificial fertilizers, pesticides, genetically altered organisms (GMOs), and antibiotics, favoring instead natural processes and materials. Essential techniques involve the rotation of crops, composting, the incorporation of green manures and legumes to enhance soil health, and the promotion of natural pest management through biodiversity and biological resources. This comprehensive strategy strives for enduring production that is ecologically sustainable and supports wholesome nutrition and welfare for individuals and societies.

Organic farming is a sustainable agricultural method that employs ecologically friendly pest management techniques and organic fertilizers obtained primarily from animal and plant residues, as well as nitrogen-fixing cover crops. The adoption of modern organic farming practices was a result of the environmental damage caused by the use of chemical pesticides and synthetic fertilizers in traditional agriculture, and it offers numerous ecological advantages.

Compared to conventional agriculture, organic farming relies less on pesticides, mitigates soil erosion, reduces nitrate contamination of groundwater and surface water, and repurposes animal waste within the farming system. However, these benefits are accompanied by higher costs for consumers and generally lower crop yields. Studies have shown that organic crop yields on average fall about 25 percent short of conventionally grown crops, although this disparity can vary significantly depending on the crop type. The future of organic agriculture will entail maintaining its environmental advantages, enhancing crop yields, lowering costs, and addressing the challenges posed by climate change and a growing global population.

Mohamed Abdel-Raheem and Muhammad Naeem Iqbal

Chapter 1

Organic Farming

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Organic Farming

Abstract

Organic farming pertains to an agricultural approach that harnesses natural processes and resources in order to generate food with an emphasis on environmental sustainability and the promotion of healthy soil. This method refrains from employing synthetic fertilizers, pesticides, and genetically modified organisms (GMOs), opting instead for practices such as composting, crop rotation, and biological pest management. Organic agriculture is characterized as a cohesive agricultural system that aims for sustainability, the improvement of soil fertility, and biological diversity, typically refraining from the use of synthetic pesticides, antibiotics, artificial fertilizers, genetically modified organisms, and growth hormones, with only occasional exceptions.

Keywords: Organic farming, environmental sustainability, agriculture, healthy soil.

1.1. Introduction

Organic agriculture is an agricultural approach that employs natural processes and resources to yield food products, with a primary focus on environmental sustainability and promoting soil health. It steers clear of artificial fertilizers, pesticides, and genetically modified organisms (GMOs), opting instead for practices like composting, crop rotation, and biological pest management. It can be described as a holistic farming system that aims for both sustainability and the improvement of soil fertility and biodiversity, while generally prohibiting the use of synthetic pesticides, antibiotics, artificial fertilizers, GMOs, and growth hormones. Organic farming, also referred to as ecological or biological farming, emphasizes the utilization of natural inputs like compost manure, green manure, and bone meal, while prioritizing techniques such as crop rotation, companion planting, and mixed cropping. Encouragement is given to biological pest control methods, such as supporting natural insect predators (Das, 2024; Gamage *et al.*, 2023; Lampkin *et al.*, 2000; McCoy and Parlevliet, 2000; Rana and Chopra, 2013; Schmidt, 2019). Organic agriculture is characterized as a holistic farming approach aimed at achieving sustainability, improving soil fertility, and promoting biodiversity by avoiding the use of synthetic pesticides, antibiotics, fertilizers, genetically modified organisms, and growth hormones. This farming practice emerged in response to the rapid shifts in agricultural methods at the beginning of the 20th century. In 2019, certified organic agriculture covered 70 million hectares (170 million acres) worldwide, with a significant portion of this land located in Australia (Association and Association, 2016; Martin, 2006; Mary, 2014; Paull, 2019; Treadwell *et al.*, 2016).

Organic regulations are established to permit the utilization of substances that occur naturally while restricting or prohibiting synthetic substances. For example, naturally existing pesticides like garlic extract, baking soda, and pyrethrin (derived from Chrysanthemum flowers) are permissible, while synthetic fertilizers and pesticides such as glyphosate are not allowed. In specific cases, synthetic substances like copper sulfate, elemental sulfur, and certain veterinary drugs may be permitted. Prohibited substances in organic standards include genetically modified organisms, nanomaterials, human sewage sludge, plant growth regulators, hormones, and antibiotics in livestock farming (Izadighalati, 2024; McEvoy, 2018; Paull, 2011c). Organic agriculture has the potential to positively impact biodiversity and promote environmental conservation at a community level. Nonetheless, the lower yields typically associated with organic farming in comparison to intensive farming may result in a heightened demand for the conversion of non-agricultural land for agricultural purposes in order to maintain similar levels of productivity. Consequently, this conversion process may lead to the decline of biodiversity and adverse climate consequences (Bavec and Bavec, 2015).

1.2. History

For centuries, agriculture was carried out without the use of synthetic chemicals. The introduction of artificial fertilizers took place in the mid-19th century. These initial fertilizers were cost-effective, potent, and easily transportable in large quantities. Advancements in chemical pesticides emerged in the 1940s, earning that decade the title of the "pesticide era". Although these innovative agricultural methods provided short-term benefits, they resulted in adverse long-term consequences such as soil compaction, erosion, reduced soil fertility, and concerns about the presence of toxic substances in the food chain. During the late 1800s and early 1900s, researchers in soil biology began exploring solutions to mitigate these negative impacts while still achieving higher crop yields (Horne and Page, 2008; Stinner, 2007). In 1921, Albert Howard, known as a founder and leader of the organic movement, along with his wife Gabrielle Howard, who were accomplished botanists, established an Institute of Plant Industry in India with the aim of enhancing conventional farming practices. The Howards introduced improved tools and techniques for animal husbandry based on their scientific expertise, and blended these with elements of Indian traditional farming methods to create guidelines for crop rotation, erosion prevention, and the effective use of composts and manures. Inspired by their observations in traditional farming, Albert Howard initiated the promotion of organic agriculture upon his return to Britain in the early 1930s (Conford and Dimbleby, 2001; Gieryn, 1999; Heckman, 2006; Howard, 1935; Kirchmann and Bergström, 2008).

In 1924, Rudolf Steiner delivered a series of eight lectures regarding agriculture, in which he emphasized the impact of celestial bodies, non-material entities, and elemental forces. These lectures were prompted by a plea from farmers who observed a decline in soil fertility and overall plant and animal well-being due to the application of synthetic fertilizers. The lectures were officially published in November 1924, and the initial English rendition, entitled The Agriculture Course, was released in 1928 (Paull, 2011d; Paull, 2013a; Paull, 2013b). In July 1939, Ehrenfried Pfeiffer, renowned for his authoritative work on biodynamic agriculture, traveled to the United Kingdom at the invitation of Walter James, 4th Baron Northbourne, to speak at the Betteshanger Summer School and Conference on Biodynamic Farming held at Northbourne's farm in Kent. The primary objective of the gathering was to unite advocates of various organic farming methods under one movement. Howard, in attendance at the conference, had the opportunity to meet Pfeiffer. The following year saw the publication of Northbourne's seminal work, Look to the Land, in which he introduced the term "organic farming". The Betteshanger conference has been viewed as a crucial connection point between biodynamic agriculture and other organic farming practices (Paull, 2011a; Paull, 2011b). In 1940, Howard published his seminal work, An Agricultural Testament, wherein he embraced Northbourne's concept of "organic farming". His scholarly contributions gained widespread recognition, earning him the moniker "father of organic farming" for his adept application of scientific knowledge and principles to traditional and natural farming methods. In the United States, J. I. Rodale, a fervent supporter of Howard's theories and biodynamic principles, established both the Rodale Institute, a working organic farm dedicated to trials and experiments, and Rodale, Inc. in Emmaus, Pennsylvania during the 1940s to promote and educate the public on organic agricultural practices. These institutions played a pivotal role in advancing the cause of organic farming. Additionally, Lady Eve Balfour made significant contributions in the United Kingdom through the Haughley Experiment, along with numerous other individuals and organizations worldwide dedicated to the development and promotion of organic farming methods (Paull, 2006).

The term "eco-agriculture" was introduced by Charles Walters in 1970, the creator of Acres Magazine, to refer to an agricultural approach that avoids the use of synthetic pesticides and chemicals, essentially synonymous with organic farming. The shift towards environmental consciousness in modern society has transitioned the organic movement from a supply-driven system to a demand-driven one. The availability of premium prices and government subsidies

has enticed farmers to adopt organic practices. In many regions of the developing world, producers adhere to traditional farming techniques that mirror organic methods but lack certification and may not incorporate the latest scientific innovations in organic agriculture. Additionally, some farmers in developing nations have made the switch to modern organic practices due to economic considerations (Paull, 2015; Yadav *et al.*, 2022).

1.3. Terminology

The term "organic," popularized by Howard and Rodale, refers to the use of soil organic matter from plant compost and animal manures to improve soil humus content, drawing on the research of early soil scientists who introduced the concept of "humus farming." Over the years, these two approaches have gradually come together (Diver, 2004; Nayler, 2014). Biodynamic farmers, however, designate the concept of "organic" to connote that a farm should be regarded as a living entity, as articulated in the following quote:

An organic farm can be accurately defined as a farm that is modeled after the structure of a natural system, embodying the integrity, independence, and harmonious interdependence of an organism, rather than simply adhering to specific methods and substances while avoiding others.

1.4. Crop diversity

Organic farming promotes crop diversity through the implementation of polyculture, where multiple crops are grown together in the same space. This practice of planting a variety of vegetable crops not only leads to a wider range of beneficial insects and soil microorganisms but also contributes to the overall health of the farm. The inclusion of diverse crops in the agricultural system helps in creating a thriving environment and plays a role in protecting species from extinction. The discipline of Agroecology has shed light on the advantages of polyculture, a technique often utilized in organic farming. Agroecology, a scientific field that integrates ecological principles in the study, design, management, and evaluation of agricultural systems, focuses on creating productive and resource-conserving systems that are culturally, socially, and economically sustainable (Fargione and Tilman, 2002; Vikas and Ranjan, 2024). Integrating a variety of crops into organic farming methods can yield numerous advantages. One such benefit is the potential to enhance soil fertility through the promotion of beneficial soil microorganisms. Additionally, the incorporation of crop diversity may serve to lower the incidence of pests and diseases by fostering a more varied and robust agroecosystem. Moreover, the presence of diverse crops can contribute to the improvement of the nutritional content of food by offering a broader spectrum of essential nutrients (Organics, 2022; Paull, 2015).

1.5. Soil management

Organic agriculture heavily relies on the natural decomposition of organic materials, employing methods such as green manure and composting to replenish soil nutrients depleted by prior crops. This biological process, facilitated by microorganisms like mycorrhiza and earthworms, releases essential nutrients for plant growth throughout the growing season. Farmers utilize diverse approaches such as crop rotation, cover cropping, minimal tillage, and application of compost to enhance soil fertility. By minimizing fuel-intensive tillage, less soil organic matter is lost to the atmosphere, resulting in carbon sequestration that mitigates greenhouse gas emissions and addresses climate change. Decreasing tillage practices can also enhance soil structure and minimize the risk of soil erosion. Plants require a range of nutrients in varying quantities to thrive. Ensuring an adequate supply of nitrogen, with a focus on timing to coincide with the plants' peak requirement, presents a challenge for organic farmers. Crop rotation and the use of green manure, specifically legumes from the Fabaceae family that fix nitrogen from

the atmosphere through a symbiotic relationship with rhizobial bacteria, help to address nitrogen deficiencies. Intercropping, which is sometimes employed for pest and disease management, can also boost soil nutrient levels, although competition between legumes and crops may arise, necessitating wider spacing between rows. Incorporating crop residues into the soil can contribute varying amounts of nitrogen from different plant species, potentially aiding in nutrient synchronization (Watson *et al.*, 2002).

Organic farmers utilize animal manure as well as processed fertilizers like seed meal, rock phosphate, and green sand to nourish their crops with essential nutrients. Amendments to pH levels may also be necessary, with options including lime, sulfur, and permitted compounds such as iron sulfate, aluminum sulfate, magnesium sulfate, and soluble boron products in the United States for organic farming practices (Gillman, 2008).

Mixed farms that integrate livestock and crop production can function as ley farms, where the soil fertility is enriched by cultivating nitrogen-fixing forage grasses like white clover or alfalfa, and then transitioning to growing cash crops or cereals once the soil has been replenished. On the other hand, farms that do not have livestock, known as "stockless" farms, may face challenges in maintaining soil fertility and may have to rely heavily on external sources such as imported manure, grain legumes, and green manures, although the ability of grain legumes to fix nitrogen is limited due to the harvesting process. Horticultural farms specializing in the cultivation of fruits and vegetables under protective conditions may have an even greater dependence on external inputs. The transportation of manure over long distances is often not economically feasible due to its bulkiness. Additionally, the availability of manure for organic farms could be at risk if a large number of farms transition to organic practices (Watson *et al.*, 2002).

1.6 Weed management

Organic weed control emphasizes reducing weed populations rather than completely eradicating them, through methods such as enhancing crop competition and utilizing phytotoxic effects on weeds. Organic farmers employ a combination of cultural, biological, mechanical, physical, and chemical strategies to effectively manage weeds without relying on synthetic herbicides. In accordance with organic standards, crop rotation is mandatory to prevent the continuous growth of a single crop in the same area, with the inclusion of cover crops and crops with varying life cycles to inhibit weed growth. Ongoing research is focused on developing organic techniques that encourage the proliferation of natural microorganisms capable of suppressing the growth or germination of common weeds (Delate, 2003; Kakati, 2025; Kremer and Li, 2003).

Various cultural practices are utilized to increase the competitiveness of crops and decrease weed pressure. These practices include selecting crop varieties that are inherently competitive, planting crops at high densities with tight row spacing, and delaying planting until the soil is warm to promote rapid crop germination. The practices of mechanical and chemical weed control on organic farms can be classified into several categories:

- Tillage involves turning the soil between crops to mix in crop residues and soil amendments, eliminate existing weed growth, and create a suitable seedbed for planting. It also includes turning the soil after seeding to eradicate weeds, such as when cultivating row crops.
- Mowing and cutting focus on removing the top growth of weeds.
- Flame weeding and thermal weeding use heat to eliminate weeds.
- Mulching prevents weed emergence by using organic materials, plastic films, or landscape fabric.

Certain naturally derived chemicals are permitted for use as herbicides in organic farming.

These include specific formulations of acetic acid (concentrated vinegar), corn gluten meal, and essential oils. Additionally, a few selective bioherbicides based on fungal pathogens have been developed. However, organic herbicides and bioherbicides currently have a limited role in the organic weed control arsenal.

Weed control can also be achieved through grazing. For instance, geese have been successfully employed to weed various organic crops like cotton, strawberries, tobacco, and corn, reviving the practice of using cotton patches geese that were once common in the southern United States prior to the 1950s. Likewise, some rice farmers introduce ducks and fish to wet paddy fields to consume both weeds and insects (Fedigan, 2015; Geiger and Biellier, 1993; Schonbeck and Stein, 2017; Szykitka, 2009).

1.7 Controlling other organisms

Organisms other than weeds that pose challenges in agricultural settings include arthropods such as insects and mites, nematodes, fungi, and bacteria. Various practices are employed, including the utilization of predatory beneficial insects like minute pirate bugs, big-eyed bugs, ladybugs, lacewings, and praying mantis to control pest populations. Parasitoid wasps and predatory mites are also utilized for pest management, although their efficacy may be reduced in outdoor settings due to environmental factors such as wind. When it comes to organic farming, naturally derived insecticides such as *Bacillus thuringiensis*, pyrethrum, spinosad, neem, and rotenone are permitted for use. However, a small percentage of organic farmers regularly use these pesticides due to concerns about their safety and environmental impact (Akhtar *et al.*, 2018; Ali *et al.*, 2017; Angon *et al.*, 2023; Osadebe *et al.*, 2018). The primary requirement for organic pesticides is that they are sourced naturally, and certain naturally sourced ingredients have sparked controversy. Contentious natural pesticides encompass rotenone, copper, nicotine sulfate, and pyrethrums. Rotenone and pyrethrum are especially contentious as they function by targeting the nervous system, similar to many traditional insecticides. Rotenone poses a significant danger to aquatic life and can produce symptoms akin to Parkinson's disease in mammals (Marking and Bills, 1976; Panov *et al.*, 2005; Pottorff, 2010; Sherer *et al.*, 2003). While pyrethrum, or natural pyrethrins, demonstrate increased efficacy against insects when paired with piperonyl butoxide to slow down the breakdown of the pyrethrins, organic guidelines typically prohibit the use of the latter compound (Jones, 1998; Part *et al.*, 2001; Wynen, 2010).

Naturally derived fungicides approved for use on organic farms include *Bacillus subtilis*, *Bacillus pumilus*, and *Trichoderma harzianum*, which are particularly effective against root diseases. Compost tea, containing a blend of beneficial microbes, has the potential to combat plant pathogens, although variations in formulations and preparation techniques may lead to inconsistent results or the growth of harmful microbes. Certain naturally derived pesticides, such as nicotine sulfate, arsenic, and strychnine, are prohibited on organic farms (Brinton, 2004; Forbes and Ramkrishnan Balasubramanian PHD, 2019; Scheuerell and Mahaffee, 2004). Synthetic pesticides permitted for use on organic farms consist of insecticidal soaps and horticultural oils for insect control, as well as Bordeaux mixture, copper hydroxide, and sodium bicarbonate for fungal management. Copper sulfate and Bordeaux mixture, commonly used in organic farming, present environmental challenges compared to some synthetic fungicides banned in organic agriculture. Concerns over the accumulation of copper to toxic levels in soil from frequent applications of copper-based fungicides are addressed in organic standards. The European Union is prioritizing the exploration of alternative fungicides for organic production to mitigate environmental impacts (Caldwell *et al.*, 2005; Cooper *et al.*, 2007; Edwards-Jones and Howells, 2001; Niggli, 2007).

1.8 Livestock

The practice of raising livestock and poultry for meat, dairy, and eggs is a longstanding agricultural pursuit that complements crop cultivation. Organic farms strive to create a natural environment for animals while also providing them with organic feed. Certification ensures that livestock are raised in accordance with USDA organic standards from birth to slaughter. One stipulation of these standards is that all animal feed must be certified as organic (Banda and Tanganyika, 2021; Chander *et al.*, 2011; Rhodes *et al.*, 2015). Organic livestock may receive medical treatment when sick; however, growth promotion through drug use is prohibited. These animals must be given organic feed and have access to pasture. In the past, horses and cattle played a crucial role on farms by providing labor, fertility, and fuel through manure recycling. While modern small-scale operations may not always include livestock, domesticated animals are still considered beneficial for organic farming, promoting true sustainability and the self-renewing capacity of a farm (Alimentarius, 2004).

1.9 Genetic modification

One defining characteristic of organic farming is the deliberate avoidance of genetically modified plants and animals. During IFOAM's 12th Scientific Conference on October 19, 1998, the Mar del Plata Declaration was adopted, with more than 600 delegates from over 60 countries voting unanimously to prohibit the use of genetically modified organisms in organic food production and agriculture. Despite strong opposition to the incorporation of transgenic technologies in organic farming, agricultural researchers Luis Herrera-Estrella and Ariel Alvarez-Morales argue in favor of integrating such technologies as a key component of sustainable agriculture, especially in developing regions. Organic farmer Raoul Adamchak and geneticist Pamela Ronald assert that many biotechnology applications in agriculture align with organic principles and have significantly advanced the cause of sustainable farming (Herrera-Estrella and Alvarez-Morales, 2001; Ronald and Adamchak, 2018). While genetically modified organisms are prohibited in organic agriculture, there is apprehension regarding the cross-contamination of organic and heirloom seed reserves by genetically modified crop pollen. This poses a challenge in preventing these altered genomes from infiltrating the organic food chain. Varied regulations across nations restrict the accessibility of GMOs to specific countries, as detailed in the discourse on the governance of genetically modified organism deployment.

1.10 Tools

Organic farmers employ various traditional farming implements and may also utilize agricultural machinery in a manner comparable to traditional farming practices. In regions of the developing world, small-scale organic farms typically rely on hand tools and diesel-powered water pumps for their agricultural operations.

1.11 Standards

Standards govern the methods of production and sometimes the final results in organic agriculture. These standards could be either voluntary or mandated by law. By the 1970s, private organizations were already certifying organic producers. The 1980s saw governments developing guidelines for organic production. By the 1990s, a shift towards legally mandated standards began, exemplified by the EU-Eco-regulation of 1991 for the European Union and a program in the UK in 1993. Following the EU's lead, Japan implemented a program in 2001, and the U.S. established the National Organic Program in 2002. As of 2007, more than 60 countries have regulations in place for organic farming. In 2005, IFOAM introduced the Principles of Organic Agriculture, a global standard for certification requirements. Generally, accreditation is given to certification bodies rather than individual farms (Forbes and Ramkrishnan Balasubramanian PHD, 2019; Rembiałkowska, 2007). The manufacturing resources utilized in

the development of USDA Organic certified products must be authorized by an NOP-accredited certifier. The EU's regulations on organic production emphasize the distinction between "natural" and "artificial" substances in determining the "organic" label for food products (Seufert *et al.*, 2017).

1.12 Composting

Utilizing manure as a fertilizer comes with the inherent danger of potential contamination of food with animal gut bacteria, which may include harmful strains of *E. coli* that have led to lethal cases of food poisoning in individuals consuming organic produce. To address this concern, the USDA organic regulations mandate that manure undergo a process of high temperature thermophilic composting in order to eliminate any harmful pathogens. In situations where untreated animal manure is utilized, a waiting period of 120 days is required before the crop can be harvested if the final product has direct contact with the soil. Alternatively, for products that do not have direct contact with the soil, a waiting period of 90 days prior to harvest is necessary as per organic standards (Fedigan, 2015; Forbes and Ramkrishnan Balasubramanian PHD, 2019). In the United States, the Organic Food Production Act of 1990 (OFPA) outlines that farms cannot obtain organic certification if the compost being utilized includes synthetic elements. The OFPA specifically prohibits the use of commercially blended fertilizers in organic farming, thereby restricting the use of any fertilizers containing prohibited substances (Amaditz, 1997).

1.13 Economics

The field of organic farming economics explores the comprehensive impact of organic farming on society, taking into account social costs, opportunity costs, unintended outcomes, information disparities, and economies of scale. Factors such as labor, carbon and methane emissions, energy consumption, eutrophication, acidification, soil health, impact on biodiversity, and land use differ significantly among farms and crops, making it challenging to make broad comparisons between organic and conventional agriculture in terms of economic performance. In the European Union, organic farmers tend to receive higher subsidies through agri-environment and animal welfare programs compared to conventional farmers (Clark and Tilman, 2017; Ritchie, 2017; Sanders, 2013).

1.14 Geographic producer distribution

Organic product markets are most robust in North America and Europe, accounting for $6 billion and $8 billion respectively of the $20 billion global market as of 2001. In 2007, Australasia held 39% of the total organic farmland, which includes Australia's 11,800,000 hectares (29,000,000 acres), although 97% of this land consists of sprawling rangeland. Sales in the United States are 20 times greater than Australasia. Europe cultivates 23% of the global organic farmland, totaling 6,900,000 hectares (17,000,000 acres), followed by Latin America and the Caribbean with 20% (6,400,000 hectares or 16,000,000 acres). Meanwhile, Asia accounts for 9.5%, North America for 7.2%, and Africa for 3% of global organic farmland (Willer and Lernoud, 2017). Apart from Australia, the nations that possess the highest amount of organic farmland include Argentina (3.1 million hectares), China (2.3 million hectares), and the United States (1.6 million hectares). A considerable portion of Argentina's organic farmland is utilized for pasture, aligning with Australia's agricultural practices. Following the United States, Spain, Germany, Brazil (the leading global agricultural exporter), Uruguay, and England rank among the countries with significant organic land coverage (Paull and Hennig, 2016). In 2005, organic production accounted for 3.9% of the total utilized agricultural area in the European Union (EU25). Austria led with 11% of its land used for organic farming, followed by Italy at 8.4%, and the Czech Republic and Greece both at 7.2%. Malta, Poland, and Ireland had the lowest rates at 0.2%, 0.6%, and 0.8% respectively. By 2009, the percentage of organic land in the EU increased to

4.7%, with Liechtenstein, Austria, and Sweden having the highest shares at 26.9%, 18.5%, and 12.6% respectively.

In Austria, 16% of farmers were engaged in organic farming in 2010, leading to a rise in organic land to 20% by the same year. Poland managed 168,000 hectares (420,000 acres) of organic land in 2005 (Fedigan, 2015; Josling, 2015; Kowalska and LUBOINSKA, 2025; Willer, 2009). In 2012, organic production covered an area of 288,261 hectares (712,310 acres) with approximately 15,500 organic farmers, resulting in retail sales of organic products reaching EUR 80 million in 2011. By 2012, organic exports had become an integral component of the government's overall economic development strategy. Following the dissolution of the Soviet Union in 1991, Cuba faced a scarcity of agricultural inputs previously obtained from Eastern bloc nations, prompting many farms in the country to adopt organic farming practices out of necessity. This shift positioned organic agriculture as a predominant method in Cuba, distinguishing it from the predominantly alternative approach taken by other countries. Notably, Cuba's organic agricultural framework features initiatives to develop genetically modified crops, particularly corn varieties engineered to resist the palomilla moth (Auld, 1999; Palaniappan and Annadurai, 2018; Soleri *et al.*, 2005).

1.15 Growth

The global market value of certified organic products was estimated at US$20 billion in 2001, which increased to US$23 billion in 2002 and surpassed US$43 billion by 2015. Retail sales of organic products reached US$80 billion worldwide in 2014, with North America and Europe contributing over 90% of the total sales. Australia led in certified organic land in 2018, accounting for 54% of the world's total with more than 35,000,000 verified organic hectares (86,000,000 acres) recorded within the country (McNeil, 2016; Paull and Hennig, 2018; Willer *et al.*, 2024).

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Chapter 2

Organic Agriculture

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Organic Agriculture

Abstract

Organic agriculture is founded on the principles of promoting health, caring for all living beings and the environment, embracing ecological practices, and upholding fairness. The methods employed in organic farming prioritize sustainability, self-sufficiency, autonomy, independence, health, animal welfare, food security, and food safety. Many view organic farming as a key component in mitigating the effects of climate change. The standards and regulations governing organic agricultural practices are established on an international level and enforced by entities such as the European Union and individual nations, with their guidelines often derived from the International Federation of Organic Agriculture Movements (IFOAM). This organization, founded in 1972 as an international coalition of organic farming groups, includes regional branches like IFOAM Organics Europe and IFOAM Asia. Since 1990, the market for organic products has experienced significant growth, with global sales reaching $150 billion in 2022, with North America earning over $64 billion and Europe EUR 53 billion. This rising demand has led to a corresponding increase in the amount of farmland managed using organic methods, which saw a 26.6 percent growth from 2021 to 2022.

Keywords: Organic agriculture, environmental sustainability, agriculture, healthy soil.

2.1. Introduction

Organic agriculture is fundamentally rooted in principles that prioritize health, the well-being of all living organisms, ecological integrity, and fairness. The practices of organic farming emphasize sustainability, self-reliance, autonomy, and independence, while also centering on nutrition, animal welfare, and the security and safety of our food supply. Furthermore, organic agriculture is widely regarded as a key component in addressing the challenges posed by climate change (Arsenault, 2014; Coleman, 2018; Luttikholt, 2007). Organic agricultural practices are subject to international regulations and enforcement by transnational bodies such as the European Union and individual countries, largely guided by the standards established by the International Federation of Organic Agriculture Movements (IFOAM). This global umbrella organization for organic farming was founded in 1972 and includes regional branches like IFOAM Organics Europe and IFOAM Asia. The market for organic products has experienced significant growth since 1990, with worldwide sales reaching $150 billion in 2022, including over $64 billion in North America and EUR 53 billion in Europe. This surge in demand has led to a corresponding increase in organically managed farmland, which expanded by 26.6 percent from 2021 to 2022 (Paull, 2010; Tietenberg and Lewis, 2023; Willer *et al.*, 2024). In 2022, organic farming is being utilized in 188 nations with roughly 96 million hectares (240 million acres) of land being farmed organically by 4.5 million farmers. This equates to around 2 percent of the global farmland (Willer *et al.*, 2024). In 2013, the organic producer count experienced a significant growth, with an increase of nearly 270,000, which equates to more than 13%. By 2014, the global count of organic producers had reached 2.3 million. The majority of this growth was observed in countries such as the Philippines, Peru, China, and Thailand. Specifically, India had the highest number of organic producers in 2013 with 650,000, followed by Uganda with 190,552 in 2014, Mexico with 169,703 in 2013, and the Philippines with 165,974 in 2014 (Welsh, 1999). In the year 2016, the organic farming sector yielded more than 1 million metric tons of bananas, in addition to over 800 thousand metric tons of soybean and nearly 500 thousand metric tons of coffee (Seufert *et al.*, 2012).

2.2. Productivity

Numerous studies comparing agricultural yields have produced varied outcomes. The discrepancies

in results can often be attributed to differences in study methodologies, such as variations in the crops under investigation and the methods used to collect data. Despite potential shortcomings in organic yields, a separate meta-analysis featured in Sustainable Agriculture Research in 2015 suggested that specific on-farm organic practices could potentially help diminish this productivity gap. Notably, the timely management of weeds and the utilization of manure in conjunction with legume forages/cover crops were found to yield positive outcomes in enhancing organic corn and soybean productivity (Pimentel *et al.*, 2005). In 2011, a meta-analysis was released in the publication Agricultural Systems which examined 362 sets of data and concluded that organic yields typically reached 80% of conventional yields. The researchers noted variations in the yield gap depending on the type of crop, with soybeans and rice surpassing the 80% average while wheat and potatoes fell below. Geographically, Asia and Central Europe exhibited higher yields compared to the global average, while Northern Europe trailed behind (De Ponti *et al.*, 2012).

2.3. Long term studies

A study conducted in 2005 compared conventional, organic animal-based and organic legume-based farming methods on a test farm at the Rodale Institute over a period of 22 years. The study revealed that the yields of corn and soybeans were similar across all three farming systems. Additionally, it was found that less fossil energy was required to produce corn in the organic animal and organic legume systems compared to conventional farming. Synthetic fertilizers and pesticides were typically avoided in the organic systems. The study was ongoing as of 2013, with a thirty-year anniversary report published by Rodale in 2012 (Fließbach *et al.*, 2004; Moyer, 2013). In Switzerland, a comprehensive long-term study was conducted comparing organic and conventional agriculture practices over a period of 21 years. The study found that crop yields from organic systems were, on average, 80% of those obtained from conventional methods. Despite this difference in yield, organic farming required significantly less fertilizer input, ranging from 34 to 51% lower, which suggests a more efficient production system. Moreover, the organic systems also used 20 to 56% less energy to produce a unit of crop, and this difference was even more pronounced, ranging from 36 to 53%, when considering energy use per land area. Additionally, despite the lower pesticide input in organic farming, the quality of organic products was found to be comparable to conventional products through analytical testing. Moreover, in some cases, organic products were actually preferred in food preference trials and image creation methods (Crowder and Reganold, 2015).

2.4. Profitability

In the United States, research has demonstrated that organic farming can yield between 2.7 to 3.8 times more profits for farmers compared to conventional farming, taking into consideration existing price premiums. On a global scale, organic farming has been found to be 22-35% more economically advantageous for farmers than conventional methods, as indicated by a meta-analysis of studies conducted across five continents in 2015 (Emily Post and Schahczenski, 2012). The profitability of organic agriculture can be explained by various factors. Initially, organic farmers refrain from using synthetic fertilizers and pesticides, which can incur substantial expenses. Furthermore, organic products currently command higher prices compared to conventionally produced goods, allowing organic farmers to potentially generate more revenue from their harvest. The premium prices for organic food play a crucial role in the economic sustainability of organic farming. In 2013, there was a 100% premium price on organic vegetables and a 57% premium price on organic fruits. These figures are derived from wholesale prices of fruits and vegetables provided by the United States Department of Agriculture's Economic Research Service. Premium prices are not limited to organic versus non-organic crops, but can also vary based on the sales venue, whether it be farmers' markets, grocery stores, or wholesale to restaurants. Many producers find direct sales at farmers' markets to be the most lucrative option as they receive the entire markup, despite this approach being labor and time-intensive (Martin and Severson, 2008; McBride

and Greene, 2013). In recent years, there has been a decrease in the organic price premiums, which has resulted in decreased economic motivation for farmers to transition to or continue using organic production practices. Research conducted over a period of 22 years at the Rodale Institute revealed that, given the current yields and costs associated with organic farming in the US, a price premium of just 10% is necessary to match conventional farming. Another study determined that on a worldwide scale, price premiums as low as 5-7% were sufficient to reach parity with conventional methods. The absence of a price premium results in a varying level of profitability for farmers (Pimentel *et al.*, 1983).

2.5. Energy efficiency

Organic farming's energy efficiency in comparison to traditional agriculture is influenced by factors such as crop variety and the scale of the farm. It is commonly observed that organic farming systems require more labor input per unit of yield when compared to conventional production methods (Fess and Benedito, 2018; Hakimi *et al.*, 2025).

2.6 Sales and marketing

The majority of sales occur in industrialized countries. A survey conducted in 2008 revealed that 69% of Americans reported purchasing organic items on occasion, a decrease from 73% in 2005. One possible explanation for this shift is that consumers may be opting for locally sourced products over organic ones (Dimitri, 2010a; Dimitri and Oberholtzer, 2008b).

2.7 Distributors

The USDA mandates that distributors, manufacturers, and processors of organic goods must obtain certification from a recognized state or private agency. As of 2007, there were 3,225 accredited organic handlers, an increase from 2,790 in 2004. These organic handlers are primarily small businesses, with 48% reporting annual sales below $1 million and 22% between $1 and $5 million. Smaller handlers tend to sell to independent natural grocery stores and chains, while larger distributors typically target natural product chains and traditional supermarkets, with a minority catering to independent natural product stores. Some handlers collaborate with conventional farmers to assist them in transitioning their land to organic farming, providing both parties with a secure sales outlet and reducing risks. In 2004, 31% of handlers offered technical support on organic standards or production to their suppliers, and 34% encouraged their suppliers to make the switch to organic. Smaller farms often band together in cooperatives to enhance the marketing of their products (Dimitri and Oberholtzer, 2008a; Greene, 2012). 93% of organic sales in the United States are conducted through traditional and natural food retail outlets, with the remaining 7% of sales taking place at farmers' markets, foodservice establishments, and other alternative distribution channels (Low and Vogel, 2011).

2.8 Direct-to-consumer sales

In the 2012 Census, direct sales to consumers reached $1.3 billion, showing a 60% increase from $812 million in 2002. The number of farms engaging in direct sales to consumers was 144,530 in 2012, compared to 116,733 in 2002. Direct-to-consumer sales encompass various channels such as farmers' markets, community supported agriculture (CSA), on-farm stores, and roadside farm stands. Some organic farms also distribute their products directly to retailers, restaurants, and institutions. As per the 2008 Organic Production Survey, around 7% of organic farm sales were conducted directly to consumers, while 10% were sold directly to retailers, and a majority of approximately 83% was channeled through wholesale markets. In contrast, only 0.4% of conventionally produced agricultural commodities were sold directly to consumers (Dimitri, 2010b; Vogel, 2014).

2.9 Labour and employment

Organic farming necessitates a higher level of manual labor compared to conventional farming practices. The higher labor costs associated with organic production play a role in the increased price of organic food products. The labor-intensive nature of organic farming can be viewed positively as it offers additional employment opportunities. According to the 2011 UNEP Green Economy Report, investing in sustainable agriculture is forecasted to result in a significant growth in job opportunities, with a projected increase of 60% in employment compared to current levels. It is estimated that investments in green agriculture could potentially generate 47 million new jobs over the next four decades, when compared to business-as-usual projections. The expansion of female labor participation within the agricultural sector has primarily occurred in areas beyond the traditionally male-dominated domain of conventional agriculture. Organic farming, in particular, boasts a higher proportion of female workers, with 21% of workers being women compared to the general farming population where the percentage is 14% (Fedigan, 2015; Halweil, 2006).

2.10 World's food security

In 2007, the Food and Agriculture Organization (FAO) of the United Nations emphasized that organic agriculture has the potential to generate higher prices and improve the income of farmers, suggesting that it should be advocated for. However, FAO highlighted the limitations of organic farming in terms of its capacity to sustain the current and future human population. Both empirical evidence and various models indicated that organic farming alone was insufficient to meet global food demands, necessitating the use of chemical fertilizers to prevent food shortages. Proponents of organic farming have contended that it may be particularly well-suited for regions experiencing food insecurity, and therefore could play a crucial role in enhancing food security in areas such as sub-Saharan Africa (Badgley and Perfecto, 2007; Union, 2001). FAO emphasized the importance of using fertilizers and other chemical inputs to enhance agricultural production, especially in Africa where the usage of fertilizers lags behind that of Asia by 90%. For instance, in Malawi, the use of seeds and fertilizers has led to increased yields. NEPAD, an African governmental development organization, has also highlighted the significance of fertilizers and improved seeds in addressing food security and malnutrition in Africa. A study conducted by McGill University in 2012 revealed that organic best management practices have been able to achieve yields that are only 13% lower on average compared to conventional methods. In impoverished nations where the majority of the world's hungry population resides, and where the costly inputs of conventional agriculture are not feasible for most farmers, the adoption of organic management has shown an average yield increase of 93%, making it a crucial aspect of enhancing food security (Badgley and Perfecto, 2007; De Schutter, 2010; Lockie *et al.*, 2006; Union, 2001).

2.11 Capacity building in developing countries

Organic farming has the potential to enhance ecological sustainability, particularly in developing nations. By adhering to organic practices, resources such as local seed varieties and manure can be utilized, leading to cost-effectiveness. The growing local and global demand for organic products presents promising opportunities for proactive producers and exporters to enhance their livelihoods. Organic agriculture requires a significant amount of knowledge and expertise. While there are ongoing efforts to build capacity on a global scale, the impact has been somewhat limited. The International Federation of Organic Agriculture Movements has made available over 170 manuals and 75 online training programs as of 2007. In 2008, the United Nations Environmental Programme (UNEP) and the United Nations Conference on Trade and Development (UNCTAD) asserted that organic farming could play a critical role in ensuring food security in Africa, surpassing the benefits of conventional production systems. They also noted that yields saw a significant increase when organic or near-organic methods were utilized, leading to improvements in soil fertility and drought resistance (Bank, 2008; Setboonsarng, 2015).

2.12 Millennium development goals

The significance of organic agriculture (OA) in supporting the Millennium Development Goals (MDG) is evident in its impact on poverty reduction efforts amid climate change challenges, as it contributes to both economic and non-economic aspects of the MDGs. These advantages are anticipated to persist beyond the MDG era. A compilation of case studies carried out in various regions in Asian countries by the Asian Development Bank Institute (ADBI), and subsequently published as a book by ADB in Manila, highlights the role of OA in enhancing both the economic and non-economic dimensions of the MDGs. Key outcomes include poverty mitigation through increased incomes, enhanced health conditions of farmers due to reduced exposure to chemicals, embedding sustainable practices in rural development strategies, improved access to clean water and sanitation, and the promotion of global development partnerships by integrating small-scale farmers into value chains. A corresponding study by the ADBI delves into the expenses associated with OA initiatives and positions them in the context of achieving the MDGs. Findings reveal significant disparities among the various case studies, indicating no uniform cost structure for implementing OA practices. The costs are contingent upon the effectiveness of OA adoption programs, with the most economical programs being more than ten times cheaper than the priciest ones. Nevertheless, a closer examination of the benefits resulting from OA adoption demonstrates that the expenses incurred per individual lifted out of poverty are considerably lower than the estimates put forth by the World Bank, which are primarily based on general income growth or the specific costs linked to achieving certain quantifiable MDGs such as education, health, and environmental targets (Markandya *et al.*, 2015; Marshall, 1991; Stolze *et al.*, 2000).

2.13 Externalities

Agriculture has detrimental effects on society through the utilization of public lands and resources, loss of biodiversity, soil erosion, pesticide use, nutrient contamination, and various additional challenges. On the other hand, there are also positive outcomes such as fostering self-sufficiency, encouraging entrepreneurship, promoting environmental stewardship, and improving air quality. When comparing organic farming practices to conventional methods, differences in externalities are evident and the impact varies depending on the specific implementation and type of crops involved. Although organic farming generally requires more land, it typically consumes less energy during production. Evaluating and contrasting externalities is complex due to factors such as the measurement scale used, whether it is based on area or production, and whether the analysis is conducted on individual plots or entire farms. The assessment of biodiversity is inconsistent across various studies, farms, and categories of organisms. Studies have shown that organic farming has a positive influence on bird populations, predatory insects, soil organisms, and plants, while non-predatory insects and pests do not benefit as much. Research conducted in 2005 revealed that the advantages of organic farming in terms of abundance were significant at smaller scales like plots and fields, but not necessarily at the level of entire farms within similar landscapes (Bengtsson *et al.*, 2005; Cranfield *et al.*, 2010; Hansen *et al.*, 2001; Marshall, 1991; Stolze *et al.*, 2000).

Several research studies have aimed to compare the traditional and organic farming systems, and the findings suggest that organic techniques have a lesser impact on biodiversity compared to conventional methods. Additionally, organic farming is found to be more energy-efficient and less wasteful per unit area, though this is not the case when measured per unit of output. Farm comparisons have revealed that organic fields have significantly lower rates of nitrate leaching per hectare compared to conventional fields, with a reduction of up to 57%. However, when measured per unit of output, the leaching rates were comparable or slightly higher in organic systems. On a per-hectare scale, organic farming systems have been shown to emit 40 – 60% less CO_2 than conventional systems, but the emissions tend to be higher when measured per unit of output. It has been suggested that organic farming could potentially lessen some of the negative externalities associated with conventional agriculture. The extent to which these benefits are realized, whether

privately or publicly, depends on the allocation of property rights (Ritchie, 2017; Williams, 2006).

2.14 Issues

The comparison of the environmental impact between organic and conventional agriculture is crucial. A value of 1.0 signifies that both systems have equivalent impacts, while values exceeding 1.0 indicate that organic systems have higher impacts. In general, organic farming tends to score worse on most metrics compared to conventional farming, although the assessment does not include impacts on biodiversity. A meta-analysis from 2017 revealed that biological agriculture requires more land per yield unit, has a higher potential for eutrophication and acidification, and generally exhibits lower energy requirements compared to conventional agriculture. Despite these differences, both systems show similarly high levels of greenhouse gas emissions. A study conducted between 2003 and 2005 by Cranfield University on behalf of the Department for Environment, Food and Rural Affairs in the UK found it challenging to compare global warming potential, acidification, and eutrophication emissions between organic and conventional farming. The research highlighted that organic production often leads to increased burdens, such as nitrogen leaching and N_2O emissions, despite lower primary energy use for most organic products. Notably, N_2O emerges as a significant contributor to global warming potential, particularly in tomatoes, where organic farming incurs more burdens apart from pesticide use. While some emissions may be lower per area, organic farming consistently requires 65% to 200% more field area compared to non-organic farming, with the highest variations observed in bread wheat and potatoes (Tuomisto *et al.*, 2012; Williams, 2006).

2.15 Environmental impact and emissions

Researchers from Oxford University conducted an analysis of 71 peer-reviewed studies and found that organic products can have a negative impact on the environment. While organic milk, cereals, and pork were found to produce higher greenhouse gas emissions compared to conventional products, organic beef and olives showed lower emissions in most cases. Overall, organic products generally required less energy but more land. On a per unit basis, organic produce was found to have higher nitrogen leaching, nitrous oxide emissions, ammonia emissions, eutrophication, and acidification potential than conventionally grown produce. The researchers emphasized the importance of considering various approaches to both conventional and organic farming practices, rather than pitting the two methods against each other. They also highlighted the need for tailored solutions to specific environmental circumstances. A review article published in the Annual Review of Resource Economics in 2018 revealed that organic agriculture is more damaging to the environment per unit of output. Additionally, the widespread expansion of organic agriculture could lead to further loss of natural habitats. Despite this, advocates of organic farming argue that it promotes closed nutrient cycles, biodiversity, effective soil management, and the potential to mitigate and even reverse the impacts of climate change. They also claim that organic agriculture has the ability to reduce fossil fuel emissions (Bruinsma *et al.*, 2015; Lorenz and Lal, 2023; Meemken and Qaim, 2018; Quarles, 2018; Weick, 2016).

The carbon sequestration efficiency of organic systems in temperate climates is nearly twice as high as that of conventional soil treatments, primarily due to the utilization of grass clovers for animal fodder and cover crops within organic crop rotations. However, research indicates that organic systems require a larger area of land to achieve the same level of yield as conventional farms. Transitioning to organic agriculture in developed nations, where the majority of arable land is already being utilized, could result in increased deforestation and a reduction in overall carbon sequestration. A recent study assessed the net greenhouse gas emissions that would arise from a theoretical complete conversion of agricultural practices in England and Wales to 100% organic production. The analysis revealed that such a shift would result in a 40% decrease in food production compared to conventional farming methods. While domestic greenhouse gas emissions would decline by 6%, the decrease in yields would necessitate an increase in food imports, leading

to changes in land usage elsewhere. Under a moderate scenario in which half of the additional land is converted from grassland and modest soil carbon sequestration is assumed, there would be a 21% rise in global greenhouse gas emissions compared to the conventional agricultural system (Hepperly *et al.*, 2006; Muller *et al.*, 2017; Smith *et al.*, 2019; Tilman *et al.*, 2001).

2.16 Nutrient leaching

Based on a comprehensive analysis of 71 studies conducted in 2012, it was found that organic products exhibited higher levels of nitrogen leaching, nitrous oxide emissions, ammonia emissions, eutrophication potential, and acidification potential. More specifically, while emissions per unit area of land were lower for organic products, they were higher per unit of food produced, largely due to the lower crop yield of organic farms. The accumulation of excess nutrients in bodies of water such as lakes, rivers, and groundwater can lead to the formation of algal blooms, eutrophication, and the subsequent creation of dead zones. Additionally, nitrates on their own have harmful effects on aquatic organisms (Undersander *et al.*, 2002).

2.17 Land use

A 2012 meta-analysis conducted at Oxford University, comprising of 71 studies, revealed that organic farming necessitates 84% more land to generate an equivalent quantity of harvest. This is primarily attributed to the lack of nutrients, however, other factors such as weed, disease, or pest infestations, lower yields from animals, and the need for land to grow fertility-building crops also contribute to this discrepancy. Although organic farming does not universally conserve land for wildlife habitats and forestry, recent advancements in organic practices have been effective in addressing these concerns. Organic animal production is not conducive to environmental sustainability. Nevertheless, specific organic animal husbandry practices have demonstrated the ability to rejuvenate degraded, marginal, or previously untapped land for agricultural purposes and wildlife conservation. Utilizing both forage and cash crops simultaneously on the same plots can reduce overall land utilization (Franco *et al.*, 2021; Thakur *et al.*, 2023).

2.18 Pesticides

Outside an organic apple orchard in Pateros, Washington, there is a sign reminding orchardists of the prohibition against spraying pesticides on the trees within the farm. In organic agricultural practices, the use of synthetic pesticides and certain naturally occurring compounds produced through chemical synthesis is strictly forbidden. The restrictions placed on organic labeling extend beyond the composition of the compound to include the method of production as well. A comprehensive but not exhaustive list of approved organic pesticides, along with their median lethal doses, includes boric acid, which is utilized as an insecticide with an LD50 of 2660 mg/kg. Copper (II) sulfate, known for its fungicidal properties, is also permitted in organic farming despite being commonly used in conventional agriculture, with an LD50 of 300 mg/kg. Alternatively, conventional agriculture can opt for the less toxic Mancozeb, with an LD50 ranging from 4,500 to 11,200 mg/kg. Lime sulfur, also known as calcium polysulfide, and sulfur are classified as acceptable synthetic materials with an LD50 of 820 mg/kg. Neem oil, employed as an insect repellant in India due to its azadirachtin content, is subject to restrictions in the UK and Europe. Pyrethrin, derived from chemicals extracted from pyrethrum flowers, serves as a highly toxic insect control agent with an LD50 of 370 mg/kg (Barański *et al.*, 2014; Mishra *et al.*, 1995).

2.19 Food quality and safety

The nutrient and anti-nutrient levels in organically produced food may vary compared to conventionally-produced food. However, due to the unpredictable nature of food production and handling, it is challenging to draw definite conclusions. Currently, there is insufficient evidence to assert that organic food is inherently safer or more nutritious than conventional food (Hepperly and

Setboonsarng, 2015; Kononets *et al.*, 2023; Magkos *et al.*, 2006; Smith-Spangler *et al.*, 2012).

2.20 Soil conservation

Supporters assert that soil managed organically exhibits superior quality and increased water retention, potentially leading to enhanced yields for organic farms during periods of drought. It is argued that organic farming has the capacity to enhance soil organic matter more effectively compared to traditional no-till farming methods, suggesting long-term yield advantages for organic farming practices. An extensive 18-year study on organic techniques applied to nutrient-depleted soil indicated that conventional methods may be more beneficial in terms of soil fertility and yield in cold-temperate climates, citing the reliance on imported materials in organic farming that may not be sustainable in the long run. In his book "Dirt: The Erosion of Civilizations," geomorphologist David Montgomery highlights a looming crisis stemming from soil erosion. Agriculture depends on approximately one meter of topsoil, which is depleting ten times faster than it is being replenished. Some advocate for no-till farming, often associated with pesticide use, as a means to reduce erosion. However, a study conducted by the USDA's Agricultural Research Service in 2007 found that manure applications in conventionally tilled organic farming are more effective in building up soil quality compared to no-till methods. The Gunsmoke Farms organic farming project in South Dakota, covering 137 square kilometers (53 square miles), experienced severe soil erosion following the implementation of tiling practices after transitioning to organic farming (Forbes and Ramkrishnan Balasubramanian PHD, 2019; Hepperly *et al.*, 2008; Kirchmann *et al.*, 2007; Paulson, 2008; Pilgeram and Amos, 2015; Roberts, 2009; Teasdale, 2007).

2.21 Biodiversity

Conserving natural resources and biodiversity is a fundamental principle of organic farming. There are three main management practices associated with organic production that are beneficial for wildlife on farmland. These practices include limiting the use of chemical pesticides and synthetic fertilizers, managing non-cropped areas in a way that is conducive to wildlife, and maintaining mixed farming practices. By implementing methods that attract beneficial insects, provide habitats for birds and mammals, and promote soil biotic diversity, organic farms can benefit from essential ecological services. Certified organic operations that adopt these practices can experience a reduced need for external fertility inputs, lower costs for pest management, access to cleaner sources of water, and improved pollination rates (Dufeu *et al.*, 2016; Hole *et al.*, 2005). In comparative studies on farm land practices, a notable majority of non-crop species demonstrate a clear preference for organic farming in terms of both abundance and diversity. Organic farms typically harbor an average of 30% more species than conventional farms, including birds, butterflies, soil microbes, beetles, earthworms, spiders, vegetation, and mammals. The absence of herbicides and pesticides in organic farming practices contributes to an increase in biodiversity, as it enhances the fitness and population density of various species. Certain weed species found in organic farms serve as attractants for beneficial insects, which in turn help improve soil quality and control weed pests. Soil-bound organisms also benefit from organic farming methods, as the higher presence of bacteria resulting from natural fertilizers like manure leads to decreased exposure to harmful chemicals. The enhanced biodiversity, particularly from beneficial soil microbes and mycorrhizae, is believed to play a role in the high yields often observed in organic farming plots. This is evidenced by a 21-year comparison of organic and conventional fields that has shown significant differences in terms of productivity and overall ecosystem health (Bengtsson *et al.*, 2005; Blakemore, 2000; Blakemore, 2018; Fließbach *et al.*, 2007; Gabriel *et al.*, 2006; van Elsen, 2000).

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Chapter 3

Relationship between Insects and Plants

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Relationship between Insects and Plants

Abstract

Plants and insects have undergone co-evolution for millions of years, leading to intricate and dynamic interactions that have influenced the biodiversity of our planet. These relationships between plants and insects can exhibit traits of mutualism, antagonism, and commensalism. The interactions between plants and insects play a crucial role in the functioning and services of agroecosystems, highlighting the importance of comprehending these complex relationships for sustainable agriculture and ecosystem management. The significance of these interactions extends to the dynamic interplay between agroecosystems and their ecological implications for the sustainability of agricultural production. In order to benefit agroecosystems, this review sought to investigate the chemical, molecular, and ecological interactions between agriculture and insects. The analysis involved a thorough examination of multiple studies on plant-insect interactions using relevant keywords and criteria, drawing information from databases including Scopus, Web of Science, Google Scholar, PubMed, PubChem, and Gene Ontology. The paper also discusses the evolution of various adaptations by insects to exploit plant resources, as well as the diverse chemical and molecular defense mechanisms employed by plants. Additionally, it delves into topics such as pest management, natural enemies, soil health, nutrient recycling, and pollination that are integral to these interactions. Enhanced plant-insect interactions can be achieved through the promotion of habitat restoration efforts to create or reinstate habitats for beneficial insects, including the planting of native flowering plants and providing nesting sites for bees. Furthermore, fostering conservation practices within agroecosystems can also contribute to improving interactions between plants and insects.

Keywords: Relationship, mutualism, antagonism, commensalism, insects, plants.

3.1. Introduction

In a dynamic environment where the availability and quality of host plants continuously change, phytophagous insects face selective pressure to seek out high-quality hosts in order to optimize their reproductive success. These insects have evolved a sophisticated sensory system that allows them to detect cues from potential hosts and a complex nervous system that enables them to process this sensory information with precision. The responses of insects to these cues are not fixed but are influenced by various factors such as the context in which they are perceived, the insect's physiological state, and its prior learning experiences. Despite their abilities, insects sometimes make errors in judgment and are attracted to unsuitable hosts. Conversely, host plants have evolved mechanisms to avoid detection by insects or defend themselves when attacked. Upon encountering insect-associated molecules, plants may either initiate defense responses or suppress defense mechanisms depending on the evolutionary dynamics between the plant and the insect. Plant volatiles emitted in response to insect feeding or oviposition can attract natural enemies while repelling herbivores, thereby enhancing plant defense mechanisms. On the other hand, plants benefit from attracting pollinators to increase their reproductive success. Interactions between insects and plants can be influenced by other organisms associated with the plant, such as plant pathogens, mycorrhizal fungi, and other insects. The plasticity of plant phenotypes allows them to adapt to biotic stress through epigenetic changes. The outcomes of interactions between insects and plants are influenced by spatial and temporal factors. In order to thrive in an environment with fluctuating availability and quality of host plants, herbivorous insects must efficiently locate suitable hosts for feeding and reproduction while avoiding plants that are unsuitable for their survival and reproduction. This requires insects to quickly identify and respond to cues from host plants. Particularly, specialized insect species must be able to distinguish specific plant species that can

support their nutrition and reproduction from those that cannot. Therefore, in a constantly changing environment where the availability and quality of host plants vary, herbivorous insects are under significant pressure to locate suitable hosts (Bruce *et al.*, 2005; Hogenhout and Bos, 2011; Mithofer and Boland, 2008; Smith and Clement, 2012). In order to enhance their effectiveness, it is necessary for them to locate suitable plants and avoid unsuitable hosts. As a result, they have created a finely tuned sensory system for detecting host signals and a neural system capable of integrating information from sensory nerves with a high level of spatial precision. Timing and location also influence plant responses to insects; for example, pre-stressed plants exhibit heightened defense reactions allowing them to respond more quickly and forcefully when under attack (Bruce and Pickett, 2011; Kim *et al.*, 2011; Martin *et al.*, 2011; Ton *et al.*, 2007).

The current presence of plant-eating insects and the vegetation they feed on is the result of a coevolutionary process that has been ongoing for 400 million years (Figure 3.1). However, insects' responses to host plant signals from their surrounding environment can be remarkably rapid, indicating their sophisticated ability to perceive and react to sensory stimuli. Particularly in specific cases involving interactions with plants, such as choices regarding where to land, decisions are made quickly and artificially in a timeframe of tens to hundreds of milliseconds (Baker, 2009; Cardé and Willis, 2008; Labandeira, 2013).

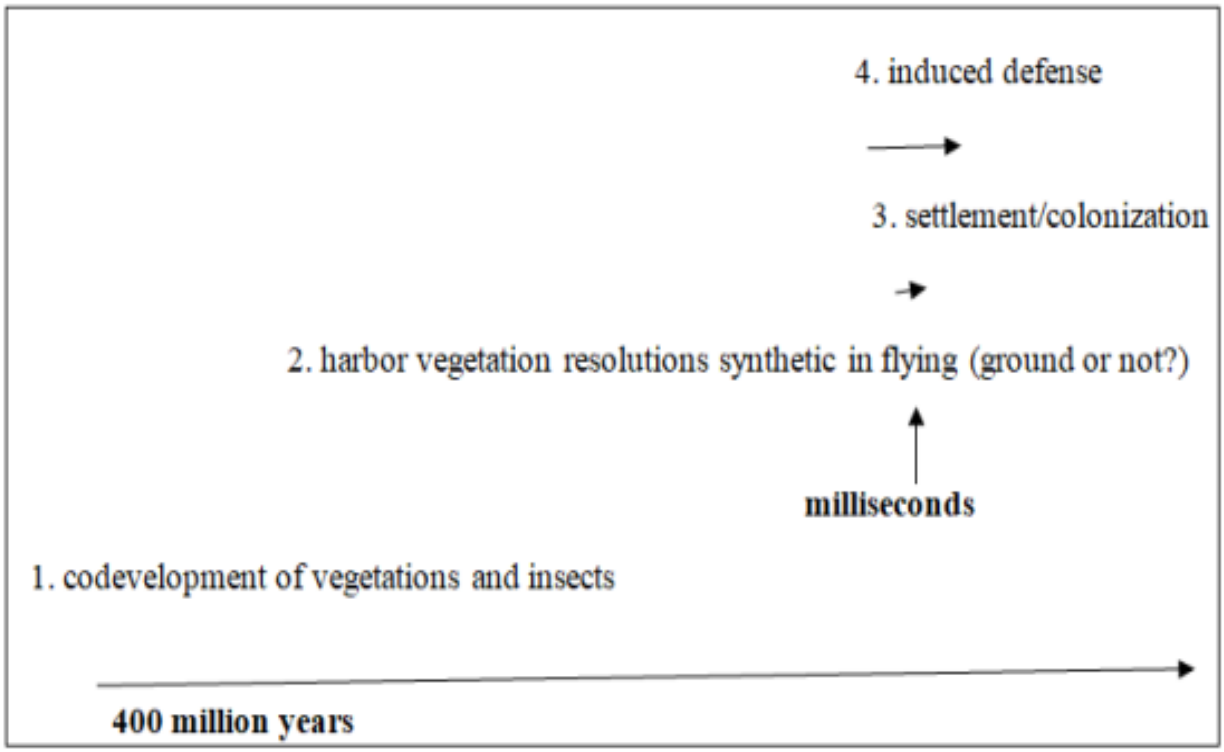

Fig. 3.1. The emergence of different schedules linked with interactions between insects and vegetation is a complex process. The evolution of these schedules has been a lengthy one, with the actual techniques involved progressing incrementally over a much shorter period of time (Hassan *et al.*, 2023).

In order to successfully create odor columns and attract insects to specific areas, it is essential to carefully construct harboring sacs of odor that last for only a brief moment. Insect responses are highly sensitive to the presence of harbor signals, which can lead to exposure to dispersals in the harbor that may trigger unique reactions within the insects. By being exposed to a variety of individual scents, insects can enhance their understanding of the environment in which they reside. This underscores the importance of considering single scent components in influencing triggered responses. The efficacy of these reactions can also be influenced by the educational background of the insects, for instance, if certain scents or groupings of scents are reinforced through a reward system (Hartlieb *et al.*, 1999; Riffell *et al.*, 2009; Webster *et al.*, 2010).

There is a significant focus on herbivorous insects due to their role in agricultural ecosystems and the indirect impact they have on food security for humans. The use of insecticides may impact agricultural practices and crop production (Iqbal and Ashraf, 2022). Additionally, there are interactions between insects and plants that involve vegetation responses. Insects play essential roles such as pollination and predation on herbivorous insects, while certain plant species attract insects for mutual benefit. These insect-plant interactions are crucial for maintaining biodiversity and promoting the coevolution of new species in terrestrial ecosystems (Bruce, 2010; Renner and Specht, 2013).

3.2. Host/non-host odor discrimination

The manner in which insects utilize natural volatile compounds found in plants to differentiate between different plant hosts (Figure 3.2), commonly involving combinations of naturally occurring volatile compounds in specific ratios, has been previously reviewed (Bruce and Pickett, 2011; Bruce *et al.*, 2005) and will not be further elaborated upon here. The distance between plants plays a crucial role in determining whether scents from both plants reach the insect's antenna simultaneously, thereby influencing the type of response elicited in the insect. Combinations of compounds play a significant role, as demonstrated by a study on plant odors of the black bean aphid, *Aphis fabae*, wherein individual odors on their own were found to be repellent, but when combined in a mixture became attractive (Webster *et al.*, 2010). Despite reaching a peak instance, it is important to note that the response to stimuli does not solely depend on the molecular composition of volatile substances emitted by plants, but also on the context in which they are perceived.

In 2005, it was hypothesized that insects employ a strategy of 'random encounter' wherein they use the precise location and timing of odors to distinguish between host scent blends and non-host odor mixtures. The combination of olfactory and visual cues further enhances their attraction to certain scents. Additionally, there is a significant aversion to non-host odors. Evidence supporting this theory can be found in the specific responses of olfactory receptor neurons (ORNs) to distinct non-host compounds, such as 3-butenyl isothiocyanate and 4-pentenyl isothiocyanate, in the black bean aphid. When tested in a critical olfactory assay, these isothiocyanates were found to be repellent. The ratio of different components in a scent blend can also play a crucial role. For example, increasing the concentration of certain compounds in an artificial host volatile blend while keeping others constant significantly reduced attractiveness to female vine berry moths in a wind-tunnel experiment (Bruce, 2010; Cha *et al.*, 2011; Han *et al.*, 2012; Hartlieb *et al.*, 1999; Nottingham *et al.*, 1991; Renner and Specht, 2013).

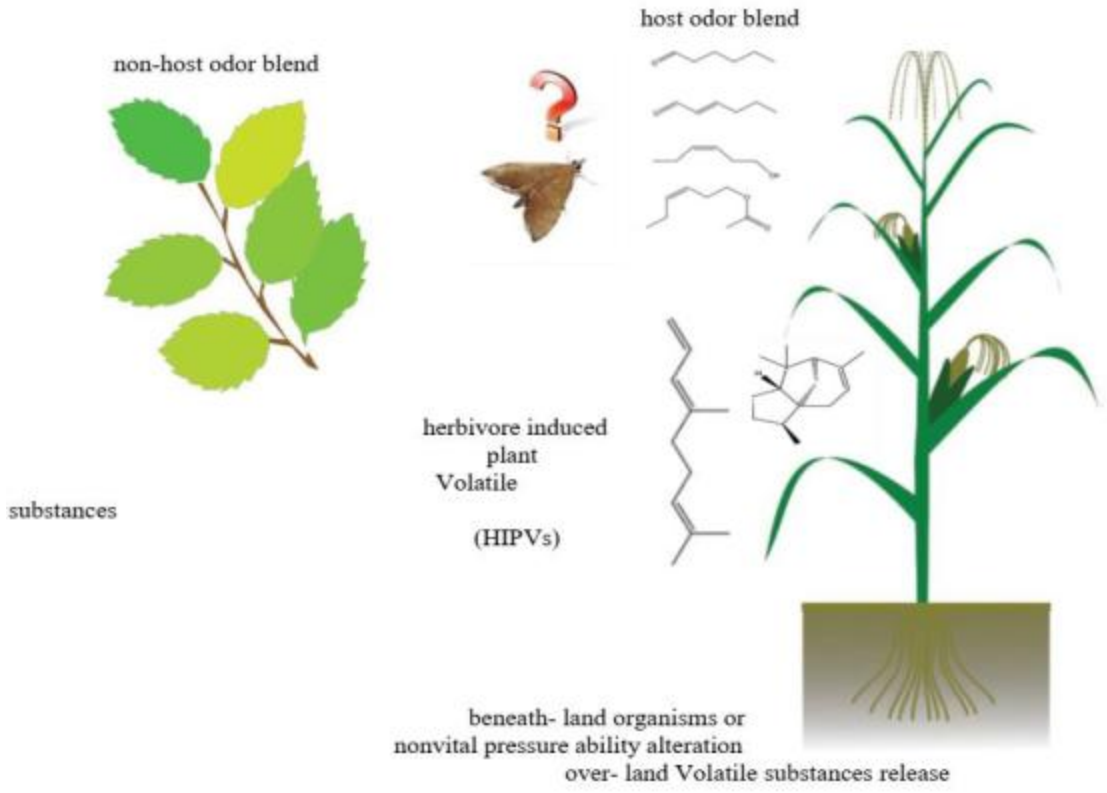

Fig. 3.2. The challenge of recognizing suitable habitats not only involves determining whether grass-eating insects prefer habitats with or without harbors, but also requires them to select harbors that offer optimal conditions. Harbors that are attractive to other insects may have defensive mechanisms in place and be less hospitable. Various environmental factors that impact both vegetation quality and insect behavior can also influence the release of volatile substances, providing additional information for foraging insects. This information is available in color on the JXB online platform (Hassan *et al.*, 2023).

3.3. How plant responses alteration over period

The coordination of vegetation protection is achieved through complex networks of organizers that adjust over time and space based on interactions with other signaling pathways. The efficacy of protection may depend on intrinsic or external factors. Timing is crucial when protection is induced or significant. Initial vegetation responses are more rapid and robust when they are repeatedly exposed to stressors (Bruce *et al.*, 2007; Conrath *et al.*, 2006; Kim *et al.*, 2012; Maffei *et al.*, 2007). Metabolites and power capacity can be more efficiently tailored to protective efficacy through an understanding of how the plant's metabolism adapts under threat. Plants have developed mechanisms to adjust their physical traits based on the level of danger they face, particularly in terms of gene expression related to defense. Enhanced resistance is seen as a continuum of external structure that is determined by the plant's ability to interpret signals from both plants and herbivores. Rapid responses such as the accumulation of Reactive Oxygen Species (ROS) and calcium signaling occur within moments of interaction between the insect and the plant. Herbivores (and Pathogenic factors) induce calcium influx through opening calcium channels, leading to a cascade of events including ROS production. These channels may be linked to plant receptors tuned to insect signals. A swift increase in ROS levels can result in immediate tissue damage, both vital and non-vital. Herbivore attack differs from mechanical damage; calcium influx and depolarization persist following herbivore attack or ingestion of herbivore secretions, distinguishing it from mechanical damage (Maffei *et al.*, 2004; Mithöfer and Boland, 2012).

Contemporary evidence suggests that depolarization plays a role in the systematic dominance of herbivore-induced resistance in plants. Prolonged changes in traits may also occur following pressure, and increased resilience may persist in subsequent generations due to epigenetic marking (Luna *et al.*, 2012; Mousavi *et al.*, 2013; Rasmann *et al.*, 2012). The critical role of plant defense chemicals in altering the ability of insects to metabolize during different stages is well acknowledged. Despite the evolution of various plant secondary metabolites as a means of defense, insects can overcome these defenses by developing mechanisms such as cytochrome P450 monooxygenases (P450s) to metabolize plant toxins. For example, the cotton bollworm (*Helicoverpa armigera*) uses a P450 enzyme, CYP6AE14, to detoxify gossypol, while the hawkmoth is able to feed on O-acyl sugars produced by *Nicotiana attenuata*. Furthermore, certain Brassica specialists have adapted to thrive on plants that produce glucosinolates. Insects with specialized adaptations can also utilize plant secondary metabolites to defend themselves against their own predators at the third trophic level (Boppré, 1978; Bruce, 2014; Mao *et al.*, 2007; Schuler and Berenbaum, 2013; Weinhold and Baldwin, 2011; Winde and Wittstock, 2011). The molecular basis of resistance to toxic cardenolides has been thoroughly elucidated and involves a specific amino acid modification in the sodium channel across the membrane, which is the target site of the toxin. Numerous insect species have also shown a similar amino acid modification, indicating a common mechanism of resistance. Insights into the process of resistance have been obtained from studies of the adaptation of tobacco (*Nicotiana tabacum*) via the peach-potato aphid, *Myzus persicae*. Aphid strains adapted to tobacco were found to possess a cytochrome P450 enzyme (CYP6CY3) that enables them to detoxify nicotine (Bass *et al.*, 2013; Dobler *et al.*, 2012).

3.4. Coevolution

The vast diversity of flowering plants on our planet, numbering nearly 275,000 species, is believed to have resulted from coevolution between plants and their important animal pollinators. Research suggests that this mutualistic relationship dates back 250 million years. Some plants have evolved to produce unique chemical compounds that attract specific pollinators through their sense of smell. For example, certain orchid flowers mimic aphid alarm pheromones to attract hoverflies for pollination (Grajales-Conesa *et al.*, 2011; Stökl *et al.*, 2011; Yuan *et al.*, 2013). Additionally, the ability of insect herbivores to consume grass has resulted in significant environmental and evolutionary changes in plant communities. Recent studies provide a framework for the rapid evolution of plant traits that confer resistance to herbivory by grass-eaters when present, and increased competitiveness in their absence. While insect herbivores have adapted to exploit plant defenses, plants have in turn developed mechanisms to defend themselves against herbivorous insects. Studies on the coevolution of plants and insect herbivores suggest that insects have been feeding on plants for millions of years. The concept of coevolution between insects and plants has been highlighted in the literature (Agrawal *et al.*, 2012; Anderson and Mitchell-Olds, 2011; Ehrlich and Raven, 1964; Hare, 2012; Johnson, 2011; Züst *et al.*, 2012). Therefore, the physical traits and behaviors we observe are the result of a longstanding history of interactions between organisms and adaptations that enhance efficiency. Plant-eating insects tend to become more specialized in utilizing certain types of vegetation over time, even though some important agricultural pests are able to feed on multiple host plants. Environmental specialization involves intricate and nuanced interactions among species and is not limited to just the plants and herbivores, but can also be influenced by interactions involving multiple feeders (Forister *et al.*, 2012; Gómez *et al.*, 2010). Their ability to facilitate bidirectional transmissions within both general and specialized populations has led to the proposition of a dynamic hypothesis suggesting that changes in habitat specialization are governed by shifts in duration, as exemplified by the leaf-mining fly genus Phytomyza. Differential selection based on environmental factors may result in the discrimination and segregation of adaptable habitats, thus influencing genetic diversity across the genome. The genome of the pea aphid (*Acyrthosiphon pisum*) has revealed several candidate genes involved in insect adaptation to specialized plant hosts, reflecting a diverse array of host strains. Variations among these strains have been identified in genes related to odor reception and salivary protein

encoding, but the specific timing and causative role of these genetic changes in driving species diversity remain unclear. Contrastingly, *Drosophila sechellia*, which specializes in feeding on *Morinda citrifolia* fruit, presents a compelling case study demonstrating heightened expression levels of sensory cells sensitive to specific fruit odors compared to *Drosophila melanogaster*, thereby enhancing its ability to distinguish between different fruit scents (Ibba *et al.*, 2010; Janz and Nylin, 2008; Jaquiéry *et al.*, 2012).

3.5. How plants identify insects

Living organisms face the challenge of identifying and responding to chemical stimuli in their environment. It is crucial for creatures to detect particles associated with potential threats in order to trigger necessary physiological and biochemical reactions for survival. Plants, unable to flee from danger, have evolved sophisticated mechanisms to detect potential threats, demonstrating their ability to respond to a wide range of stimuli. Discrimination of particles is a crucial process in the defense mechanisms of both plants and animals, and there is significant biomedical research focused on this subject (Akira *et al.*, 2006; Boller and Felix, 2009). It is becoming increasingly evident that particle discrimination through recruit-recipient interaction plays a crucial role in plant physiology, particularly in interactions between plants and insects. Understanding the roles of recipients and recruits is essential for comprehending plant defenses against herbivores. Plants possess sensors capable of detecting specific signals associated with herbivores, as well as general indicators of cellular damage, enabling them to enhance their defenses. Particle discrimination mechanisms facilitate this process by priming recipients to respond to signals related to herbivores or damage, thereby triggering defensive responses against insects. Additionally, miRNAs have been implicated in detecting interactions between insects and plants, with *Aphis gossypii* miRNAs showing distinct patterns in resistant and susceptible reactions within different melon varieties, some carrying the Vat resistance gene and others lacking it. Understanding the timing of plant metabolic responses to herbivore attacks is crucial to effectively tailor metabolites and energy resources for defense (Bonaventure, 2012; Chaudhary *et al.*, 2014; Erb *et al.*, 2012; Heil *et al.*, 2012; Kettles *et al.*, 2013; Monaghan and Zipfel, 2012; Pandey and Baldwin, 2007; Prince *et al.*, 2014; Sattar *et al.*, 2012).

Despite this, there is currently limited understanding regarding the molecular basis of insect perception through plants, the signaling mechanisms involved in this perception, and how plants distinguish between different species of harmful insects. There is more knowledge available regarding plant responses to pathogenic factors, and research is ongoing on insect-plant interactions. The field of chemical ecology has numerous examples of plants responding to volatile substances such as HIPVs and other chemicals that enhance their defenses (Arimura *et al.*, 2009; Baldwin *et al.*, 2006). Vegetation not only responds promptly to particles released by harmful organisms, but also has the ability to react to volatile substances emitted by neighboring plants that are under threat. Although the target recipients are identified, their specific receptors have yet to be determined. For example, studies have identified three genes in plants that confer resistance to insects, all of which belong to the NB-LRR gene family: the Mi 1 gene in tomatoes provides resistance to *Macrosiphum euphorbiae*, the Bph14 gene in rice confers resistance to *Nilaparvata lugens*, and the Vat gene in melons imparts resistance to *A. gossypii* (Arimura *et al.*, 2009; Boissot *et al.*, 2010; Du *et al.*, 2009; Rossi *et al.*, 1998). The concept of durability involves the perceived recipients being exposed to previously unidentified insect disruptors. These pests belong to the insect order Hemiptera, known for being secretive feeders on grass and utilizing a suction method for obtaining nutrition. It is hypothesized that HAMP may be a small particle or protein present in the insect's saliva.

There is a possibility that the detergent-like properties of fatty acids could inhibit the integrity of cell membranes and induce the release of calcium ions, thereby triggering cellular responses. However, studies have shown that radiolabeled volicitin binds rapidly, specifically, and saturably to cell membranes, suggesting the existence of a receptor. HAMPs have also been identified in the

secretion from insect egg deposition (Hilker and Meiners, 2006; Tamiru *et al.*, 2011; Truitt *et al.*, 2004). The chemical compositions of these substances have been identified as effective repellents for the pea weevil, *Bruchus pisorum*, and benzyl cyanide for *P. brassicae*. There are also systematic changes in gene expression related to defense mechanisms, such as the release of volatile compounds from neighboring leaves when insect eggs are placed on a single leaf. An in-depth study revealed that exposure of Arabidopsis to *P. brassicae* egg extract resulted in a rapid activation of genes involved in responding to pathogen-associated molecular patterns (PAMPs). The expression of the defense gene PR-1 required the genes EDS1, SID2, and, to some extent, NPR1, indicating the involvement of the salicylic acid pathway in response to egg perception. During an investigation to identify potential receivers of the egg extract stimulants, a receptor-like kinase mutant, lecRK-I.8, was identified, showing significantly reduced activation of PR-1 in response to egg-derived signals. This discovery of a putative plant receiver suggests that discrimination processes occur in plants that enable them to detect molecules associated with insects (Doss *et al.*, 2000; Fatouros *et al.*, 2008; Gouhier-Darimont *et al.*, 2013).

3.6 Plant protection

Plants have faced the challenge of defending themselves against insect attacks. Rooted in the ground, they are unable to flee from grazing insects. To combat this, plants have evolved a variety of sophisticated defense mechanisms to protect their tissues. These include the production of toxic or anti-nutritive compounds that act as a deterrent to herbivores, as well as physical defenses such as lignin (Ballaré, 2011; De Moraes *et al.*, 2001; Franceschi *et al.*, 2005; Harborne, 1993; Kessler and Baldwin, 2001). These mechanisms provide immediate protection to grass eaters through the presence of toxic, anti-nutritive, or repellent effects. Examples of protective compounds include protease inhibitors found in pigeonpea that effectively deter the cotton bollworm, threonine deaminase in tomatoes that breaks down threonine in insect intestines, 7-epizingiberene in the glandular trichomes of wild tomatoes, and O-acyl sugars in the glandular trichomes of tomatoes and other plants in the Solanaceae family. Some defensive compounds are inherent while others are induced in response to an attack. The salicylic acid (SA) pathway is often, though not always, associated with induced protection against pathogens, while the jasmonic acid (JA) pathway is linked to protection against grass eaters (Bleeker *et al.*, 2012; Dicke and van Loon, 2000; Gonzales-Vigil *et al.*, 2011; Parde *et al.*, 2012; Schilmiller *et al.*, 2012). Nevertheless, numerous studies have demonstrated a more intricate scenario, with the involvement of multiple pathways in different interactions between pathogens and herbivores depending on the specific species involved. Plant secondary metabolism also serves as an indirect defense mechanism by attracting natural enemies of herbivores. Studies using mutants have identified that herbivore-induced plant volatile (HIPV) emissions require the Jasmonate-signaling pathway in Arabidopsis when exposed to aphids and in tomato when exposed to hawkmoth larvae, although other mechanisms may vary. The homoterpenes 4,8-dimethylnona-1,3,7-triene (DMNT) and 4,8,12-trimethyltrideca-1,3,7,11-tetraene (TMTT) are some of the most common HIPVs produced by angiosperms, and the metabolic pathway and biosynthetic pathway supporting their production have been elucidated in Arabidopsis (De Moraes *et al.*, 1998; Degenhardt *et al.*, 2010; Diezel *et al.*, 2009; Girling *et al.*, 2008; Heil, 2008; Schilmiller *et al.*, 2012; Stout *et al.*, 2006; Tholl *et al.*, 2011; Turlings *et al.*, 1990).

Recently, it has been observed that Herbivore-Induced Plant Volatiles (HIPVs) contribute to enhancing plant efficiency. Evidence from agricultural research indicates that *Nicotiana attenuata* plants emitting HIPVs produced twice as many sprouts and blossoms compared to plants that did not emit HIPVs. The presence of predators (Geocoris spp.) led to a 50% reduction in herbivore populations attracted to plants emitting HIPVs. Variations in the speed of response to insects have been noted among different genetic varieties of plants, particularly in maize. Some varieties exhibit a strong response to insect cues, while others show minimal or no reaction, suggesting differences in their ability to detect insect stimuli. In addition to influencing their natural enemies, the emission of HIPVs can also affect herbivores themselves by deterring additional colonization (Bruce *et al.*, 2010; Degen *et al.*, 2012; Degen *et al.*, 2004; Schuman *et al.*, 2012). Previous research revealed

that female *Spodoptera frugiperda* moths exhibit a strong response to maize HIPVs (Signoretti *et al.*, 2012). Females show a preference for volatile compounds emitted by undamaged plants compared to those released by plants under attack by herbivores, although the timing of these events is significant, with the effects not evident immediately after maize damage (0-1 h) but becoming apparent 5-6 hours post-injury. The priority of undamaged plants in releasing environmental cues and developmental signals serves to prepare for potential competitors and natural enemies of their offspring.

Additionally, plants are susceptible to the release of HIPVs from their injured neighbors (Baldwin *et al.*, 2006), as their responses to these compounds and other stress-related volatiles appear to occur on a relatively small scale (Frost *et al.*, 2008). This may function as an adaptive strategy to prevent unnecessary reactions unless the concentration reaches a level indicative of a true threat. Plants not only respond to insect feeding damage but also demonstrate sensitivity to the presence of insect eggs, which represent the earliest stages of insect attack (Beyaert *et al.*, 2012). This early detection is crucial for plants to activate defense mechanisms before the detrimental feeding stages of the insect life cycle begin. Consequently, the release of HIPVs by infested plants in response to egg deposition attracts natural enemies (Forister *et al.*, 2012; Tamiru *et al.*, 2011) or triggers immediate defenses, thereby reducing insect development on plants exposed to eggs (Beyaert *et al.*, 2012; Bruce *et al.*, 2010; Frost *et al.*, 2008; Geiselhardt *et al.*, 2013; Signoretti *et al.*, 2012). In several instances, the presence of certain substances can lead to a suppression of volatile substance release in plants and a change in the composition of compounds, variables that may or may not be regulated internally. A thorough investigation has shown that exposure of Arabidopsis to cabbage white butterfly egg derivatives resulted in a rapid activation of specific genes related to pathogen-associated molecular patterns (PAMPs). The expression of the PR-1 defense gene required the presence of EDS1, SID2, and partially NPR1, indicating the involvement of the salicylic acid pathway following egg recognition. Furthermore, a mutant lacking a receptor-like kinase, lecRKI.8, exhibited reduced activation of PR-1 in response to egg derivative exposure. This identification of a potential plant receptor suggests that recognition mechanisms exist in plants that enable them to detect and respond to specific molecules released by insects (Bruce, 2012; Peñaflor *et al.*, 2011).

3.7 Conclusions

Environmental interactions between insects and plants are intricate and dynamic. What occurs in one setting at a particular time may not occur in another setting at a different time, and each insect-plant interaction has its own unique characteristics. Both the insect and the plant can undergo changes over time: the insect may change its behavior in the short term and undergo genetic transformations in the long term, while the plant may change due to induced defense mechanisms in the short term, epigenetic changes in the medium term, and genetic transformations in the long term. There are variations among different populations of both insects and plants. The genetic and temporary variability of living organisms allows for adaptation in a constantly changing environment that is also unpredictable. Responses are complicated because exposure to different companion organisms can influence the suitability of a plant for a particular insect. Agricultural ecosystems are often simplified due to limited diversity compared to natural systems. Additionally, many of the natural resilience traits found in wild plants may have inadvertently been lost in favor of high crop yields and pesticide use. In order to reduce dependence on pesticides, farmers are faced with the challenge of reintroducing the resilience mechanisms found in wild plants into crop varieties and enhancing biological pest control. Minimizing the damage to crops caused by pests, which is often addressed through pesticide use, could offer a tangible way to increase overall crop productivity per unit of land.

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Chapter 4

Organic Farming and Insects

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Organic Farming and Insects

Abstract

Organic agriculture promotes the optimization of natural biological processes for the management of farms, specifically in terms of soil fertilization and pest control, thereby reducing or eliminating the use of synthetic fertilizers, pesticides, and growth-promoting substances for plants and animals. These methods contribute to an increase in arthropod diversity, particularly among soil-dwelling insects. Common practices in organic farming, such as intercropping, cover crops, and hedges, create alternative habitats for arthropod communities, providing refugia that serve as a food source for pollinators through pollen grains and nectar. The interactions among various plant and animal species within the organic farming ecosystem, including weeds, birds, and mammals, significantly influence the abundance and diversity of insects. This chapter serves to outline the effects of organic farming practices on insect populations' abundance and diversity. Additionally, the discussion explores the role of organic farming in mitigating the adverse impacts of agricultural intensification, urban development, deforestation, and climate change on the global decline and loss of insect diversity.

Keywords: Impacts, Organic Farming, Insects Abundance, Diversity.

4.1. Introduction

In comparison to vertebrates, insects have not received as much emphasis in terms of the decline in diversity and conservation efforts. A recent publication by entomologists in Krefeld, Germany revealed a significant 76% reduction in insect biomass over a 27-year study period. Referred to as the "Krefeld study," this research has generated widespread attention and discussions within the global scientific community and the general public. Disturbing terms such as ecological Armageddon, insect Armageddon, insect defaunation, insect apocalypse, and insect decline in the Anthropocene were utilized to characterize this event (Hallmann *et al.*, 2017; Leandro and Jay-Robert, 2019).

The Krefeld study has been associated with the global decline of insects, much like how "silent spring" is associated with the harmful effects of pesticides. A study carried out by Lister and Garcia in Mexico, spanning 36 years in a rainforest, revealed a significant decrease of 98% and 78% in epigeal and canopy-dwelling arthropods, respectively. Sanchez-Bayo and Wyckhuys conducted a meta-analysis of 73 reports on insect decline worldwide, concluding that there has been a substantial decline that could result in the extinction of 40% of the world's insect species (Lister and Garcia, 2018; Sánchez-Bayo and Wyckhuys, 2019).

The concerning signs of a worldwide decrease in insect populations have prompted numerous scholars to investigate the root causes and resulting effects of this decline on ecosystems. Primary factors contributing to the decline of insects include loss of natural habitats, expansion of intensive agricultural practices, urban expansion, introduction of non-native species, shifts in climate patterns, and contamination from chemical pesticides and fertilizers (Ceballos *et al.*, 2017; Sánchez-Bayo and Wyckhuys, 2019).

Agricultural intensification and habitat loss rank as the primary contributors to the global decline in insect populations. The reduction in habitats primarily stems from deforestation, urban sprawl, light pollution, and industrial activities, all of which have detrimental effects on terrestrial and aquatic arthropod ecosystems (Ceballos *et al.*, 2017; Gallé *et al.*, 2019; Lehmann *et al.*, 2020; Montañez and Amarillo-Suárez, 2014).

The widespread reduction in global insect populations is having a noticeable effect on the ecosystem's ability to function properly, particularly evident in the diminished services related to pollination, trophic interactions, and nutrient recycling. Strategies such as preserving insect habitats, reducing the use of synthetic pesticides, and promoting organic farming are crucial steps in halting the ongoing decline of insect populations and encouraging the restoration of biodiversity (Grabovska *et al.*, 2020; Hallmann *et al.*, 2014; Stein-Bachinger *et al.*, 2021; van Strien *et al.*, 2016).

4.2. The significance of insects in ecological systems

The global insect population is thought to comprise around one million species, leaving an estimated 4.5 to 7 million still undiscovered and unnamed. Insects play a crucial role in maintaining ecosystem balance through their participation in three key natural processes: pollination of fruit trees, breakdown of organic material into humus, and regulation of natural pests (Figure 4.1) (Fox, 2013; Kawahara *et al.*, 2021; Stein-Bachinger *et al.*, 2021; Stork, 2018). Insects play a crucial role in the food chain, especially for animals at higher trophic levels such as birds, reptiles, amphibians, and fish. They also contribute essential ecosystem services, such as pollinating over 75% of crops and wild plants, managing waste and nutrient cycling, and producing valuable products like honey, silk, venom, and shellac. Insects serve as a protein source for both domestic animals and humans through entomophagy. The annual ecosystem services provided by wild pollinators in the United States alone are estimated to be worth $57 billion (Figure 4.2) (Losey and Vaughan, 2006; Ollerton *et al.*, 2011).

The connection between the variety of pollinators and plants in a specific region is mutually dependent. A lack of diversity among pollinators could result in an imbalance in plant diversity as certain plants may only be selectively pollinated. Consequently, the presence of wild bees has a significant impact on the diversity of weeds and vice versa. It is important to note that Garibaldi et al. emphasized the critical role of conserving the diversity of bees for the overall biodiversity of an ecosystem. Additionally, hoverflies (Syrphidae) are another group of pollinators that are often unrecognized despite their importance (Garibaldi *et al.*, 2011; Klaus *et al.*, 2013).

They fulfill diverse ecological roles including pollinating various plant species, managing insect populations as biocontrol agents, and serving as bioindicators to assess the functionality of the ecosystem.

Insects are essential components of functioning ecosystems, playing a crucial role in providing intangible benefits such as recreational and aesthetic value through their presence (Janzen and Hallwachs, 2021; Kawahara *et al.*, 2021). Recognizing the crucial importance of insects in maintaining ecological balance is essential for promoting the implementation of measures aimed at slowing the decline of these creatures. Educating the public about the vital ecological functions insects serve as pollinators, prey, and recyclers of nutrients can be achieved through programs such as citizen science and various extension media (Kawahara *et al.*, 2021).

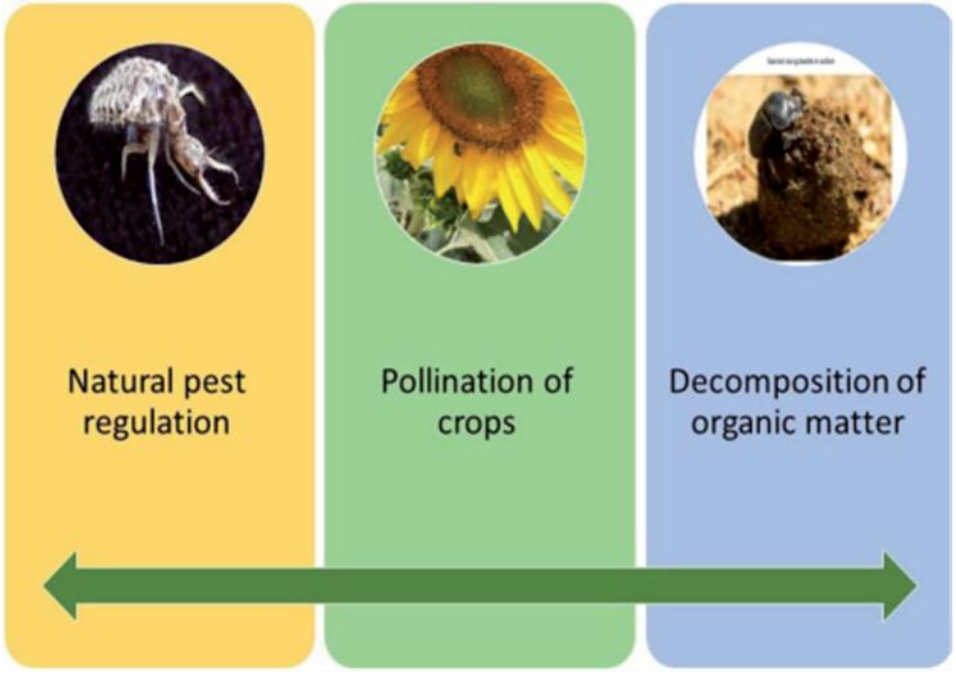

Fig. 4.1. The primary ecosystem services rendered by insects are crucial for upholding resilience, sustainability, and optimal operational efficiency (El-Shafie, 2022).

Fig. 4.2. Bees and butterflies play a crucial role in the ecosystem by serving as vital pollinators (El-Shafie, 2022).

4.3. Potential factors leading to a worldwide decline in insect populations and the consequent effects on ecosystems

The primary factors contributing to the worldwide decline in insect populations and loss of biodiversity include the destruction of insect habitats, intensification of agriculture, urban development, spread of invasive species, pollution from agricultural chemicals, and the effects of climate change (Benton *et al.*, 2002; Fox, 2013; Iqbal and Ashraf, 2022; Iqbal and Ashraf, 2023; Sánchez-Bayo and Wyckhuys, 2019).

Climate change is a significant concern in tropical regions, but its effects on species populations in temperate regions may be more limited. Factors such as agricultural intensification, urbanization, deforestation, and pesticide pollution are responsible for the majority (78.7%) of declines in species populations, with invasive species, climate change, and other pollutants accounting for a much smaller portion (21.3%). One of the key human activities contributing to biodiversity loss is the destruction of insect habitats (Figure 4.3) (Sánchez-Bayo and Wyckhuys, 2019).

The utilization of pesticides is recognized as a significant factor in the worldwide decrease of insects and loss of biodiversity. As a result, the decline of insects has an indirect impact on vertebrate predators. Herbicides, commonly utilized in traditional farming practices, eradicate weeds and wild plants that serve as a vital source of nutrition and habitat for arthropods, both pests and their natural predators. Fluctuations in insect biomass are crucial for the ecological balance of the ecosystem (Hallmann *et al.*, 2017; Schulz *et al.*, 2021).

Fig. 4.3. A feral colony of the dwarf honeybees, *Apis florea* on a newly cut branch of the button mangrove, *Conocarpus erectus* L. (type of habitat destruction) (El-Shafie, 2022).

During a 27-year study utilizing Malaise traps for continuous insect monitoring in Germany, it was observed that there was a seasonal decrease in flying insect biomass by 76% (Hallmann *et al.*, 2017).

Aquatic invertebrates such as crustaceans, mayflies, caddisflies, and dragonflies are significantly impacted by pyrethroid insecticides. Neonicotinoids, however, have negative effects on pollinators like honeybees and bumblebees, especially when applied as a post-bloom spray on perennial trees and field crops. The decline of insects globally can be attributed to various factors, with industrial pollution being one of the primary causes. The fertilizer industry alone may contribute up to 10% to this decline (Sánchez-Bayo and Wyckhuys, 2019).

The presence of excess artificial light, known as light pollution, can result in the attraction of moths towards light bulbs, making them vulnerable to predation by lizards, toads, birds, and other predators. This phenomenon detrimentally impacts insects, particularly those that rely on bioluminescence for mating signaling such as fireflies. Among various types of artificial lighting, mercury vapor, metal halide, and compact fluorescent bulbs have a greater adverse effect on moths sensitive to nighttime illumination compared to LED and sodium lamps (Boyes *et al.*, 2021).

Nevertheless, the impact of artificial light on insect populations and their decrease is yet to be fully understood. According to Sanchez-Bayo and Wyckhuys (Sánchez-Bayo and Wyckhuys, 2019), who analyzed the factors contributing to the global decline in insects, Lepidoptera, Hymenoptera, and Coleoptera in terrestrial environments, as well as Odonata, Plecoptera, Trichoptera, and Ephemeroptera in aquatic habitats, were found to be particularly impacted.

Insect biomass is often utilized as a surrogate to assess insect biodiversity, but it is important to recognize the limitations of this index. Instead, researchers suggest utilizing more reliable measures of biodiversity trends that take into account traits-based phylogeny in response to changes in spatial and temporal factors. Moreover, Didham et al. underscore the importance of incorporating data from extended research studies and diversity metrics when assessing the decline of insects (Didham *et al.*, 2020). To establish a consensus regarding the global decline of insects, it is essential to conduct more long-term studies that focus on biomass, abundance, and biodiversity (Habel *et al.*, 2019).

In regions with tropical and subtropical climates, where a vast array of insect species exists, there is a lack of comprehensive long-term data and species checklists, unlike in temperate regions. Consequently, many insect species in these regions may face extinction unnoticed, often before they are even identified or named. As a result of these factors, the precise impact of the global decline in insect populations on ecosystem functionality remains to be quantified (Wagner *et al.*, 2021).

Hence, extensive research and documentation through thorough examinations and meticulous organization are essential in tropical and subtropical regions.

4.4. Differences between conventional and organic farming systems

Natural biological processes, such as the functions of soil microorganisms, nutrient cycling, and biocontrol agents, are harnessed in the organic farming approach to control pest levels and prevent economic damage. Additionally, tillage and cultivation techniques are employed to regulate soil fertility and effectively manage crop nutrients (Gomiero *et al.*, 2011; Henning *et al.*, 1991; Hole *et al.*, 2005; Lorenz and Lal, 2022).

In traditional farms, synthetic chemicals such as fertilizers, insecticides, and herbicides are frequently utilized for pest control (Asad *et al.*, 2016; Iqbal, 2024), whereas organic farms prefer to employ botanical and microbial pesticides that have minimal impact on the ecosystem (Iqbal and Ashraf, 2019; Osadebe *et al.*, 2018). Pest management strategies on organic farms also incorporate methods such as crop rotation, mechanical cultivation, mulching, and flaming. As a result of utilizing non-harmful pesticides and eco-friendly pest control techniques, organic farms tend to support a greater variety of arthropod species compared to conventional farms (Gomiero *et al.*, 2011).

Organic agroecosystems can be distinguished from conventional ones by their higher level of insect diversity, as evidenced by various indices, the variety of taxa, and the number of individual insects present. Research has shown that organic fields of winter wheat tend to have a greater population of plant-eating insects compared to conventional fields, but organic ecotones and nearby protective forest shelterbelts exhibit a higher proportion of predators and parasites. The similarity between the organic field ecosystems and conventional forest belts, as measured by the Sorensen coefficient,

suggests the migration of plant-eating insects from conventional fields to surrounding areas (Grabovska *et al.*, 2020; Letourneau and Goldstein, 2001; Stein-Bachinger *et al.*, 2021).

4.5. Impact of organic farming on faunal and floral biodiversity

Biodiversity encompasses various levels, including species diversity, genetic diversity, and habitat and ecosystem diversity. It plays a critical role in ecosystem functioning and important processes like pollination, soil erosion reduction, dung decomposition in pastures, and natural pest control in soil and crops. Maintaining biodiversity is crucial for the stability and resilience of ecosystems (Di Falco, 2012; Vereecken *et al.*, 2021).

Organic agriculture and pastures have a greater biodiversity compared to conventional counterparts, as they are not contaminated by chemical veterinary drugs. The presence of dung beetles in these environments serves a crucial ecological role by decomposing and recycling dung, thereby contributing to soil fertility and overall quality in natural or organic pastures (Figure 4.4).

Dung beetles can be classified into three main categories: rollers (Scarabaeidae), tunnelers (Geotrupidae and Scarabaeidae), and dwellers (Aphodiidae). Research indicates that organic farming practices lead to higher levels of insect diversity and population compared to conventional farming methods. Multiple studies have shown that organic farming promotes the presence of a greater number of insect orders, families, and individual organisms. This conclusion is further validated by a comprehensive analysis of various published research findings on the subject (Montañez and Amarillo-Suárez, 2014; Rahmann, 2011; Stein-Bachinger *et al.*, 2021).

Fig. 4.4. A sacred dung beetle contributing to the recycling of nutrients in pasturelands (El-Shafie, 2022).

Furthermore, various biodiversity indices, including Shannon, Menhinick, Margalef, Berger-Parker, and Piclou, have substantiated the heightened insect diversity observed in the organic winter wheat field. Additionally, the organic ecotones and forest shelters demonstrated a more than twofold increase in the population of predators and parasitoids (Grabovska *et al.*, 2020).

In organic farming, there was a discovery that the number of insect species and their abundance were 22% and 36% greater than in conventional farming. Similarly, the richness and abundance of spider species were found to be 15% and 55% higher, respectively, compared to conventional farming. Organic farms serve as alternative habitats that support predator and parasitoid

communities through the presence of hedges, which function as refuges and sources of food, such as pollen and nectar, for adult insects of various species (Figure 4.5) (Stein-Bachinger *et al.*, 2021).

Marshall and colleagues corroborated this finding, noting that numerous types of arable weeds attract a diverse range of insect species (Marshall *et al.*, 2003). Schmidt and fellow researchers observed a 62% increase in spider populations in organic farms compared to conventional farms. Additionally, they emphasized the positive effects of landscape diversification, a characteristic of organic farming, on parasitoid wasps, ladybird beetles, and ground beetles (Schmidt *et al.*, 2005).

Fig. 4.5. Hedges around organic farms provide refugia for predators and parasitoids (El-Shafie, 2022).

4.6 The main practices on organic farms that promote higher insect biodiversity

The conservation of biodiversity is significantly impacted by the type of landscapes surrounding farms, ranging from conventional to seminatural or organic, as well as the size of the farms. In organic farming, various practices and crop husbandry measures are implemented to promote biodiversity, such as abstaining from herbicide use, prohibiting synthetic chemical pesticides, utilizing purely organic fertilizers, incorporating rotation with leguminous crops, and maintaining a heterogeneous farm structure (Bengtsson and AHNSTROM, 2005). Various practices within organic farming lead to an increase in arthropod diversity, particularly among soil-dwelling insects. This innovative farming system promotes natural processes such as the decomposition of organic matter, the use of livestock manure, and composting - all providing ideal environments for numerous insect species to thrive.

Saprophagous insects, such as springtails (Collembolla), exhibit greater abundance in organic farms compared to conventional ones. Additionally, the implementation of cover crop mulching serves to enhance soil fertility, regulate temperature, and preserve moisture, consequently favoring the presence of insects in the agricultural ecosystem. Minimal soil disruption in organic farming allows soil microorganisms and arthropods to flourish undisturbed. The integration of predators, parasitoids, and natural insecticides in the management of pests within organic farming systems does not have any adverse effects on arthropod communities. Furthermore, reports indicate that honeybees, wild bees, and bumblebees have successfully utilized the diverse flora present in organic fields. The diversity of weeds, trees, shrubs, and hedges within organic farms also attracts

various bee species and other generalist pollinators, enhancing biodiversity within these ecosystems (Lentini *et al.*, 2012).

4.7 Organic farming and cover-crop management reduce pest predation

Declines in arthropod populations on a global scale call for a reassessment of current agricultural methods. Organic farming, intricate landscapes featuring a high proportion of semi-natural habitats, and local vineyard management techniques, such as the utilization of flower-rich cover-crop mixtures, offer potential strategies to boost arthropod diversity and, consequently, enhance natural pest control within viticulture.

Our study investigated the impact of organic farming, various types of inter-row vegetation in vineyards, and the composition of surrounding landscapes on the natural control of a prominent grapevine pest, the grape berry moth *Lobesia botrana*, while also identifying its primary natural adversaries. Surprisingly, the presence of sown cover-crops and the practice of organic farming resulted in a reduction of natural pest control. Notably, bush crickets emerged as one of the most prevalent natural enemies in the region selected for the Austrian study. The adverse effects of organic farming observed in our research are likely associated with intensified applications of fungicides. Hence, a promising tactic to diminish fungicide usage and encourage more sustainable viticulture could involve adopting grape varieties that possess resistance to fungi.

The intensification of agriculture, particularly through habitat simplification, landscape homogenization, and the extensive use of pesticides and fertilizers, is contributing to the decline of arthropods on a global scale, thus diminishing the ability to provide essential ecosystem services like natural pest control. Organic farming emerges as a promising methodology for augmenting natural predators of pest species and thereby boosting their efficacy in pest management (Bengtsson *et al.*, 2005; Bianchi *et al.*, 2006; Gurr *et al.*, 2003; Hallmann *et al.*, 2017; Muneret *et al.*, 2018; Puig-Montserrat *et al.*, 2017; Sánchez-Bayo and Wyckhuys, 2019; Seibold *et al.*, 2019).

The advantages of organic farming in terms of pest control appear to have a lesser impact on perennial crops like grapevines compared to annual crops, potentially influenced by the surrounding landscape. Regions with intricate landscapes containing more seminatural areas tend to offer greater levels of natural pest control. Seminatural habitats adjacent to vineyards, particularly those with woody vegetation, have the potential to enhance populations of beneficial insects like lacewings, spiders, mites, beetles, and parasitoid wasps. However, the complexity of landscapes may also have negative effects on the presence of natural enemies and pest infestations, possibly due to higher availability of resources within vineyards as opposed to seminatural surroundings. Furthermore, pests may find certain resources in seminatural habitats advantageous during specific phases of their lifecycle (Bruggisser *et al.*, 2010; Gonçalves *et al.*, 2018; Judt *et al.*, 2019; Muneret *et al.*, 2019; Paredes *et al.*, 2021; Reiff *et al.*, 2021; Serée *et al.*, 2020; Thomson and Hoffmann, 2009; Veres *et al.*, 2013).

Moreover, the adoption of local vineyard management techniques such as the use of flower-rich cover-crop mixtures has been found to boost the population of beneficial organisms like predatory mites, hymenopteran parasitoids, spiders, earwigs, and carabids. Tailoring flower strips to meet the needs of specific natural enemies can also encourage natural pest control in neighboring fields. As a result, it is likely that vineyards planted with diverse cover-crop mixtures will experience an increase in natural pest control. Nevertheless, it is essential to differentiate the impact of cover-crop mixtures compared to bare ground or spontaneous vegetation in the inter-rows, as some researchers have observed greater arthropod diversity in vineyards with indigenous ground cover. The advantages of cover-crops in comparison to spontaneous vegetation have been less explored than their advantages over bare ground (Eckert *et al.*, 2020; Sáenz-Romo *et al.*, 2019).

The European grapevine moth, known scientifically as *Lobesia botrana* and belonging to the Lepidoptera order Tortricidae, is considered a significant pest for grapevines in Europe. This species typically goes through two to four generations per year, with Austria experiencing two generations most commonly, and occasionally three. The first generation larvae typically feed on inflorescences, while subsequent generations target berries, often causing Botrytis cinerea infections. *L. botrana* faces predation from various taxa such as Dermaptera, Hemiptera, Neuroptera, Diptera, Coleoptera, ants, and multiple spider and mite families. Additionally, several parasitic Hymenoptera species, namely Trichogramma and Campoplex capitatior, are known to attack different developmental stages of the European grapevine moth (Pennington *et al.*, 2018; Thiery and Moreau, 2005; Xuéreb and Thiery, 2006).

Several natural predators are vulnerable to fungicides like sulfur and copper, which are commonly used in organic viticulture instead of the synthetic fungicides typically used in traditional or integrated vineyards. Fungicides are most effective when applied preventatively rather than after an issue arises, making them a popular choice for grape growers who typically spray several times a year. There is a growing desire among wine producers for less harmful synthetic fungicides, leading to relatively low unintended consequences of most synthetic alternatives. This raises the question of whether the benefits of organic farming for natural predators and pest control are evident in modern viticulture practices. During the study period, a significant percentage of *L. botrana* eggs and pupae were consumed by predators. Surprisingly, there was a 10% increase in predation of *L. botrana* pupae in integrated vineyards compared to organic ones, contrary to our initial expectations (Nash *et al.*, 2010; Thomson *et al.*, 2000; Thomson and Hoffmann, 2006).

However, the rates of predation were generally found to be relatively high, around 80% for pupae and 85% for eggs. On the other hand, insecticides were applied in both organic and conventional vineyards in Bordeaux. Furthermore, the relatively small size of the elongated vineyards in our study area, comprising only a few vine rows, may result in a larger contact area between vineyards and surrounding seminatural areas, leading to stronger edge effects that could enhance natural pest control when compared to larger, more square-shaped vineyards in Bordeaux and the Palatinate winegrowing region (Muneret *et al.*, 2019; Pennington *et al.*, 2018).

Other research studies have also indicated a beneficial impact on pest management in elongated fields with a higher ratio of perimeter to area within annual cropping systems. This phenomenon can be attributed to the closer proximity of field edges and the increased interaction between crop fields and nearby semi-natural habitats (Kragten and de Snoo, 2004; Östman *et al.*, 2001).

Organic farming, contrary to expectations, did not improve natural pest control; in fact, it led to a decrease in predation rates on pupae. This difference can be attributed to the higher frequency of pesticide applications in organic vineyards, particularly the use of nonspecific fungicides like copper and sulfur, resulting in significantly higher APTLc values compared to integrated vineyards. Sulfur, in particular, is known to have adverse effects on a wide range of natural enemies in viticulture, with a high toxicity rating according to the IOBC (International Organisation for Biological and Integrated Control). Application of fungicides containing copper, sulfur, and potassium bicarbonate has been shown to diminish the population of natural enemies and reduce egg predation in vineyards in Germany. Additionally, Muneret et al. discovered that while egg predation increased with decreasing pesticide use, larval predation on grape berry moths remained unchanged. Interestingly, pesticide use was lower in organic vineyards than in conventional vineyards in France. The French study revealed that conventional vineyards had double the pesticide input as compared to organic vineyards (Muneret *et al.*, 2019; Nash *et al.*, 2010; Pennington *et al.*, 2018).

The variation in pesticide usage between organic and conventional/integrated vineyards may be attributed to the differing practices in pesticide application between Austria and France. In Bordeaux, only 6% of the pesticides used were insecticides to combat grape berry moths and leafhoppers, whereas in Austria, insecticides were only utilized on two occasions in vineyards. Fungicides typically make up the majority of pesticide applications in viticulture, accounting for 96%

of all treatments. Our study found that the disparity between organic and conventional viticulture primarily stemmed from varying frequencies of pesticide applications, emphasizing the potential detrimental effects of fungicide toxicity on non-target organisms. The reduction of pesticide use and the incorporation of less harmful alternatives represent a promising avenue to improve natural pest management in vineyards and should be taken into consideration within agri-environmental initiatives (Bereswill *et al.*, 2012; Pennington *et al.*, 2018).

The vineyards with spontaneous vegetation cover exhibited the highest rates of pupae predation. In Germany, however, egg predation rates of *L. botrana* were found to be higher in an experimental vineyard that was sown with flower-rich cover crops compared to vineyards with spontaneous vegetation. The use of native cover crop species in South African vineyards increased arthropod diversity and enhanced the abundance of natural enemies, resulting in increased predation of the light brown apple moth in Australia. Additionally, the abundance of predators such as spiders, earwigs, and ants was found to decrease with higher levels of tillage intensity. In Italy, vineyards that were frequently tilled showed higher infestations of *L. botrana* compared to vineyards planted with cover crops (Danne *et al.*, 2010; Hoffmann *et al.*, 2017; Serra *et al.*, 2006).

Bare soil vineyards were not present; however, the vineyards with spontaneous vegetation exhibited the lowest level of tillage intensity, which could potentially explain the higher rates of predation in those particular vineyards. Additionally, herbicides were exclusively utilized in four integrated vineyards with cover-crops that were low in species diversity and only present under the vines. The frequency of tillage in the rows was observed to be higher in organic vineyards. These various forms of disturbance may have impacted the occurrence of predators and overall pest control within the study. The potential advantages of diverse spontaneous vegetation or cover-crops rich in flowers, which can serve as valuable resources for predatory arthropods, should be taken into consideration in agri-environmental initiatives within the viticulture industry.

Surprisingly, both egg predation and pupae predation did not show an association with landscape composition. Likewise, the infestation of *L. botrana* and the abundance of predators were not influenced by the proportion of seminatural habitats in France. In fact, *L. botrana* egg predation even decreased as the proportion of seminatural habitats increased. A study by Papura et al. demonstrated that populations of harvestmen, crucial predators of grape berry moths, grew with a rise in seminatural habitats within the landscape (Papura *et al.*, 2020). Gonçalves et al. noted a general decline in predator abundance as the proportion of seminatural habitats increased. In the same study, ant abundance in vineyards increased with a greater proportion of large-scale vineyards and small-scale seminatural habitats (Gonçalves *et al.*, 2017). In contrast, research by Thomson and Hoffmann revealed an increase in the abundance of natural enemies and parasitism of pest moth eggs in vineyards that were in close proximity to wooded areas in Australia. It is assumed that perennial crops like vineyards offer ample food sources and refuge for agrobiont species such as earwigs and ants to complete their life cycle within the field, therefore lessening the impact of surrounding landscapes (Ješovnik *et al.*, 2019; Thomson and Hoffmann, 2009).

The transmission of effects from natural habitats to cultivated crops that is seen in annual crops may not be as significant in vineyards. Specifically, the influence of the surrounding landscape may be minimal when a diverse vegetation cover is integrated into the spaces between vineyard rows (Batáry *et al.*, 2011; Schmidt and Tscharntke, 2005).

Although the images depicting the natural predators of *L. botrana* were captured in just two of the vineyards examined and may not be entirely indicative of the entire study area, they offer significant insights into the variety of natural enemies targeting *L. botrana*. A total of 178 natural predators actively preying on *L. botrana* were documented through photographs, emphasizing the effective pest control capabilities of earwigs, ants, and bush crickets. Surveillance through cameras in vineyards in New Zealand showed the most intense predation activity in the grapevine canopies by earwigs (Rusch *et al.*, 2017).

Similarly, Pennington and colleagues validated the predation of *L. botrana* eggs by ants, earwigs, and green lacewings through surveillance using camera-equipped sentinel cards (Pennington *et al.*, 2018). It is noteworthy that our observations revealed that the peak activity of natural enemies occurred during the evening and nighttime, a trend that aligns with the findings of Frank and others, who reported nocturnal predation activity ranging from 50% to 60% (Frank *et al.*, 2007).

Earwigs are known to consume eggs, larvae, and pupae of lepidopteran pests, however, their presence in vineyards can lead to issues when present in high numbers as they may feed on grape berries, contaminate bunches with feces, and spread fungal pathogens, resulting in a reduction in grape must quality. Despite their ability to fly, earwigs were found to have limited abundance on cherry trees due to their isolation from other woody habitats. Conversely, the abundance of earwigs in apple orchards was not impacted by factors such as plant species richness, landscape composition, or the choice between organic and conventional management. It was observed that a reduction in pesticide use in apple orchards led to an increase in earwigs and other natural enemies, thereby aiding in the control of woolly aphids (Frank *et al.*, 2007; Kehrli *et al.*, 2012; Nicholas *et al.*, 2005; Rusch *et al.*, 2017).

Based on their dependence on ground vegetation in their initial developmental stages, earwigs were more prevalent in Spanish vineyards with naturally occurring vegetation as opposed to bare soil and intentionally planted flower-rich cover crops. Our research revealed that vineyards utilizing integrated pest management methods had reduced fungicide application and, consequently, lower toxicity levels, leading to increased presence of earwigs and predation on *L. botrana*. Therefore, vineyards with minimal disruption to soil tillage and pesticide usage can anticipate higher populations of earwigs and a more effective natural pest control system (Sáenz-Romo *et al.*, 2019).

In certain regions where wine is produced, ants have been found to interfere with the natural control of mealybugs and aphids by protecting them from their natural predators and consuming the honeydew they produce. As a result, the presence of ants is not desired in some vineyards. However, research conducted in Australian vineyards has shown that native ant populations do not impact the presence or predation rates of other arthropod predators on moth pests. Furthermore, ants have been identified as valuable natural predators of various pests, including moths, in agricultural settings such as blueberry fields, corn crops, and grasslands in the United States.

Studies conducted in cherry orchards in Switzerland and vineyards in Portugal have revealed that the densities of ants in these environments are not influenced by the compositions of the surrounding landscapes. However, it has been observed that ant populations are higher in organic vineyards compared to conventional ones and in vineyards where cover-crops are implemented instead of traditional tillage methods in Italy (Masoni *et al.*, 2017; Wilson and Daane, 2017).

Ants were more abundant on the recorded sentinel cards in the organic vineyards examined in this study. This could be due to the ants' increased tolerance to pesticide toxicity or their avoidance strategies, as evidenced by the higher earwig population in integrated vineyards.

Several species of bush crickets, including the two Phaneroptera species identified as the predominant predators of *L. botrana* pupae in this study, are omnivorous and can consume both plants and grapevine pests. Additionally, bush crickets such as *Meconema meridionale*, *M. thalassinum*, and *Tettigonia viridissima* are primarily carnivorous and known to prey on pests like leaf miners, chrysomelids, and green leafhoppers. Notably, this study is the first to highlight the significant potential of bush crickets in controlling grape berry moths in Austrian vineyards, despite their reputation as pests in other regions like California (Thomson *et al.*, 2007; Varela *et al.*, 2010; Weinberg *et al.*, 2009).

4.8 Conclusions

The examination of data concerning insect biodiversity indicates that organic farming significantly promotes the abundance and diversity of insects. Relying solely on biomass as a metric to monitor

the global decline of insects is insufficient. The majority of research on biodiversity has been conducted in temperate regions, where long-term data is available. Limited studies have been carried out in tropical and subtropical regions, which are home to a large number of insects, resulting in a lack of available data to track insect decline trends. To establish a consensus on the primary factors driving this decline, it is imperative to use rigorous methodologies for monitoring changes in abundance and biodiversity, as well as conducting long-term research studies.

Implementing organic farming practices and promoting landscape heterogeneity in agricultural systems may serve to mitigate the decline in insect biodiversity and slow the rate of global insect population decrease. We observed modest yet beneficial impacts of spontaneous vegetation and integrated farming on the natural pest control of *L. botrana* pupae in vineyards in Austria. The relatively adverse effect of organic viticulture is likely attributed to the detrimental unintended consequences of frequent sulfur (and copper) applications on arthropods, coupled with the deliberate avoidance of highly harmful insecticides by integrated winegrowers. The sustained implementation of mating disruption pheromones against grape berry moths has significantly diminished the need for insecticide application in the research area. This underscores the importance of assessing management practices such as organic farming on a case-by-case basis, even though they are commonly viewed as advantageous for biodiversity and pest control. Moreover, the usage of fungicides varies among organic and integrated vineyards, suggesting a potential for reducing fungicide application. The emergence of new fungus-resistant grape varieties presents an intriguing opportunity for achieving more sustainable viticulture by enabling up to a 95% reduction in fungicide use.

Additionally, initiatives aimed at supporting agriculture and the environment, such as the Austrian agri-environmental program, should encourage the utilization of naturally occurring vegetation or diverse cover-crop blends to enhance biodiversity and the resulting ecosystem benefits, such as the promotion of natural pest management in vineyards.

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Chapter 5

Organic Farming and Insect Control

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Organic Farming and Insect Control

Abstract

Managing insect pests in organic production systems poses significant challenges for farmers. The guidelines set by the Federal National Organic Program (NOP) outline approved strategies, but effectively implementing them requires a deep understanding of entomology. Many growers find the tactics permitted by the NOP to be restrictive, citing important components such as pest monitoring and identification that are not included. Educational initiatives must explore diverse teaching methods and outreach strategies to introduce tailored pest management approaches that are suitable for specific regions, while emphasizing collaboration between growers and local experts. This analysis highlights the obstacles and knowledge requirements associated with following the NOP's pest management guidelines, proposing an educational framework that incorporates additional professional support to encourage the adoption of innovative pest control methods or the refinement of existing practices, with a particular focus on the importance of monitoring insect populations.

Keywords: Biological control, pest management, monitoring, identification, pest control.

5.1. Introduction

Crop rotation has been demonstrated to effectively decrease particular pest risks in specific crops. By implementing crop rotation, farmers can proactively plan for specific pest management outcomes by alternating between host and non-host plants. However, not all farmers are able to adopt crop rotations due to constraints such as limited space, lack of agronomic knowledge, their business model, the expense of leasing land for planting a cover crop that does not generate revenue, or simply their preference to cultivate only one type of crop. Monitoring is essential for the successful utilization of crop rotation for pest management, sometimes extending beyond the boundaries of the field. For instance, in potato farming systems, crop rotations have proven effective in controlling Colorado potato beetles, but only when fields are rotated at a distance of at least 400 m from previous potato cultivation (Mohler, 2009; Sexson and Wyman, 2005). For these agricultural producers, the implementation of coordinated monitoring initiatives at a regional level may lead to enhanced management strategies. While crop rotation has the potential to benefit organic farmers, there is a lack of generalized recommendations for producers, highlighting the necessity for farm and crop-specific monitoring data at both the individual and regional levels in order to make informed management decisions. Regional monitoring programs must be efficient in terms of time and labor, and may need to explore alternative methods beyond physical means (such as nets and beat sheets), such as utilizing herbivore-induced plant volatiles to attract natural enemies to specific areas for monitoring purposes. The coordination of regional monitoring activities is likely to be facilitated with the development of user-friendly monitoring tools. Depending on the circumstances, extension offices could potentially play a key role in organizing and overseeing monitoring efforts, given that pest populations often transcend different property boundaries within a region (Jones *et al.*, 2009).

Soil and nutrient management involve making strategic investments in inputs to enhance various aspects of soil health over the long term. This field is currently the focus of extensive research, particularly in terms of identifying inputs that can not only improve soil health but also provide additional ecological benefits like suppressing soil pathogens. Despite this ongoing research, there is a lack of data-backed recommendations for organic farmers regarding regionally and crop-specific soil inputs that can effectively aid in controlling insect pests. Recent studies have concentrated on studying the soil microbiome and exploring ways to enhance its potential impact on above-ground herbivores. However, there is still a scarcity of evidence to support data-driven recommendations

for growers (Headrick, 2021; Jones *et al.*, 2009; Magdoff and Van Es, 2000). The management of soil and nutrients necessitates ongoing monitoring and the implementation of appropriate measures to address any identified deficiencies. According to the guidelines outlined in the Organic Systems Plan section G4.0, soil monitoring and sampling activities are mandated in order to renew annual certification inspections. Prior to an inspection, organic certifiers specify the quantity of soil and tissue samples that need to be collected from the grower. Various private companies offer analytical services, which encompass instructions on sample collection and receipt, analysis findings identifying deficiencies, and optional suggestions for remediation. The processing of each sample typically falls in the price range of USD 50 to USD 100, with the additional cost of remediation recommendations amounting to more than double for organic farms compared to conventional ones (Van Driesche *et al.*, 2009). Sanitation and other cultural practices face similar challenges in terms of reliable recommendations, much like crop rotation, soil management, and nutrient management. The National Organic Program (NOP) instructs growers to eliminate disease vectors, weed seeds, and habitat for pest organisms from the growing environment. However, this directive may lead to potential issues since removing habitat for pests, such as plant residues, also eradicates the natural enemies of those pests. A comprehensive evaluation of the insect population through diversity surveys could provide growers with insights into the potential impacts on insect communities before undertaking widespread removal or tillage of crop residues. Nevertheless, there is a scarcity of research available to support confident implementation by growers, and the existing published studies offer uncertain outcomes (Hajek and Eilenberg, 2018; Lam and Pedigo, 1998; Mudge *et al.*, 2009; Quinn *et al.*, 2016).

Cultural practices that promote crop health encompass selecting plant species and varieties with resistance to common pests, weeds, and diseases. Plant resistance as a method of insect pest management has shown effectiveness since the early 1900s, particularly against certain pests in specific settings. A challenge for organic farmers is the slower pace of developing new plant varieties resistant to insect pests compared to conventional farming methods. Organic farming prohibits the use of genetically modified crops, which are typically developed more quickly than pest-resistant varieties through traditional breeding programs. This limitation is considered a constraint on the range of pest management options available to organic growers. In certain instances, growers may have the opportunity to engage in the selection of land races for crops that demonstrate potential resistance to pests (Anderson *et al.*, 2019; Döring *et al.*, 2012; Grasswitz, 2019). The advantage of this approach lies in its alignment with the NOP mandate of choosing varieties that are well-suited to specific environmental conditions. However, the drawback is that not all crops or varieties are easily propagated, and some growers may lack the necessary resources to carry out such activities. These strategies may not account for the diversity of cropping systems that are certified organic or the scale of such operations. Larger growers typically rely on nurseries or seed companies for source materials and tend to practice monocropping due to economic considerations, making landrace selection difficult, if not unfeasible. Nevertheless, educational programs can help certain growers develop a better understanding of landraces and how to identify and propagate resilient crop plants (Grasswitz, 2019; Salaheen and Biswas, 2019).

5.2. Augmentation biological control, natural enemy habitat development, and non-synthetic controls augmentation

Although initially downplayed by researchers (Michaud, 2018; Van Driesche *et al.*, 2009), augmentation biological control methods have maintained popularity within insect pest management programs and have become a prominent economic sector within the industry, with significant projected growth (Hashmi *et al.*, 2018; Hassanein *et al.*, 2018; Iqbal and Ashraf, 2017; Iqbal and Ashraf, 2019). A survey conducted between 2004 and 2006 revealed that commercially available natural enemies accounted for less than 10% of the market for biologically-based pest

control, with an estimated annual value of USD 25-30 million at the wholesale level. Augmentation has played a vital role in arthropod pest management and has contributed to the reduction in insecticide use in controlled cropping systems (Michaud, 2018; Pilkington *et al.*, 2010; Salaheen and Biswas, 2019; Smith *et al.*, 2020). However, the implementation of augmentation practices in open field settings is hindered by ecological and practical challenges such as the availability and quality of purchased natural enemies, access to professional advice for selecting suitable species, efficient and timely deployment, and methods for assessing effectiveness to balance costs. The expertise required to effectively utilize augmentation strategies targeting a specific pest/natural enemy is extensive and becomes even more complex in a diverse farming system that incorporates conservation biological control methods. In 2019, the increasing popularity and perceived benefits of augmentation were evident in California's cannabis and hemp production industry. Many of these new growers relied on chemical applications as their primary response to arthropod pests, followed by the release of natural enemies in high quantities. Nevertheless, inundative releases can be costly and yield subpar outcomes, necessitating the provision of data-driven recommendations and entomological knowledge for growers to make cost-effective use of inundation (Baker *et al.*, 2020; Salliou and Barnaud, 2017; Van Lenteren, 2000; Wilson *et al.*, 2019; Wilson *et al.*, 2014). The method of augmentation through inoculation is deemed more efficient than inundation; however, it necessitates the availability of data regarding pest population dynamics in the field through continuous monitoring to facilitate timely applications. This knowledge is typically obtained through the assistance of field representatives associated with a biological pest management firm. Past experiences have indicated that farmers tend to release purchased natural predators either in a flood-like manner or according to a predetermined schedule in an effort to address perceived pest issues. The tendency to introduce natural enemies may stem from the common human trait of feeling the need to take action rather than remain inactive. This decision is often made without concrete economic rationale, realistic expectations, or concern for potential negative outcomes, as the use of commercial natural enemies is generally regarded as posing minimal environmental dangers. Informed field representatives or other experts can serve as valuable intermediaries in countering these impulsive actions (Coll and Wajnberg, 2017; Wilson *et al.*, 2014).

5.3. Natural enemy habitat development

The establishment of habitat for natural enemies on agricultural land is one component of conservation biological control, the other being the utilization of targeted pesticides. The practice of conservation biological control is referred to by various names in literature, such as Ecological pest management (EPM), Farmscaping, and whole-farm management. The main objective is to promote the activity of natural enemies and create a farming environment that minimizes the need for external inputs, in contrast to augmentation strategies that require continuous input. Habitat development involves two key components: planting insectary plants in close proximity to crops to support natural enemies, such as hedgerows and buffer strips, and increasing overall crop diversity on farms, which incorporates insectary plants as well (Brennan, 2016; Coll and Wajnberg, 2017; Malézieux *et al.*, 2009; Snyder, 2019; Zehnder, 2013). A deep understanding of biological and cropping systems is necessary for the effective implementation of habitat management strategies that can lead to predictable outcomes in both agricultural and ecological approaches. Insectary plantings, even with a single plant species, can significantly increase diversity and assist in pest control. Novice growers may find it easier to adopt a system based on a single plant species initially. An example of this is the relationship between alyssum, syrphid flies, and aphids, which is well-documented and reliable. Utilizing insectary plants can help boost the population of natural enemies and provide some benefits in pest management. However, further research is required to offer growers recommendations that ensure consistent and reliable pest control. Efforts should also be made to study perennial insectary plant species, as current research has mainly focused on annual species (Ingrao *et al.*, 2017; Van Wert, 2020; Winkler *et al.*, 2010). Introducing additional crop species to alter the Farmscape necessitates acquiring new knowledge for successful cultivation, which may cause growers to be cautious when considering extensive changes to their plantings.

The development of seed mixes tailored to support the requirements of natural enemies can be costly, and the promotion of conservation biological control as a solution for managing persistent pest problems by the academic community may not consider the willingness or capability of growers to modify their farming practices to enhance plant diversity. The surrounding landscape context of a farm can influence the effectiveness of incorporating hedgerows or insectary plants to boost the diversity of beneficial insects, including natural enemies and pollinators. For instance, a hedgerow planting in an otherwise stark landscape may yield minimal positive results in fostering natural enemies due to the absence of a recruitment reservoir. The presence of habitat heterogeneity in and around farms was shown to have a beneficial impact on natural enemy activity in the referenced studies, underscoring the importance of considering the broader landscape context (Horne *et al.*, 2008; Landis *et al.*, 2000).

Efforts to maximize the effectiveness of conservation biological control methods are ongoing, with potential for implementation in educational programs aimed at transferring technology to growers within the agricultural community. It is essential for growers interested in promoting farm diversity to possess the necessary resources and willingness to conduct in-field experiments for the validation of specific strategies tailored to their region's climate and crop variety. While conservation biological control strategies show promise, alternative farmscaping concepts like Push-Pull technology have not been well-researched or widely adopted. Despite the availability of certain components for these systems, comprehensive studies are needed to determine their efficacy in practical agricultural settings. The use of living mulches has demonstrated varied results, with some studies indicating positive outcomes in organic cauliflower systems in Europe, while others suggest potential drawbacks. Research on different mulch types is crucial to ascertain their benefits in specific cropping systems. Ongoing evaluations of the advantages and disadvantages of plastic mulches are still underway, with limited evidence of their significant impact on insect pest management (Eigenbrode *et al.*, 2016; Gregg *et al.*, 2018; Razzak *et al.*, 2019; Vorsah *et al.*, 2020). Cautious farmers who are averse to taking risks may encounter challenges in implementing the aforementioned practices, as they may require significant changes to their current farming methods that could be impractical or undesirable. They may also question the potential return on investment. If these strategies were more feasible and guaranteed a substantial return on the investment of time and resources, they would likely be more universally embraced and implemented. Lack of guidance and reassurance may lead growers to continue utilizing more traditional methods that provide general pest management solutions without requiring in-depth knowledge of farm-specific pest issues (Baker *et al.*, 2020; Magdoff and Van Es, 2000).

5.4. Non-synthetic controls

Non-chemical methods of control involve the utilization of lures, traps, and repellents. Typically, lures consist of a semiochemical or food attractant intended to draw in specific species or higher taxa, such as fruit flies, in order to capture and eliminate them. However, lures can also be employed to attract natural predators. The use of lures and traps is restricted by factors such as target species specificity, cost, and the need for collaboration with neighboring areas to effectively reduce pest populations to acceptable levels, particularly when the pest species has limited dispersal abilities. While repellents may have potential benefits, extensive research is necessary to ensure that field applications are reliable enough to justify the associated expenses (Lucchi *et al.*, 2017; Stratton *et al.*, 2019; Valcarcel *et al.*, 2020; Yousef *et al.*, 2018). A variety of methods, including lures, traps, and repellents, have been developed to reduce overall pesticide usage in organic farming systems. However, for these approaches to be effective and cost-efficient, growers must have a strong understanding of monitoring and analyzing pest population trends, identifying insect pests, and estimating degree days. Pheromone mating disruption has been effectively utilized for lepidopteran pests in agriculture for many years, with numerous examples of success. However, there are fewer applications of pheromone mating disruption for other species, often due to biological incompatibilities such as asexually replicating species or multiple generations within a species. Research into utilizing sex pheromones in other species should be encouraged for future

organic pest management, as it is a powerful tool for population control that can greatly reduce the need for pesticides. Nevertheless, careful monitoring is crucial to ensure the proper timing, placement of traps, and follow-up measures for effectiveness (Kovanci *et al.*, 2005).

The issues related to pesticide use are widely recognized and include concerns such as worker and environmental safety, insecticide resistance, proper storage and handling, compliance with label requirements, reporting of use, accurate applications, residues, pollinator poisoning, and marketing challenges. It has been demonstrated that growers worldwide are willing to pay higher prices for pesticide products that are safer for beneficial insects, as long as they see economic and environmental benefits resulting from their use. Organic farmers currently prefer botanical or microbial pesticides, which constitute a rapidly expanding and diverse market. The preference for microbial pesticides leans towards those that mimic the application and function of traditional pesticides, such as microbial Bt. Limited research exists on the specific types, frequency, and quantity of insecticides utilized by organic growers. A survey on cannabis cultivation, encompassing not only organic methods but also reduced-risk chemical strategies, revealed that "microbials" were favored among growers, followed by "unknown organic products," azadirachtin, and oils as the top four insecticidal products utilized (Arthurs and Dara, 2019; Chandler *et al.*, 2011; Stevens and Lewis, 2017). Entomopathogenic nematodes (EPN) have gained popularity as an alternative to chemical pesticides for pest control due to their unique biological characteristics and ease of application. Some growers are able to apply EPN using conventional pesticide application or irrigation equipment, which may increase their acceptance among farmers. However, organic growers encounter technical challenges as many commercial EPN formulations contain fungicides that are not approved by regulatory bodies such as the NOP or Organic Materials Review Institute.
Growers tend to resort to chemical pesticides when they perceive a threat from pests, rather than relying solely on preventive measures. Despite efforts by academics to promote ecologically sound pest management strategies, growers prioritize protecting their investments and income by quickly addressing any pest issues. Some argue that the range of chemical options approved for organic farming should be expanded, citing evidence that organic pesticides are often ineffective, leading to increased usage, environmental harm, non-target effects, and a lack of discernible health benefits compared to conventionally grown crops (Castle and Naranjo, 2009; Dara, 2019; McGuire, 2017).

5.5. Monitoring and identification

A comprehensive monitoring system is essential for growers to assess the need for pest control measures and to ensure accurate timing. Evaluating insect pest populations, including determining their presence, density, and distribution, is a challenging aspect of pest management that presents difficulties for both growers and agricultural advisors.

5.5.1. Monitoring

Surveillance or observation can be a laborious task for farmers as it requires continual oversight and thorough assessment to gauge the effectiveness of treatments. Monitoring a farm's ecosystem necessitates a deep understanding of weeds, diseases, insects, and animals. The complexity of monitoring is heightened in diverse farming systems, where the sheer variety of crops adds to the knowledge required. Nonetheless, the benefits of regular surveillance include early detection, crucial for effectively timing and implementing pest control measures, especially for methods that take time to yield results, such as biological control through inoculation or conservation techniques like planting insectary vegetation. Assessing whether an insect population poses a threat to profitability adds a further layer of complexity, calling for up-to-date and historical data (Flint, 2012; Higley, 1986). Evaluating the extent of economic harm and determining the necessary intervention points necessitates precise and consistent data gathered from the field, with many farmers traditionally depending on "rule of thumb" benchmarks derived from personal expertise rather than a systematic evaluation of economic injury thresholds. The absence of definitive thresholds for various pests and agricultural systems is a recognized deficiency that could be addressed through regular surveillance,

though the findings from such monitoring should be incorporated into the yearly certification process in order to establish relevant benchmarks tailored to each farmer's specific circumstances (Ehler, 2006; Piñero and Keay, 2018; Poston *et al.*, 1983).

5.5.2. Identification

Identification is a crucial initial step in the formulation of a pest management strategy in any agricultural setting. Limited research exists on the challenges faced by growers in correctly identifying plant pests. A study by Piñero and Keay in Missouri involved 84 conventional and organic growers who assessed their own ability to identify pests, giving themselves an average rating of 3.14 out of 5, with no concrete evaluation of their accuracy. The efficacy of pest management products and techniques that target specific taxa and stages hinges on accurate identification, requiring growers to identify pests up to the taxonomic order level at least. For instance, certain Bt products focus on Lepidoptera and are particularly effective on early instars, necessitating knowledge of the stage class distributions of pest populations in the field. Species-level identification is essential for conducting literature searches, implementing evidence-based recommendations, and selecting suitable natural enemies for biological control programs (Huang *et al.*, 1999; Levy, 2005; Peacock *et al.*, 1998; Piñero and Keay, 2018). App-based surveillance and identification tools are expected to advance in quality, though it is essential to prioritize academic supervision for their creation and subsequent integration into educational programs on pest management. While some institutions have compiled lists of apps along with basic descriptions, there is a lack of rigorous screening in place. These apps typically come with costs or require account registration, are often tailored to specific crops like corn or strawberries, and lack tools for population analysis crucial for effective pest management decision-making. Any recommendations offered for crop-specific pest issues may either be sourced from established institutional websites or from sources without verification, leading to potential doubts about their reliability. Over time, the developers of such apps might not sustain their operations, provide necessary updates, or offer satisfactory customer support. As a result, it is sensible to turn to land grant colleges and universities in the creation of apps that offer growers dependable, cost-free, advertisement-free, data-backed, and tested tools suited to their crops and regions to aid in tailored management decisions (Wright *et al.*, 2016; Yang *et al.*, 2008).

5.6 Biological knowledge

All farmers are confronted with the challenge of possessing adequate biological expertise to effectively utilize specific pest control techniques. Biological control is a knowledge-driven management strategy that individuals can benefit from by having a solid foundation in entomology to ensure successful execution. The dynamics of predator/prey population regulation, including inherent delays, are a crucial concept for manipulating biological control agents in augmentation initiatives. Proficiency in the fundamentals of insect pheromone biology and degree days is essential for accurately timing the implementation of mating disruption programs or the application of natural enemies, pathogens, microbials, or other approved insecticides against a specific life stage, such as the codling moth (Blog, 2025; Cardé and Minks, 1995; Jones, 2021).

5.7 External factors

Organic farmers, like all farmers, encounter significant and potentially devastating economic obstacles due to invasive species and subsequent government quarantine regulations. It is uncertain to what extent certifying agencies are knowledgeable and current regarding invasive species. The ramifications of a pest incursion can be sudden and disruptive to the marketing of the existing crop, or even lead to a requirement for crop destruction. If unauthorized pesticides or other non-certified eradication methods are necessary for combating invasive species on or near the crop, the organic farmer may risk losing certification for all or part of a harvest, as seen in instances such as the light brown apple moth and Asian citrus psyllid; although it is rare for the farm to lose its

certification entirely and have to undergo the three-year recertification process from the beginning. The dissemination of timely information and the implementation of effective public relations campaigns are essential for the academic community to involve the public in invasive species initiatives. Farmers, as well as the general public, exhibit heightened concern and apprehension related to the consequences of invasive species, and programs like the California Citrus Threat are an exemplary model for tackling this specific challenge (Clark, 2012; Sparks *et al.*, 2021). Organic farmers are confronted with challenges caused by migratory insect pests and the inadvertent introduction of genetically modified crop elements through factors such as pollen drift. Species such as whiteflies, thrips, and diamondback moths possess the ability to unexpectedly invade an area, causing a swift and drastic shift in pest dynamics for a crop. The presence of migratory pests can result in growers facing populations that have developed resistance to pesticides, making traditional organic insecticides ineffective. It is crucial for growers to familiarize themselves with resistance management strategies and adhere to the Insecticide Resistance Action Committee (IRAC) mode of action numbering system to develop a comprehensive pest management plan (Deutsch *et al.*, 2018; Leach *et al.*, 2019; Sparks *et al.*, 2021).

5.8 Overcoming challenges and looking to the future

Ultimately, the level of knowledge required by growers is increasing, leading to a greater demand for information and verification when making decisions regarding pest management (Ferguson and Grafton-Cardwell, 2014). The conventional method of disseminating information to farmers commences with scholarly professionals engaging in research following a set of protocols known as the Atwater Directives. These services, which are funded by the state, offer information at no cost. Nevertheless, budget cuts in cooperative extension have hindered the service's ability to deliver the requisite level of personalized, hands-on guidance and follow-up visits essential for modern growers (Piñero *et al.*, 2018; Schatzberg and Zilberman, 2016). The decrease in the cooperative extension program in California has been partially offset by the implementation of the Department of Pesticide Regulation's PCA licensing program. Growers in the region have increasingly relied on Pest Control Advisors (PCAs) for pest management information and advice since the program's inception. According to a recent study by Vanzant, statistics indicate a growing dependence on PCAs. In 1983, 75% of tomato growers in a large survey considered PCAs as their top source of pest control information. By the year 2000, a survey of 453 almond growers in the San Joaquin and Sacramento Valleys found that 97% of respondents turned to PCAs for pest management advice. In 2007, a survey of 266 California cotton growers revealed that 99% relied on PCAs for their pest management requirements. A more recent analysis conducted by Goldberger and Lehrer discovered that PCAs and representatives from chemical companies were the primary sources of pest management information for walnut and pear growers in the Pacific northwest (Gott and Coyle, 2019; Vanzant, 2014).

5.9 Conclusions

This chapter delves into the challenges organic growers face when adhering to the Federal NOP guidelines for pest management, noting that these guidelines may limit their ability to successfully manage a variety of pest situations in an economically viable manner. The intricate knowledge, particularly in entomology, required to effectively implement current management tactics can be overwhelming for growers, and there are notable deficiencies in the guidelines that, if addressed, could facilitate grower adoption of practices leading to better decision-making and efficacy. The guidelines were never intended to be exhaustive, thus their general nature allows for interpretation. Certifying agencies collaborate with individual growers to establish acceptable pest management strategies and ensure compliance for annual certification. However, this does not alleviate concerns over the limited range of tools available in comparison to conventional crop production systems, nor does it provide the requisite training for the successful implementation of existing or emerging

tactics. The foundation of knowledge necessary for an economically sustainable pest management program is extensive. Traditional educational programs for growers offered by entities such as universities, extension services, non-profits, and state and federal agriculture departments face challenges due to budget constraints and reductions in personnel, hindering the provision of personalized training and follow-up support to ensure growers proficiently utilize current and newly developed pest management techniques. A notable deficiency in the NOP guidelines is the absence of provisions for pest monitoring and identification. Monitoring offers numerous benefits, including early detection of pest populations, assessment of location and density, identification of growth trends, establishment of a historical record, appropriate timing of cultural, biological, and chemical management approaches, and assessment of efficacy. Incorporating monitoring and identification into the crop pest, weed, and disease management practice standard will emphasize the importance of these practices, making them obligatory for certification and eventually standard practice.

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Chapter 6

Balancing Sustainability Metrics

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Balancing Sustainability Metrics

Abstract

There are varying opinions regarding the potential drawbacks of expanding organic land area, with some suggesting that doing so may lead to nitrogen and other nutrient constraints on crop yields. There are also concerns about whether the increased land area needed for organic farming to sustain yields may negate the environmental benefits it offers. One of the primary criticisms of organic agriculture is its lower productivity compared to conventional methods, which presents a significant challenge when it comes to meeting the food demands of a growing global population without further expanding agricultural land. On the other hand, there are those who argue that the environmental advantages of organic farming far outweigh its lower yields, and that investing more in research and breeding efforts for organic systems could help bridge the yield gap.

Keywords: Balancing, sustainability, metrics.

6.1. Introduction

Some individuals assert that expanding organic land area on a large scale could result in nitrogen and other nutrient restrictions on crop yields, raising doubts about whether the increased land area needed for organic farming to sustain yields negates its environmental benefits. The principal critique of organic agriculture is often the lower productivity it offers in contrast to conventional farming methods, a challenge that is especially significant as we strive to feed a growing global population without expanding agricultural land further. On the other hand, there are those who argue that the environmental benefits of organic agriculture surpass the lower yields, suggesting that dedicating more research and breeding resources to organic systems could help bridge the yield gap (Bachmann *et al.*, 2009; Reganold *et al.*, 2011). Her statement implies that incorporating multifunctional farming techniques, such as organic farming, along with promoting plant-based diets and reducing food waste, are crucial components for a more sustainable food system. It is often overlooked in these discussions that we currently produce enough calories to feed the entire population, but there are issues with ensuring equal access for all individuals. On a global scale, 1.9 billion adults are overweight, with 600 million considered obese, while 793 million people are suffering from undernourishment. Additionally, more than 28% of children under the age of five are experiencing stunted growth due to malnutrition (Organization, 2016; Pocketbook, 2015). Discussions notwithstanding, while yield remains a significant sustainability measure, the complexity of the issue goes beyond mere kilograms of food per hectare. Conventional farming methods, widely adopted for their ability to increase food and product supplies, have often come at the expense of other sustainability objectives. The farm management system can be enhanced by effective agricultural techniques. However, many farmers and residents are still unable to use contemporary, environmentally friendly, and sustainable farming practices (Arshad *et al.*, 2017; Haider *et al.*, 2016; Iqbal *et al.*, 2017). Negative impacts such as environmental degradation, public health issues, dwindling genetic diversity of crops, and disruption of ecosystem services have been associated with conventional farming practices, extending beyond their immediate boundaries and without proper consideration of these externalities. The performance evaluation of organic farming systems within the sustainability framework suggests that they achieve a more balanced approach towards multiple sustainability goals compared to conventional methods (as depicted in Figure 6.1). Although organic farming systems typically yield lower outputs than conventional agriculture, they are posited to be more economically profitable and environmentally sound. Moreover, they are purported to offer food that is equally or more nutritious, with minimal to zero pesticide residue presence. Initial findings also suggest that organic agriculture plays a more effective role in enhancing ecosystem services beyond just yield, in addition to providing various social sustainability

advantages. It is worth noting that research on this subject has been predominantly conducted in developed regions, warranting an increase in studies in less-developed areas, particularly those with tropical and subtropical climates.

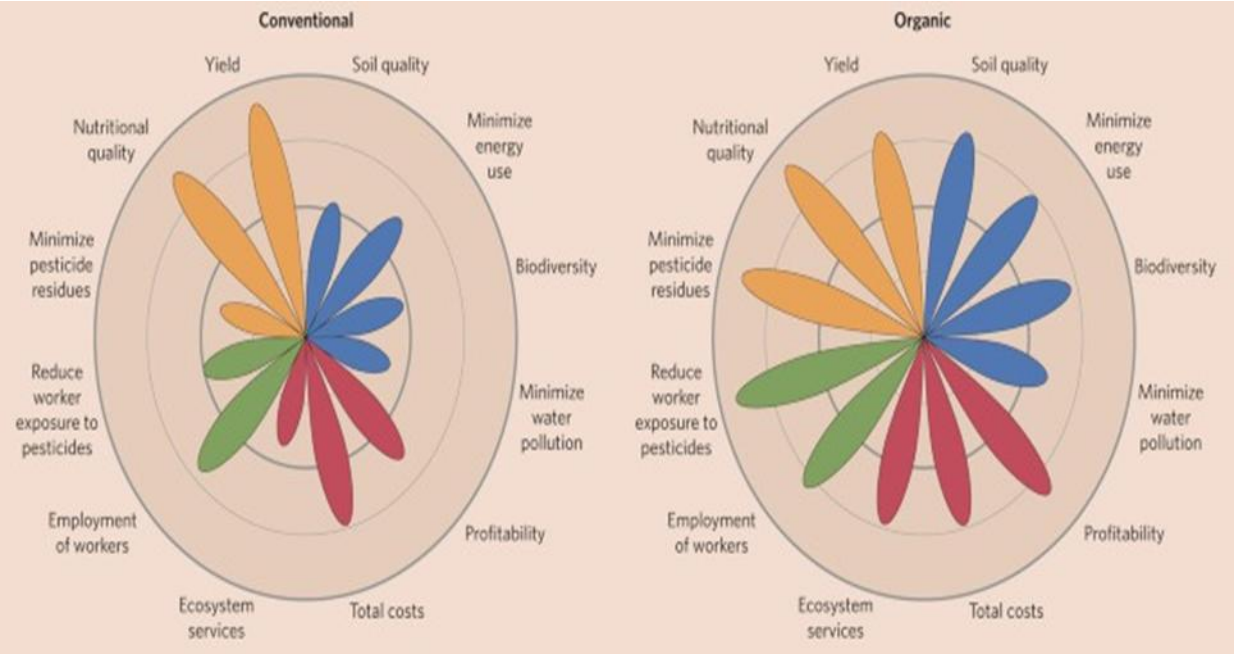

Fig. 6.1. Assessment of organic farming relative to conventional farming in the four major areas of sustainability (Reganold and Wachter, 2016).

Based on the research outlined, the sizes of the 12 flower petals are determined qualitatively and reflect the performance levels of particular sustainability indicators in comparison to the four circles symbolizing different percentages. Petals in orange correspond to production sectors, those in blue signify environmental sustainability, red petals symbolize economic sustainability, while green petals represent wellbeing. The comparisons drawn from the lengths of the petals suggest that organic farming practices are more effective in achieving a harmonious equilibrium across all four dimensions of sustainability (Canton, 2021a; Jackson, 2008). With a mere 1% of agricultural land worldwide dedicated to organic production, the potential for organic agriculture to play a more substantial role in global food production is evident due to its numerous sustainability advantages. However, challenges persist for farmers in embracing organic methods, in both advanced and developing nations (Jackson, 2008).

6.2. Barriers and policies

Challenges hindering the adoption of organic agriculture by farmers include significant vested interests and prevailing policies, a dearth of information and expertise, inadequate infrastructure, economic hurdles, as well as misperceptions and cultural prejudices. Large global and national agribusiness corporations, as well as agrochemical industries, commodity groups, and food companies, possess a strong vested interest in the mainstream agro industrial model, wield increasing market dominance within the food system, and have substantially influenced public policy to support this model. The amalgamation of industries, the centralization of market authority, and various historical and current agricultural policies have resulted in reduced agricultural variety and have discouraged agricultural ingenuity (Canton, 2021a; Jackson, 2008; Organization, 2016; Pocketbook, 2015; Reganold *et al.*, 2011).

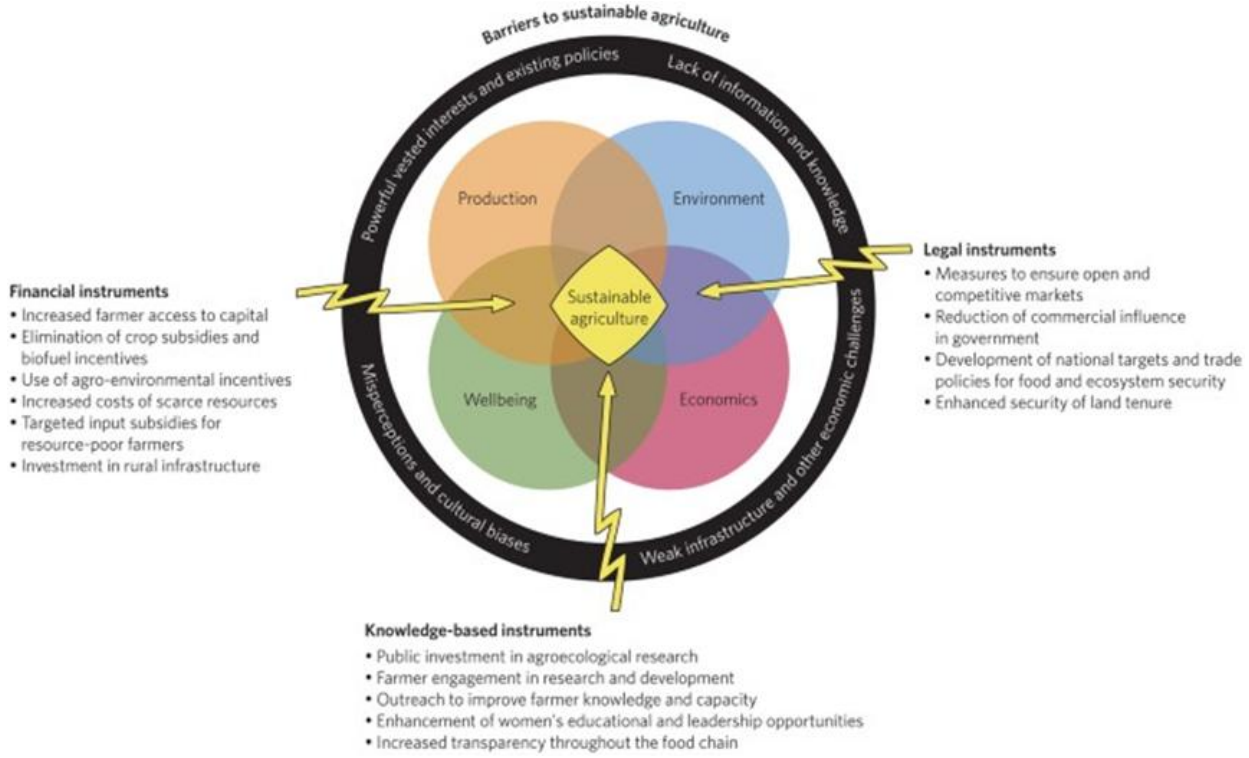

Fig. 6.2. Policy instruments for overcoming barriers to farmers adopting more sustainable farming systems (Reganold and Wachter, 2016).

In order for a farm to be considered sustainable, it must achieve four key objectives as outlined at the center: (1) producing sufficient quantities of high-quality food (production); (2) improving the natural resource base and environment (environment); (3) maintaining financial stability (economics); and (4) contributing to the welfare of farmers and their surrounding communities (wellbeing). Despite the attractiveness of the sustainable agriculture concept, the endeavor to attain agricultural sustainability poses significant challenges for farmers. Merely being organic does not guarantee sustainability for a farm. However, research indicates that organic farming methods excel at balancing the four sustainability goals compared to conventional practices and are more likely to achieve agricultural sustainability (intersection area). Nevertheless, obstacles to the adoption of organic agriculture persist, including entrenched interests and policies, lack of information and knowledge, inadequate infrastructure, economic hurdles, and misperceptions and cultural biases. These impediments parallel those faced by other innovative systems like agroforestry, conservation agriculture, integrated farming, and mixed crop-livestock systems. Diverse policy tools are necessary to surmount these hindrances, falling into categories of financial, legal, and knowledge-based instruments. The figure illustrates examples of such instruments (Sharifi *et al.*, 2010).

There has been a significant disparity in the allocation of public and private funds towards research and development for organic farming systems compared to conventional systems globally, leading to a shortage of crop and livestock breeding tailored to organic farming conditions and a lack of knowledge resources for organic farmers. In the past, funding for research on organic systems has been more substantial in Europe than in the United States. Additionally, research on organic agriculture in underdeveloped nations comprises only a minimal percentage of the total scientific literature available on the subject (Constance and Choi, 2010). Certain farmers encounter challenges related to infrastructure and economics, such as the expenses associated with certification and the difficulties of accessing markets, loans, and insurance. Particularly in rural areas and underdeveloped countries, there is a lack of additional labor, markets for organic products,

storage and distribution facilities, and suitable certification requirements. Furthermore, negative cultural attitudes toward organic farming and entrenched conventional beliefs among individuals and organizations serve as barriers to the wider adoption of organic practices. Considering these hurdles, it is imperative for governments to facilitate the development and implementation of not only organic farming methods but also other innovative and sustainable agricultural systems. Such initiatives should aim to enhance agricultural performance across all aspects of sustainability and necessitate the use of various knowledge-based, legal, and financial policies. Knowledge-based policy tools are essential for creating a supportive environment for agricultural innovation, education, and outreach. Specifically, these instruments should focus on promoting engagement between farmers and scientists in research and development decision-making processes, improving farmers' knowledge and skills through effective extension and outreach programs like farmer field schools and communication technologies, and advancing educational and leadership opportunities for women in agriculture (Canton, 2021b; Pretty and Bharucha, 2014; Stolze and Lampkin, 2009).

Legal mechanisms must assume a more robust role in ensuring open and competitive markets, controlling commercial influence in government, and enhancing transparency in the food production system. Furthermore, these mechanisms are crucial for minimizing food waste, bolstering land tenure security for farmers, and establishing national objectives for trade policies that support both food and ecosystem security. Financial mechanisms are essential for assigning monetary value to the externalities stemming from agricultural practices and empowering farmers by providing them with access to capital, infrastructure, and competitive markets. In developed nations, it is recommended to replace direct and indirect crop subsidies and biofuel incentives with targeted agro-environmental incentives, such as payments aimed at promoting biodiversity protection and soil conservation. Some policy institutions have determined that elevating costs associated with fossil fuels, irrigation water, and other finite resources significantly encourages more effective farming techniques. In less-developed nations, targeted input subsidies and investments in rural infrastructure serve as pivotal financial tools. For instance, subsidizing organic nutrient inputs alongside mineral fertilizer inputs for the most impoverished farmers can prove to be a successful approach for increasing yields and enhancing soil quality (Co-operation and Development, 2013; Sánchez, 2010).

6.3. Beyond organic agriculture

Organic agriculture has been demonstrated to create employment opportunities, generate profits, enhance soil and environmental health, and foster interpersonal connections between farmers and consumers. While organic agriculture holds significant promise in enhancing global food and ecosystem security, it is essential to recognize that no single farming system can effectively sustainably nourish the planet. Instead, a combination of organic methods and other innovative farming practices such as agroforestry, integrated farming, conservation agriculture, mixed crop and livestock systems, as well as yet-to-be-discovered approaches, will be crucial for ensuring the future security of global food and ecosystems. For instance, integrated farming systems that incorporate predominantly organic techniques alongside some conventional methods have proven to be more sustainable than exclusively conventional farming systems and are likely to play a pivotal role in this regard. Achieving global food and ecosystem security necessitates more than simply establishing sustainable farming systems worldwide. Efforts must also focus on reducing food waste, enhancing food distribution and accessibility, stabilizing human population growth, halting the conversion of food into fuel, and encouraging shifts towards a more plant-focused diet (Davis *et al.*, 2012; Reganold *et al.*, 2001). Balancing commitment to each of the four sustainability pillars - production, environment, economics, and social wellbeing - serves to inspire rather than restrict farmers and researchers in their pursuit of innovation. Policymakers are tasked with the challenge of establishing supportive conditions for the expansion of organic and other inventive farming methods, in order to achieve genuinely sustainable production models. This undertaking is substantial in scope, yet the potential impact on food security and ecosystem integrity is substantial. Achieving this goal will necessitate the deployment of a comprehensive array of impactful policies, scientific and

socioeconomic progress, farmer creativity, and public involvement (Stockdale *et al.*, 2001; Van Alfen, 2014; Willer *et al.*, 2024; Yih *et al.*, 2015).

6.4. Strategies for feeding the world more sustainably with organic agriculture

Advancements in agriculture have significantly boosted food supply in recent years, yet have also led to significant detrimental effects on the environment, including excess reactive nitrogen, eutrophication of ecosystems, greenhouse gas emissions, and loss of biodiversity. It is widely believed that by 2050, agricultural production will need to rise by 50% to adequately nourish a projected global population surpassing 9 billion. This challenge is compounded by changing dietary habits. Consequently, it is imperative to mitigate the adverse environmental impacts of agriculture while ensuring continued food sufficiency. Various strategies have been proposed to achieve this objective, such as enhancing production and resource efficiency, embracing holistic approaches like agroecology and organic farming, and reducing consumption of animal products and food waste (Canfield *et al.*, 2010; Lichtfouse *et al.*, 2011; Pingali, 2012).

Organic agriculture represents a tangible yet contentious proposal for enhancing the sustainability of food systems. It avoids the use of synthetic fertilizers and pesticides, emphasizes crop rotations, and prioritizes soil fertility and closed nutrient cycles. The favorable environmental performance of organic agriculture has been extensively documented when assessed across various indicators. However, organic farming typically yields lower outputs, necessitating larger land areas for equivalent production compared to conventional methods. This discrepancy may diminish or eliminate the environmental advantages of organic agriculture when measured on a per-product basis rather than a per-area basis. Additionally, the elimination of synthetic N-fertilizers in organic farming could result in nutrient deficiencies, even with increased legume cultivation. Consequently, the capacity of organic agriculture to provide sustainable food for the global population has been called into question (Boye and Arcand, 2012; Connor, 2013; Foley *et al.*, 2011; Reganold and Wachter, 2016).

Several writers have weighed in on the topic of decreased yields in organic farming by examining the issue of nutrient availability. However, none of these individuals have conducted a thorough examination of nutrient availability within organic production systems. Furthermore, these studies have failed to explore a comprehensive food systems perspective and have overlooked the impact of animal feeding practices, consumer trends, and food wastage (including both loss and waste) on land demand. Addressing these factors could lead to the development of strategies that significantly reduce land usage, mitigate environmental harm, and enhance global food availability (Badgley *et al.*, 2007; Erb *et al.*, 2016; Schader *et al.*, 2015).

We aim to address the existing research gap by adopting a food systems approach that goes beyond simply focusing on production, yields, and environmental impacts for specific commodities. Initially, our study delves into the effects of transitioning to organic agriculture on a variety of environmental and production indicators. We then enhance this organic conversion scenario by introducing two additional modifications to the food system: (a) decreasing livestock feed sourced from arable land (referred to as food-competing feed) which consequently leads to reductions in animal population and supply of animal products (and consequently human consumption), as well as a decrease in the utilization of natural resources and environmental impacts; and (b) reducing food wastage, resulting in lower production levels and corresponding impacts (Halberg *et al.*, 2006). Our primary research inquiry revolves around the comparison of environmental impacts between organic agriculture and conventional agriculture when producing a specific quantity of food in terms of protein and calories. We also explore the potential of incorporating organic agriculture alongside other strategies to mitigate negative effects of transitioning to organic production. Our evaluation delves into the various factors involved in implementing organic agriculture within complementary food system changes to promote sustainability. While there are several global models available to

analyze different aspects of food production and consumption, organic production is often overlooked, with none incorporating the key agronomic features of organic agriculture systematically. Our evaluation also considers the effects of climate change on crop yields to determine the effectiveness of these strategies in varying conditions, as detailed in the Methods section for further information (Behera *et al.*, 2013; Halberg *et al.*, 2006).

6.5 Conclusions

Our findings suggest that the transition to organic agriculture results in a higher demand for land compared to conventional production methods. However, this shift offers benefits in terms of decreased nitrogen surplus and pesticide usage. When integrated with additional modifications in the global food system, such as altered feeding practices, reduced animal populations, and changes in waste management, organic agriculture has the potential to provide sustenance for over 9 billion individuals by the year 2050 in a sustainable manner. By implementing this comprehensive approach, we can achieve sufficient global food availability while positively impacting various environmental metrics, including the demand for agricultural land.

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Chapter 7

Effect of Pesticides on Insect Systems

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Effect of Pesticides on Insect Systems

Abstract

Recent years have witnessed heightened scrutiny of the non-target sublethal effects of pesticides on behavioural and physiological traits of insects. Traditionally, attention has focused on investigating pesticides' primary modes of action, often overlooking the potential secondary mechanisms. This review brings forth the nuanced impacts of sublethal pesticide exposure on the immune system of target and non-target insect species. Pesticides, such as for example neonicotinoids, suppress immune response, while others, like certain organophosphates and some insect growth regulators (IGRs), appear to bolster immunocompetence under certain circumstances. Beyond their individual impacts, the synergic effects of pesticide mixtures on insect immunity are garnering increasing interest. This review thus summarizes recent advances in the immunomodulatory effects of pesticides, detailing both mechanisms and consequences of such interactions. The implications of these effects for ecosystem preservation and viability of beneficial organisms, such as pollinators and natural enemies of pests, are discussed. The review also considers further research directions on pesticide secondary modes of action and explores potential implications for integrated pest management (IPM) programs, as several model organisms studied are crop pest species. While current data provide an expansive overview of how insect innate immunity is modulated, concrete endpoints remain elusive requiring further research into pesticide secondary modes of actions.

Keywords: Integrated pest management (IPM), pesticides, insects, systems.

7.1. Introduction

As agricultural production increases, the use of chemical fertilizers, herbicides, and other synthetic pesticides has equally increased over the years. Inadequate pesticide application description and monitoring has generated a heated debate among governmental organizations, agricultural industries, and conservation organizations about pesticide effects on insect species richness and abundance. An average pesticide application of 1.58 kg per ha per year, 0.37 kg per person per year, and 0.79 kg per USD 1000 per year. Insects have experienced a greater species abundance decline than birds, plants, and other organisms, which could pose a significant challenge to global ecosystem management. Although other factors such as urbanization, deforestation, monoculture, industrialization may have contributed to the decline in insect species, the extensive application of agro-chemicals appears to cause the most serious threat. Therefore, the development of sustainable and environmentally friendly management strategies is critical for mitigating insect species' decline.

7.2. Pesticides usage and distribution in agricultural production

In 2022, the total pesticide used in agriculture was 3.70 million tonnes, representing a 4% increase from 2021, a 13% increase over a decade, and a doubling since 1990. These pesticides comprise herbicides (47.5%), insecticides (29.5%), fungicides (17.5%), and 5.5% others (DATA, 2024; FAO, 2019). Furthermore, 610 chemical compounds containing organochlorine insecticides, which were banned due to resistance and safety concerns, are being replaced with newer chemical products. Although several pesticide products are used, agricultural yield losses are estimated at 37% due to insects (13%), weeds (12%), and diseases (Prakash and Verma, 2011). The mode of action of pesticide active ingredients determines their specificity and toxicity, whereas their effectiveness on organisms is largely determined by the dose administered to them. Pesticides such as carbamates,

neonicotinoid, organophosphorus, synthetic pyrethroid, and organochlorine are well-known neurotoxins that affect arthropods' nervous systems. As a result, these products are assumed to disrupt the physiology of terrestrial and aquatic arthropods. Herbicides are among the most toxic pesticides to other organisms, particularly insects, because they disrupt their metabolic and reproductive systems. Fungicides are used to treat fungal infections and can also act as antibiotics against certain fungi. However, organomercurial products are considered neurotoxic and toxic to arthropods in several areas. As a result, the active ingredients in most pesticides affect a wide range of taxonomic groups rather than just the target species (Prakash and Verma, 2011). Europe and North America account for one-third and one-quarter of the total market, respectively (Baird and Van den Brink, 2007; Baxter and Cummings, 2008). Overall, herbicides are estimated to comprise half of pesticide applications in North America, followed by insecticides (19%), fungicides (13%), and others (22%). Some countries, such as India and South Africa, continue to use DDT and lindane to control mosquito vectors and tsetse flies as needed (Grondona *et al.*, 2023). The global distribution of pesticide types varies by crop, with corn, soybean, and cotton having the highest herbicide usage (75% in the United States). Orchards predominantly use insecticides, whereas vineyards and vegetables plantations primarily use fungicides (Baxter and Cummings, 2008). The average pesticide usage worldwide is estimated to be 4.4 kg/ha per year, with agriculture accounting for roughly one-fifth of the Earth's land area. As a result, insect diversity and other ecosystem services are severely threatened (Grondona *et al.*, 2023).

7.3. Impact of pesticide application on insects' biodiversity

Pesticides are known to be harmful to insects, with direct mortality frequently reported, with non-target insects being the most vulnerable when compared to other insects. These pesticides work directly by disrupting the insect's nervous system or damaging its exoskeleton, causing paralysis and death. Pesticides affect both insects that migrate to sprayed fields and those present during treatments. Pesticides such as malathion, metamidophos, abamectin, acetamiprid, imidacloprid, and acephate are reported to be toxic to both target and non-target insects. Moreover, the direct effects of metamidophos, cartap, and abamectin were found to cause high mortality among a group of insects (Feber *et al.*, 2007; Kannan *et al.*, 2020). Excessive use of insecticides such as organophores, carbamates, and purethroids also reduced hymenopteran and coleopteran populations, which are known to play an important role in food web and crop protection (Zaller, 2020). According to general scientific consensus, pesticides' extreme direct impact has resulted in the decline in most beneficial insects and pollinators. For instance, neonicotinoids increased bee and butterfly mortality while reducing their behaviour and survival (Bengtsson *et al.*, 2005). Glyphosate exposure caused changes in bees' gut microbiome, leaving them vulnerable. In the United Kingdom, the direct effects of pesticides reduced butterfly species richness on conventional farms more than on organic farms. Carabid beetles and other non-target insects were more affected by conventional farm management than organic farms. The direct effect of insecticide application affected bugs, wild bees, and moth populations, but not the target pests (Fletcher and Barnett, 2003). In the United Kingdom, organophosphates (42%), carbamates (29%), and pyrethroids (14%) were found to have a direct effect on the species richness and abundance of bees (Scott-Dupree *et al.*, 2009).

Pesticides used to control pests in wheat and sunflower fields, such as imidacloprid and clothianidin, resulted in high mortality rates among bumble and wild bees (Liu *et al.*, 2007). In France, imidacloprid significantly reduced the diversity of Lepidoptera, bugs, coleopterans, and other species when compared to the target pests (Fox, 2013). Lepidoptera moths and butterflies are known to be vulnerable to habitat loss due to their unique host plant adaptation system (Hahn *et al.*, 2015). Lepidoptera species are widespread and play important roles in ecosystem services and management (Maes and Van Dyck, 2001). In Belgium, 45 butterfly species declined by nearly 69% as a result of excessive agricultural pesticide use during the twentieth century (Van Dyck *et al.*,

2009). In the Netherlands, 11 out of 20 cosmopolitan butterfly species are reported to be declining, while four local species (*Lasiommata megera*, *Gonepteryx rhamni*, Aglais io, and *Thymelicus lineola*) are critically endangered (Groenendijk and van der Meulen, 2004). A corresponding report also showed an 85% decline in 733 moth species, with 38% threatened and 34% susceptible in the Netherlands (Franzén and Johannesson, 2007). In Sweden, a report indicated a drastic decline in (45%), endangerment of (22%), and extinct of (159 species) 269 species (Kuussaari *et al.*, 2007). In Finland, farmland species experienced a greater decrease in biodiversity (60%) compared to forest species (40%) (Melero *et al.*, 2016). A population study in Spain revealed that 66 butterfly species were declining on farmlands, 15 were increasing, and 5 were stable in forest zones (Van Swaay *et al.*, 2006). Out of 576 butterfly species in Europe, 71 are endangered and declining (van Swaay *et al.*, 2010). In comparison, cropland butterflies declined the most (19%), followed by wetlands (15%) and forests (14%). The greater decline observed in cropland butterflies could be attributed to the excessive use of pesticides compared to other habitats. This was confirmed by the observation that 80% of butterfly species have declined as a result of pesticide application (Swengel and Swengel, 2015).

According to extensive data from the United Kingdom, 41 cropland butterfly species are on the decline. This was attributed to agricultural expansion and the excessive use of pesticides and chemical fertilisers. There has been no comprehensive study on the trend of insect biodiversity in the United States. Nonetheless, a few studies revealed unstable species populations in Wisconsin and Iowa's prairies and bogs. This was the result of climate change and agricultural intensification (Breed *et al.*, 2013). In 2012, agricultural intensification and widespread pesticide use reduced 67 butterfly species to 23. In 2010, the southern part of the state experienced an 80% population decline as a result of agricultural intensification and excessive pesticide use (Nakamura, 2011). A detailed data base in Asia shows that the populations of butterfly species are threatened (15–20%) and endangered (80%), with two species on the verge of extinction in Japan (Chen *et al.*, 2011). A previous report in Malaysia revealed a 19% reduction in the moth population at Mount Kinabalu due to agricultural intensification and pesticide (Habel *et al.*, 2016). In Great Britain, a previous study showed 28% decrease in larger moth total abundance (Breed *et al.*, 2013). Burnet moths also decreased from 117 species to 71, with most of them considered highly endangered in Germany (Conrad *et al.*, 2006). A previous study in the UK showed a two-third decline in widespread and common macro-moths over 35 years of study (Conrad *et al.*, 2004). The percentage of common macro-moth species showing a significant decrease was higher (54%) than those showing an increase (22%) in the UK. A similar trend of moths' species abundance and richness decrease has been reported in Scotland (46%) over a 24-year study. A decrease in burnet moths' total abundance was reported in Great Britain (50%) and Scotland (20%) (Dennis *et al.*, 2019).

7.4. Sustainable farming practices

Ecological restoration is required to improve habitat connectivity when a degraded ecosystem is unable to restore itself (Tasser *et al.*, 2019). Sustainable agricultural production plays a major role in biodiversity management and conservation. Raising farmers' awareness can help them adopt sustainable farming practices by changing how they think and feel about them (Fatima *et al.*, 2018; Iqbal and Ashraf, 2021). Result-Oriented Measures that focus on biodiversity fluctuations caused by farmers' management practices have been established, targeting biodiversity restoration. Agricultural sustainability, coupled with innovative technologies, could ensure consistent ecosystem service resilience. This strategy could also contribute to global food security for both the present and future generations (Herzon *et al.*, 2018). Farmers are expected to increase output while protecting natural resources, biodiversity habitats, and the environment. Unfortunately, a recent survey found that most farmers are unaware of timely insect pest infestations and thus use a variety of management techniques, including indiscriminate pesticide application, which kills non-target insects. These practices disrupt ecosystem services, potentially resulting in a decline in insect biodiversity and the spread of other pests. Thus, crop rotations, intercropping, agroforestry, reduced tillage, and proper pesticide application rates are recommended as ways to ensure

sustainable agriculture and stable insect biodiversity. Moreover, strategic development of integrated pest management could reduce the extensive use of toxic pesticides (Jabbar *et al.*, 2020).

7.5. The effects of pesticides on insect respiratory physiology

Insect respiration is a highly sensitive system, which responds rapidly to any stressor (Sláma and Miller, 1987). Kestler demonstrated that respiratory measurements can be used to detect reversible and irreversible toxicosis in insects (Kestler, 1991). Understanding the real nonharming doses of pesticides on nontarget organisms should be an important component in calculating the suggested/allowed doses for controlling pests. Techniques based on changes in autonomic processes can add valuable data to fill gaps in our knowledge. The aim of this review is to collate data and clarify the general respiratory effects observed after treatment of insects with different pesticides.

7.6. Respiratory physiology in insects

7.6.1. Gas-exchange patterns and metabolic rate

The insect tracheal system consists of branching tubes through which air moves to the tissues, enabling gas exchange within the whole body. The external openings of the tracheal system are called spiracles, which act as muscular valves and control the amount of gases getting through. When metabolic needs are high, the spiracles are wide open and the insect breathes continuously. When metabolic demands are lower, less oxygen is needed (Watanabe, 2008), and continuous gas exchange is replaced by patterns during which spiracles are closed some of the time (Chown *et al.*, 2006; Lighton, 1996). With the lowest energy demands, the insect keeps the spiracles closed most of the time and opens them for moments periodically. This pattern is called discontinuous gas exchange (DGE). DGE involves the constriction of the spiracles of the insect tracheae (constriction phase, C) during which no CO_2 release occurs; the C-phase is followed by fluttering (flutter phase, F) when the spiracles partly open and close in rapid succession keeping the tracheal oxygen at a certain level. Finally, the opening of spiracles (open phase, O) allows maximum gas exchange (Buck, 1958; Buck and Keister, 1955). The pattern of CO_2 release reflects the activity level of the insect. DGE occurs only during the quiet state of the insect (Karise *et al.*, 2010; Metspalu *et al.*, 2002). During the deep resting state, the DGE cycles involve a very long closed phase and short rapid outbreaks of CO_2 release (Jõgar *et al.*, 2014), a state that reflects the basic metabolic rate of the organism. If the quiescent state is disturbed and the activity level is raised, the pattern changes: the CFO cycles become shorter and the mean amount of CO_2 released usually increases. Eventually, the DGE pattern disappears and is replaced by cyclic gas exchange (CGE) or continuous (Cont) respiration (Basson and Terblanche, 2011; Contreras and Bradley, 2009).

7.6.2. DGE and water loss rate

Water loss is a mechanistic consequence of gas exchange (Chown *et al.*, 2011). Increasing metabolic rate leads to an increase in water loss rate (Tomlinson and Phillips, 2012; Withers *et al.*, 2012). Insects often endure shorter or longer periods of immobility because of their developmental stage, unfavorable environmental conditions (Lehmann *et al.*, 2015; Tomlinson and Phillips, 2012), paralysis due to contact with toxicants (Jagers *et al.*, 1995; Jagers op Akkerhuis *et al.*, 1999), or death feigning for protection (Krams *et al.*, 2014; Krams *et al.*, 2013) during which it is important to decrease water loss rate to avoid desiccation. The presence of DGE in insects and some other arthropod taxa is most often considered as an adaptation to reduce respiratory water loss rate (Quinlan and Hadley, 1993; Quinlan and Lighton, 1999). In DGE during C and F phases, the spiracles are closed or flutter and no outward movement of gas molecules (including H_2O) can occur (Harak *et al.*, 1999; Jõgar *et al.*, 2011). The water vapor leaves the insect body through the cuticle or spiracles. In most insect species studied, spiracular water loss makes up approximately 10% of

all water loss (Chown, 2011). This seems to be an inconsiderable amount, which still may prove to be critical in conditions where water is a limiting factor (Matthews and White, 2012; Williams *et al.*, 2010).

There is proof that the varying patterns of DGE contribute differently to the rate of water loss (Jogar *et al.*, 2004). However, in some experiments where the insects were forced to open or close the spiracles because of hyperoxic or hypoxic conditions, the presence or absence of DGE has been shown not to affect water loss rate (Groenewald *et al.*, 2013; Quinlan and Hadley, 1993). In many studies, only the total water loss has been estimated. The gravimetrical method of weighing the insect before and after the experiment does not allow separation of the gas-exchange patterns and phases within DGE (Jogar *et al.*, 2004; Tomlinson and Phillips, 2012). Modern gas analyzers (eg, LiCor 6262 or 7000, LiCor, Lincoln, NE, USA) allow simultaneous recording of different gases, which enable the measurement of water loss during the open and C+F phases of DGE (Karise *et al.*, 2016; Muljar *et al.*, 2012). At that time, the only H_2O detected is evaporated through the cuticle. During the O phase of DGE, the additive peak indicates H_2O emergence through the spiracles.

7.6.3. Factors affecting insect respiratory physiology

The metabolic rate and gas-exchange patterns of any organism depend on several factors. For insects, the first effector is the life stage. The metabolic rate of the larva is generally higher than that of the pupa because the former is feeding intensively (Boardman and Terblanche, 2015; Mänd *et al.*, 2006). Furthermore, larvae preparing for pupation have a higher resting metabolic rate than those not preparing for pupation (Nestel *et al.*, 2007; Terblanche *et al.*, 2014). The metabolic rate may also change due to parasitism of the larva as was shown for *Manduca sexta* L. (Alleyne *et al.*, 1997). The metabolic rate of bumble bee queens depends on whether they are pre- or postwintered (Beekman and Van Stratum, 1999) and also on their task in the nest (Silvola, 1984). The second aspect that must be taken into consideration in respiratory studies is the individual properties of the subject. Metabolic rate has been shown to be affected by its sex (Boratyński *et al.*, 2010), behavior (Artacho and Nespolo, 2009; Harak *et al.*, 1998), and body mass (Boratyński and Koteja, 2009), although some studies, for example, in the bumble bee *Bombus terrestris* L. (Karise *et al.*, 2010; Karise *et al.*, 2016; Muljar *et al.*, 2012) failed to find the latter correlation. Temperature affects the metabolic rate to a great degree (Lighton and Lovegrove, 1990; Tomlinson and Phillips, 2012). At higher temperatures, the metabolic rate is usually higher. This phenomenon has its limits. Each species has its own normal activity temperatures below and above which the vital functions are slowed down (Lachenicht *et al.*, 2010; Lehmann *et al.*, 2015; Must *et al.*, 2010). In both situations, the insect usually hides quietly until the conditions become favorable again (Hoch *et al.*, 2009). In addition, in some species, the activity level is not correlated directly with temperature. For part of the time, honey bees and bumble bees stay inside the nest, where temperature remains around 30°C, and is the temperature actively controlled by nest mates (Stabentheiner *et al.*, 2010).

The foragers go out in the cooler temperatures. It has been observed that the metabolic rate of resting or walking bumble bees is higher at cooler than higher temperatures.58 Water availability is a limiting factor for most terrestrial insects. Because of their relatively large body surface compared to their body mass, water evaporation is more hazardous to insects than to larger animals (Chown, 2002). Insects have adaptations to avoid water loss. The insects' cuticle with its waterproofing long-chain saturated hydrocarbons provides a barrier to water loss (Denlinger and Yocum, 1998). The excretion system involves a water reabsorption capability, and thus much of water can be saved (Chown and Nicolson, 2004). Metabolic water production is essential not only for eggs and pupae but also, for instance, in insects living in stored grain consuming only dry food with no access to water (Jindra and Sehnal, 1990). Restricting water loss through spiracles can contribute to restricting total water loss, although, in most insect species, respiratory water loss has been estimated to be much less than 20% (Chown, 2002). Insects from arid regions certainly benefit from restricting respiratory water loss (Matthews and White, 2012; Williams *et al.*, 2010). Lowering

metabolic rate in extremely dry conditions has been observed even with bumble bees (Karise, 2007), which inhabit the middle latitudes where water is mostly available.

7.6.4. Effects of lethal and sublethal doses of pesticides on insect respiration

The most common insecticides (organophosphorus compounds, pyrethroids, and neonicotinoids) target the nervous system, which controls automatic functions in an organism. Studies dealing with the effects on the autonomous functions in insects have involved several types of pesticides: synthetic insecticides (Hatjina *et al.*, 2013; Kestler, 1991; Muljar *et al.*, 2012; Zheng *et al.*, 2013), botanical extracts (Harak *et al.*, 1999; Jõgar *et al.*, 2008; Sibul *et al.*, 2004), bacterial toxins (Dingha *et al.*, 2005), biofungicides and -insecticides, and inert powders (Karise *et al.*, 2016). These studies have been conducted with almost all developmental stages of insects from distinct systematic families. Autonomic functions are highly sensitive, and alterations in metabolic rate and respiratory patterns occur long before death. A study demonstrated changes in the patterns of hemocoelic pulses after treatment with different doses of pyrethroids, carbamates, and organophosphorus insecticides (Sláma and Miller, 1987). According to this study (Kestler, 1991), the paralysis leads to exponential wash out of CO_2 from the tissues with some activity because of tremors. At the end, a smooth CO_2 release can be seen. The gradual loss of resting CFO(V) cycles in moribund insects, sometime after the onset of the reversible excitation phase, was described as the typical physiological effect. The very same pattern may occur due to desiccation or hard handling stress. If the effect of the stressor disappears before the end of cyclic respiration, the toxicosis may be reversible. The nerve damaging effect of the phosphine was evident as, after returning to normoxia following the phosphine treatment, normal DGE pattern was not reinstated in any of the trials. The treatments with pyrethroids also cause changes in normal patterns of DGE due to over excitation or paralysis (Dingha *et al.*, 2005).

7.6.5. Fecundity and reproduction

The most common reproductive effects of sublethal pesticides include reduced fecundity, a lower egg-laying rate, or a reduced amount of brood in general. The number of eggs laid may fall by up to 45% over several generations. For example, fipronil reduces the concentration and availability of spermatozoa in drones of *A. mellifera* and thus limits male fertility (Bingsohn *et al.*, 2016; Milone and Tarpy, 2021; Sâmia *et al.*, 2019). The same effect was observed in *Tribolium castaneum* following the administration of two different drugs, and was passed to the next generation due to epigenetic regulation. However, pesticides also cause morphological changes in the reproductive system. The botanical azadirachtin causes ovarian atrophy in the bumble bee, with higher concentrations resulting in the absence of oocytes (Bingsohn *et al.*, 2016). Other effects include a crumbled follicular epithelium and vacuolization of the germarium in the ovaries of the assassin bug *R. kumarii* . A shift in the sex ratio towards more male offspring could be shown in various parasitoid wasps. Using in-hive video recordings, reduced feeding visits and feeding durations of nurse bees in response to retarded larval development in clothianidin or thiacloprid-exposed *A. mellifera* colonies could be shown (Delpuech and Meyet, 2003; Siefert *et al.*, 2020). Moreover, in *A. mellifera*, exposure to sublethal doses of clothianidin caused workers to change the composition and production of royal jelly, which did not change the number of encapsulated brood cells but did increase larval mortality. Honey bees, thus, appear to compensate for pesticide-induced brood death by increasing the brood initiation rate. Computer simulations predicted that these compensation mechanisms weaken the colony by inhibiting swarming behavior and reducing long-term survival. In *A. mellifera*, exposure to the neonicotinoids thiamethoxam and clothianidin can also affect the reproductive capacities of males. Although the total number of drones produced by a colony was not altered, the drones delayed flight activities by 3 days, and the number of living sperm was reduced by 28% (Schott *et al.*, 2021; Straub *et al.*, 2021).

7.6.6. Behavioral effects

The awareness that contaminants and other environmental stressors have a significant influence on the behavior of organisms and can therefore also have negative effects on entire ecosystems is growing increasingly with new research findings. However, there are still some gaps in knowledge regarding behavioral ecotoxicology, which then affect the assessment of risks from pesticide use (Ford *et al.*, 2021).

Behaviors determine, among other things, individual fitness by influencing reproductive success, which has consequences for population dynamics, species interactions, and ecosystem function. The complexity of all interactions and processes that can be influenced, and the resulting far-reaching consequences, show the importance of considering this topic, for example when assessing the risk of pesticides (Calatayud-Vernich *et al.*, 2018; Ford *et al.*, 2021).

7.6.7. Feeding behavior

The desired effects of pesticides include the reduction of feeding damage by crop pests, but a similar impact is observed in non-target insects, such as reducing the foraging time, frequency, and efficiency in honey bees and bumble bees. Pesticides can accumulate in all plant tissues and secretions, including pollen and nectar, and pollinators are therefore quickly exposed to the active substances. The rate of honey bee visits to feeding sites decreased significantly in one study when the syrup was treated with fipronil, whereas fipronil and imidacloprid did not affect frequency of visits in another study, but did minimize food intake and feeder activity (Colin *et al.*, 2004; Naumann *et al.*, 1994). Similarly, the oral intake of deltamethrin reduced syrup uptake by honey bees and bumble bees. Thiamethoxam caused bumble bees to engage in longer foraging bouts with less frequent returns to the nest to deliver the pollen. For other pesticides, such as the botanical azadirachtin, no change in the rate of visits to feeding stations was observed. Similarly, no change in foraging activity was observed when bees were exposed to pollen contaminated with the fungicides chlorothalonil and propicanizole or the insecticides chlorypyrifos and fenpropathrin. However, waggle dancing by *A. mellifera* was inhibited by imidacloprid, thus reducing recruitment activity and food procurement (Dechaume-Moncharmont, 2003; Naumann *et al.*, 1994; Traynor and Lamas, 2021). In some predatory carabid species such as *Pterostichus melas* , acute thiamthoxam intoxication also leads to lower food intake (Ivanković Tatalović, 2023). The topical application of fipronil to the thorax of *A. mellifera* made their antennae less sensitive to low concentrations of sucrose, inhibiting their ability to track food sources. Interestingly, exposure to thiamethoxam causes very young worker bees to take over the function of foragers and commence foraging flights, increasing the risk of forager bee loss. Pesticides such as fipronil and acetamiprid also increase the thirst response of honey bees, resulting in the uptake of more water (Coulon *et al.*, 2020). Sublethal pesticides also reduce predation rates by up to 90%. This was observed after exposure of *Serangium japonicum*, a biological agent for the control of *Bemisia tabaci* , to thiamethoxam. However, the predation rate of *S. japonicum* recovered after 24 h of exposure or 24 h after the end of exposure. Larvae of *C. septempunctata* consume fewer aphids on plants treated with deltamethrin, which may reflect avoidance behavior. If the aphids themselves are treated with azadirachtin, a combined repellent and antifeedant effect is observed in ladybirds and lacewings (Ahmad *et al.*, 2003; Fernandes *et al.*, 2016; Yao *et al.*, 2015). In contrast, the 11-spotted ladybird (*Coccinella undepunctata* Linnaeus, 1758) became more predacious following exposure to pirimicarb and pymetrozine, but this was an indirect effect caused by the reduced mobility of prey. On the other hand, permethrin, tebufenozide and thiamethoxam have a direct repellent effect on the predatory bug species *Podisus nigrispinus*. The attack rate of predatory species is often reported to decline in the presence of insecticides, and the prey handling time increases (Cabral *et al.*, 2011; GholamzadehChitgar *et al.*, 2014). The process of catching prey and, for example, the ability of the assassin bug *Acanthaspis pedestri* to paralyze its prey, can also be inhibited. The species *A. pedestri* also showed concentration-dependent random movement and restlessness following treatment with cypermethrin. Likewise, the beetle *Nebria brevicollis* regurgitated 53–80% of aphids

treated with deltamethrin. A change in the feeding rate or the amount of food consumed can also influence food–gene interactions, as previously shown with broccoli and stress-resistance genes in *T. castaneum*. Pesticides ingested with the feed also can influence gene expression, as discussed above (Grünwald *et al.*, 2013; Wiles and Jepson, 1993).

7.7 Conclusions

This chapter reveals that insects face greater diversity decline within a few decades unless farmers adopt new sustainable agricultural strategies. Although other factors such as urbanisation, deforestation, monoculture, and industrialisation may have contributed to the decline in insect species, extensive pesticide usage appears to be the most serious threat. Apparently, protecting threatened species in natural reserves does not guarantee their survival, as indiscriminate pesticide use and agricultural intensification continue to rise. This is due to most farmers' desire to meet the global food demand as the population grows, so they ignore the risks of pesticides' effects on human health and nontarget insects. To mitigate species richness loss, habitat conservation and restoration combined with a significant reduction in agrochemical use in intensive agriculture areas must be prioritised globally. Apparently, excessive application of pesticides does not increase yield and instead contributes to pest resistance, endangers farmer's and consumer's lives, and leads to insects' species decline. Over time, the development of integrated pest management (IPM) in Europe and developing African and Asian countries has increased crop yields. Therefore, developing safety management techniques for residual chemicals in agro-food and agricultural environments, guided by integrated pest and weed management approaches, is the most effective way to increase insect species richness and abundance.

The majority of studies addressing the impact of pesticides on beneficial insects focus on honey bees and other pollinators. The sublethal effect of pesticides on non-target insects depend on factors such as the insect species, age, sex, caste, physiological condition, as well as the type and concentration of the active ingredient(s) and the exposure route. Both positive and negative effects have been observed, although negative effects are more commonly reported. It can also be difficult to reach a precise definition of a sublethal dose. For example, the moment of death in *A. mellifera* is difficult to determine because this would require the measurement of vital signs such as heartbeat, respiration, or neural activity. However, honey bees can recover from a completely immobile and inert state, which according to OECD guidelines is indicative of death. In order to assess the importance of sublethal amounts of pesticides in relation to insect decline, it is important to study the effects of different doses and exposure routes in a broad range of species, and also to study the impact of combinations of different active ingredients.

7.8 Future prospects

Insects cause enormous yield losses globally during agricultural production and storage and can, therefore, be considered as the most important competitors for human nutrition. The food supply security for the growing human population depends on industrial agriculture encompassing the use of pesticides. Lethal concentrations of insecticides trigger the evolution of resistance by strong directional selection. A recent study demonstrates that also transgenerational sublethal exposure to an insecticide can raise resistance in the offspring of the Colorado potato beetle (*Leptinotarsa decemlineata*, Say, 1824) via undesired positive hormetic effects. Our current insights into sublethal effects of pesticides on insects argue for extended and ambitious efforts to reduce the health risk for them and other nontarget organisms. In this context, the EU, for example, plans further restrictions for the approval of novel pesticides. The risk assessment for the latter should be expanded beyond the existing guidelines to encompass innovative methods allowing the detection of harmful influences on complex parameters such as behavior, fecundity, longevity, learning, and memory in insects, particularly in honey bees and other pollinators. However, this results in a dilemma because extended risk assessment and safety hurdles increase the costs for the development of novel pesticides enabling the future control of pest insects that evolved resistance

to those that are currently used. If the costs for the development of new pesticides exceed the expected return on investment, even big agricultural companies will not further invest in chemical plant protection. In order to replace successively chemical pesticides, we need increasing investment in alternative, more sustainable and species-specific control options for pest insects such as those based on RNA interference or biological control agents.

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Chapter 8

Soil Fertility and Organic Farming

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Soil Fertility and Organic Farming

Abstract

Arbuscular mycorrhizal fungi (AMF) play a vital role in supporting soil ecosystem services by promoting plant growth and enhancing soil quality through nutrient cycling and carbon storage. With the increasing focus on sustainable agricultural methods, it is imperative to address soil fertility issues on organic vegetable farms. An evaluation of soil fertility parameters in four different organic farms cultivating outdoor vegetables revealed levels below the recommended standards for organic production. Shortages of essential macronutrients such as nitrogen, phosphorus, and potassium, as well as insufficient total carbon content, indicative of soil organic matter, were identified. Inadequate bacterial biomass for soil organic matter decomposition, nitrogen, and phosphorus circulation were also observed, suggesting a deficiency in the fertility required for optimal organic crop growth in these plots. The diminished soil fertility in these organic farms can be attributed to the recent transition from conventional farming practices, involving the use of synthetic pesticides and chemical fertilizers, to organic cultivation approximately seven years ago. This shift may have had a negative impact on soil microorganisms, resulting in reduced fertility, nutrient availability, and hampering the ability to sustain organic production. The results of this study underscore the significant soil fertility challenges faced by organic vegetable farms, highlighting the necessity for farmers and agricultural practitioners to implement effective soil management strategies to enhance soil fertility, microbial populations, nutrient availability, and overall soil health for successful organic production.

Keywords: Organic farming, soil fertility, microbial diversity, arbuscular mycorrhizal fungi.

8.1. Introduction

Arbuscular mycorrhizal fungi (AMF) are essential components of soil ecosystems that play a crucial role in enhancing plant nutrient absorption, soil structure, and carbon sequestration processes. These fungi establish symbiotic relationships with a vast majority of terrestrial plant species, aiding in the uptake of phosphorus and nitrogen through their hyphal network which is often limited in soil but vital for plant development. AMF also play a key role in soil aggregation, enhancing soil aeration and water retention. Their presence has a significant impact on carbon cycling by increasing carbon allocation to plant roots and biomass (Hoysted *et al.*, 2023; Kakouridis *et al.*, 2024; Martin and van Der Heijden, 2024). Approximately 5–20% of the total carbon uptake by plants is allocated to arbuscular mycorrhizal fungi (AMF), leading to the enhancement of soil organic carbon (SOC) accumulation in the subsoil. The functional significance of AMF in soil health highlights their potential in mitigating the impacts of climate change and promoting agricultural sustainability, particularly in organic farming systems that prioritize biotic interactions over chemical inputs. Several research studies have noted the effects of different agricultural practices on the diversity and abundance of AMF, yet findings have been inconsistent and variable, illustrating the intricate nature of these relationships and the influence of localized environmental factors and management practices. Intensive agricultural activities such as prolonged monoculture, heavy use of fertilizers and pesticides, and extensive tillage generally result in decreased AMF diversity and abundance when compared to less input-intensive or more natural farming systems (Chen *et al.*, 2022b; Guzman *et al.*, 2021; Luo *et al.*, 2023; Peng *et al.*, 2024). In contrast, organic farming practices, which involve minimal use of fertilizers, crop rotation, cover cropping, reduced tillage, and organic amendments, have been found to support higher levels of arbuscular mycorrhizal fungi (AMF) diversity and abundance compared to conventional high-input farming systems. However, empirical evidence regarding the impact of these different farming methods on AMF diversity is varied, underscoring the need for comprehensive studies across various agricultural systems. Investigating

the specific relationships between AMF diversity, abundance, and soil health parameters is essential for optimizing agricultural techniques to maximize ecological benefits. AMF diversity plays a critical role in enhancing soil resilience against adverse environmental conditions like drought and nutrient deficiencies by enabling different species to occupy distinct ecological niches and fulfill specialized functions. Additionally, it promotes stability in nutrient and carbon cycling processes (Higo *et al.*, 2016; Püschel *et al.*, 2023; Shen *et al.*, 2022; Wojciechowski *et al.*, 2023; Zhao and Naeth, 2022). High concentrations of arbuscular mycorrhizal fungi (AMF) have the ability to expand the reach of their hyphal networks beyond the root zones of plants, leading to improved absorption of nutrients and reduced leaching, ultimately increasing the effectiveness of nutrient utilization in the soil. The density of AMF is strongly correlated with higher levels of soil organic matter due to the production of glomalin, a substance that aids in the retention of carbon in the soil. By comparing the colonization of AMF in chili pepper, potato, and maize, it is evident that while these crops all experience similar advantages such as enhanced growth and nutrient absorption, there are notable disparities in the intensity of colonization and response to nitrogen levels, emphasizing the necessity of tailored management approaches for each specific crop type. For example, chili pepper exhibits a high degree of colonization and distinct gene expression patterns related to ammonium transporter genes, distinct from the patterns observed in potato and maize (Fang *et al.*, 2023; Kakouridis *et al.*, 2022; Zhang *et al.*, 2023). Comprehension of these mechanisms will enable the customization of agricultural procedures to suit the precise requirements of soil and crops, such as adjusting phosphorus input levels where arbuscular mycorrhizal fungi effectively mobilize phosphorus or aligning nitrogen availability with peak crop requirements, which could potentially improve yields in specific circumstances without the need for additional fertilizers. A comprehensive strategy is essential for examining the effects of alterations in arbuscular mycorrhizal fungi diversity or population, as affected by agricultural methods, on soil quality and ecosystem services.

8.2. Impact of agricultural practice on the physicochemical characteristics of the soil

The agricultural practice did not have any discernible effect on the physicochemical characteristics of the soil. Physicochemical analyses were carried out on soils where maize, pepper, and potato were cultivated using both conventional and organic farming methods. The findings revealed notable disparities in certain soil characteristics between the two agricultural systems for each crop studied. Nevertheless, when the data from all three crops were consolidated, there were no significant variations in soil parameters between the conventional and organic farming systems. This suggests that although organic and conventional techniques have distinct impacts on soil physicochemistry depending on the crop being grown, these effects may not consistently apply across different types of crops (Walkley and Black, 1934).

8.3. AMF diversity across various crop types

AMF Diversity remains consistent regardless of agricultural practices employed across various crop types. The alpha and beta diversity of arbuscular mycorrhizal fungi (AMF) was assessed in various agricultural settings and crop varieties. Our findings indicated that alpha diversity was notably lower in organic pepper cultivation compared to conventional methods, yet no significant differences were observed in maize, potato, or when all crops were combined. Beta diversity analysis through NMDS revealed no notable variations related to agricultural practices, suggesting that the type of farming practice did not significantly impact the composition of AMF communities. Nonetheless, distinct statistical variances were noted in beta diversity among different crops, although no clear pattern was evident in relation to specific crops based on the NMDS plots. This suggests that although crop type does influence AMF community structures, the specific agricultural method utilized does not have a significant impact on overall AMF diversity (Wright and Upadhyaya, 1998).

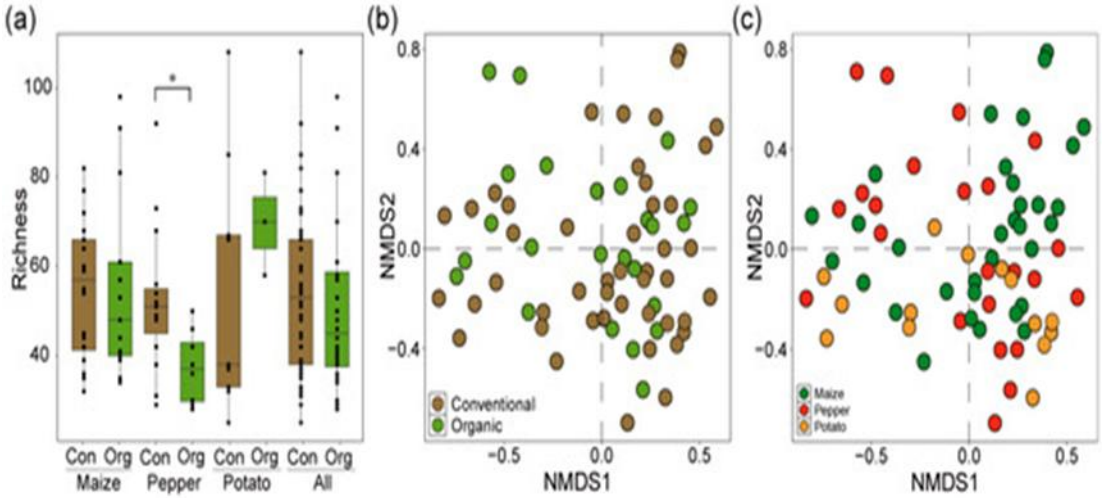

Fig. 8.1. Evaluation of the diversity of arbuscular mycorrhizal fungi (AMF) in traditional and organic farming systems across various crop varieties. (a) Analysis of the richness (alpha diversity) of AMF in corn, bell peppers, and potatoes grown under conventional (Con) and organic (Org) agricultural methods. The presence of an asterisk (*) indicates significant variations between traditional and organic systems. Non-metric multidimensional scaling (NMDS) examination of beta diversity of AMF classified by farming practices (b) and crop categories (c) with a stress value of 0.229 (Park *et al.*, 2024).

8.4. Identification of microbial populations using molecular techniques

Steady levels of microbial populations were identified using molecular techniques in various agricultural techniques applied to different types of crops (Awad *et al.*, 2019; Echevarría, 2019; Fatima *et al.*, 2018; Iqbal *et al.*, 2019; Sandhu *et al.*, 2018; Zaynab *et al.*, 2017). By utilizing quantitative polymerase chain reaction (qPCR), an analysis was conducted on the levels of bacteria (16S rRNA genes), fungi (18S rRNA genes), and arbuscular mycorrhizal fungi (AMF) (18S rRNA genes) in soils that were planted with maize, pepper, and potato using various agricultural methods. The findings revealed no notable variances in the gene copy quantities of the three genes across the different crops or between traditional and organic farming techniques, as displayed in Figure 2. Specifically, the gene copy quantities of 16S ranged from about 5.4×10^8 to 3.3×10^{10} copies per gram of soil, with no substantial distinctions observed among the farming methods (Figure 2a). The copy quantities of fungal 18S genes showed fluctuations from around 1.2×10^8 to 2.1×10^{11} copies per gram of soil across all crops and practices (Figure 2b). In the case of AMF, gene copy quantities remained relatively consistent at approximately 1.2×10^6 to 2.1×10^8 copies per gram of soil regardless of the crop or farming practice (Figure 2c). Overall, these results indicated that the general abundance of AMF, fungi, and bacteria appeared to be similar between traditional and organic practices across various crops. This implies that the type of agricultural practice implemented does not appear to have a significant impact on the microbial abundance within the studied agricultural soil environments (Klindworth *et al.*, 2013).

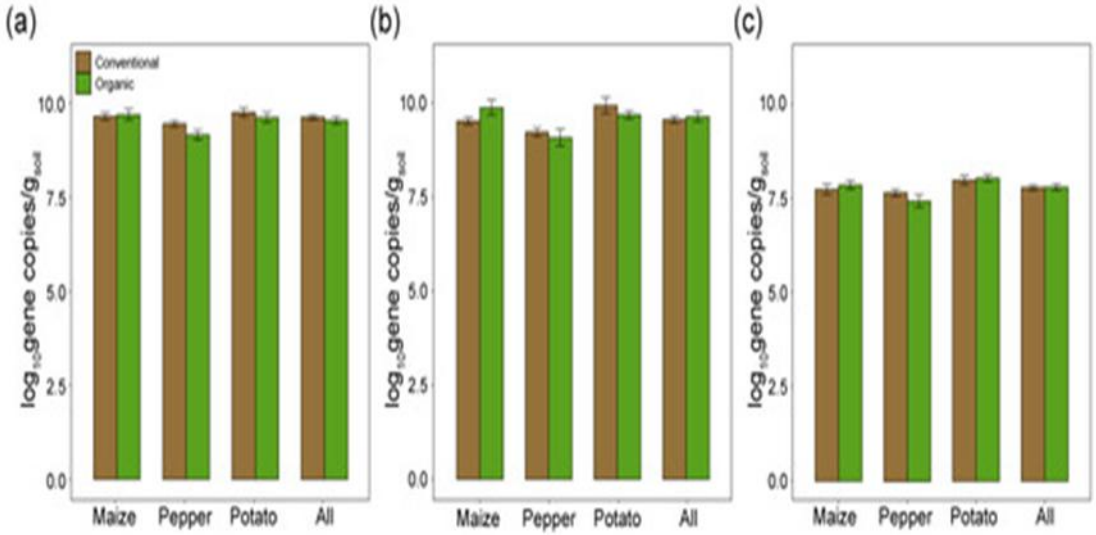

Fig. 8.2. Analysis using quantitative PCR was conducted to measure the microbial abundance in agricultural soils. This study examined the log-transformed gene copy numbers per gram of soil for bacteria, fungi, and arbuscular mycorrhizal fungi (AMF) in both conventional and organic farming systems, across various crops and combined samples. The error bars presented in the figures indicate the standard deviations from the mean values (Park *et al.*, 2024).

8.5. The abundance of arbuscular mycorrhizal fungi (AMF)

The abundance of arbuscular mycorrhizal fungi (AMF) is linked to the levels of soil nutrients and carbon content in the context of organic farming practices. The correlation between the abundance of bacteria, fungi, and AMF with nutrient and soil carbon indices was analyzed across various agricultural practices (Öpik *et al.*, 2010). Our research findings indicate that while the physical and chemical characteristics, as well as the diversity and abundance of arbuscular mycorrhizal fungi (AMF), remain relatively consistent across different crops and agricultural techniques, the impact of AMF on soil health is significantly greater in organically managed fields (Lee *et al.*, 2008).

Our study involving multiple crops found no significant variations in soil physicochemical parameters between conventional and organic farming systems. This indicates that the influence of agricultural methods on soil properties is largely dependent on the specific crop being grown and may not be broadly applicable to diverse cropping systems. The differences observed in individual crop analyses suggest that certain crops may respond uniquely to similar agricultural techniques. For instance, in the case of pepper cultivation, organic practices could potentially boost soil nitrogen levels due to better integration of organic fertilizers and increased microbial activity supporting nitrogen fixation. Conversely, for maize cultivation, the high demand for nutrients may overshadow any slight benefits provided by organic practices, resulting in minimal disparities in soil parameters compared to conventional methods (Mihelič *et al.*, 2024; Yao *et al.*, 2023). Although there was variation in the analysis of each crop, the absence of consistent patterns across all crops suggests that larger environmental and management factors could have an impact on or hide the outcomes of specific agricultural methods. The absence of notable disparities in the alpha and beta diversity of AMF between traditional and organic farming systems is in agreement with prior studies that suggest AMF communities are resilient to different agricultural techniques. While it is commonly believed that organic farming practices promote microbial diversity due to lower chemical usage and higher organic supplements (Shu *et al.*, 2022), our research indicates that the diversity of arbuscular mycorrhizal fungi (AMF) may not be as responsive to changes as originally assumed. Some studies have shown no significant differences in AMF diversity between organic and conventional farming

systems for specific crops. This may be due to various factors such as historical management practices, soil nutrient levels, climate conditions, plant diversity, or crop-specific effects taking precedence over the impacts of different farming systems. The notable decrease in alpha diversity observed in soil cultivated with peppers under organic methods could be the result of crop-specific interactions or localized soil conditions that warrant further investigation. This highlights the significance of considering multiple factors in agricultural practices to effectively manage AMF populations and improve overall soil health (Albracht *et al.*, 2024; Brito *et al.*, 2021; Chen *et al.*, 2022a; Labouyrie *et al.*, 2023).

Our research results illustrate strong positive associations between the abundance of arbuscular mycorrhizal fungi (AMF) and important soil health indicators like phosphorus levels and soil organic carbon (SOC) in the context of organic farming methods. AMF establish mutually beneficial relationships with plant roots, enabling the transfer of vital nutrients necessary for plant growth. For instance, AMF hyphae penetrate the soil to access nutrients like phosphorus and nitrogen beyond the reach of plant roots, thereby enhancing the efficiency of nutrient absorption by plants. This symbiotic association is particularly beneficial in organic agricultural systems where the use of artificial fertilizers is minimized, and plants rely more on natural biological processes for obtaining nutrients. Organic farming techniques such as minimal tillage practices aid in the preservation of AMF networks and prevent disruptions caused by traditional tillage methods that can hinder the colonization of AMF (Hu *et al.*, 2015; Mhlanga *et al.*, 2022; Wang *et al.*, 2023). Furthermore, organic farms steer clear of utilizing fungicides and pesticides that may harm arbuscular mycorrhizal fungi (AMF) and keep soil phosphorus levels at a minimum, thus prompting plants to rely on AMF for nutrient absorption. The promotion of a wider variety of crops and the utilization of organic supplements in organic agriculture lead to the development of more robust and diverse AMF populations, as opposed to traditional farming methods that typically rely on modern crop varieties which are not as conducive to AMF symbiosis. These strategies employed in organic farming serve to enhance the importance of AMF, enabling them to flourish and make a substantial contribution to the sustainability of agricultural ecosystems (Hu *et al.*, 2015; Jakobsen *et al.*, 2021; Lu *et al.*, 2023; Qi *et al.*, 2022; van't Padje *et al.*, 2021).

The similarities in bacterial and AMF abundance patterns observed, particularly concerning SOC and P_2O_5, indicate a synergistic interaction in organically managed systems that significantly impact soil nutrient dynamics. Both bacteria and AMF play essential roles in the biogeochemical processes that regulate nutrient availability and cycling in the soil. Bacteria contribute to organic matter decomposition, nitrogen fixation, and phosphate solubilization, while AMF primarily improve phosphorus uptake and other micronutrients through extensive hyphal networks that increase root surface area in contact with the soil. Additionally, the slightly higher ratio of AMF to bacteria in organic farming implies a subtle change in microbial community dynamics where AMF may have a greater influence in these systems compared to traditional practices. This shift could suggest a soil environment in organic systems that promote AMF growth or activity, potentially due to higher organic matter levels that AMF can effectively utilize. Such a shift is significant as it can enhance crop access to soil nutrients that are less mobile and more difficult to obtain, such as phosphorus, through the symbiotic relationships that AMF establish with plant roots (Cao *et al.*, 2022; Duan *et al.*, 2023). These interconnected factors underscore the intricate nature of microbial interactions in soil and the potential benefits of organic farming methods in utilizing these interactions for sustainable agriculture. Organic practices have the potential to improve the efficiency of nutrient uptake in plants by promoting a higher ratio of arbuscular mycorrhizal fungi (AMF) to bacteria, which can lead to improvements in soil health and sustainable yield. While this study offers valuable insights into the connections between agricultural practices, AMF diversity, and soil health, it is not without limitations. The findings of the study align with previous research on the resilience of AMF diversity in response to conventional and organic practices. However, further investigation is needed to fully understand the intricate interactions between AMF and different agricultural inputs, especially considering varying climates, past land management practices, and soil conditions. The study did not analyze the diversity and structure of bacterial communities, nor did it consider their

beta diversity, which hinders our comprehension of the complete microbial dynamics and interactions in soil. Inclusion of analyses on bacterial diversity and structure in future research could offer a more comprehensive understanding of the microbial ecosystem and its response to agricultural practices. Future studies should focus on long-term research incorporating a wider range of environmental variables and detailed tracking of microbial changes over time to better understand the lasting effects of different farming practices on AMF communities and their roles in ecosystem services. Additionally, expanding the scope of research to include a greater variety of crop systems and utilizing advanced molecular techniques could enhance our understanding of the specific mechanisms by which AMF contribute to soil health and plant productivity under different agricultural systems.

8.6. Soil fertility and cultivation of organic vegetables

In recent years, there has been an increasing recognition of the adverse impacts that traditional farming methods have on the environment, human health, and biodiversity. In response to these challenges, sustainable organic agriculture has emerged as a holistic and restorative approach to food production. The practice of organic agriculture has been in existence in the Philippines since the 1980s, with only nine organic farms covering 95 acres in 1999. However, significant progress was made in 2005 when organic agriculture was incorporated into the country's policy through Executive Order 481, titled "Promotion and Development of Organic Agriculture in the Philippines." The Philippine government further advanced its efforts in 2010 with the enactment of the Organic Agriculture Act, or Republic Act 10068. This legislation aimed to foster the growth and advancement of the country's organic farming sector by establishing an organic certification program and offering farmers technical assistance and financial resources to promote the widespread adoption of organic practices (Carating and Tejada, 2012; Maohong, 2018).

Organic farming in the Philippines has gained traction due to the increasing awareness among consumers regarding health and environmental issues. Research conducted in various provinces has shown that organic farms exhibit significant improvements in soil properties compared to non-organic counterparts. For example, in Benguet Province, organic farms had higher levels of soil organic matter, total nitrogen, and available phosphorus than non-organic farms. Similarly, in Laguna Province, organic vegetable farms displayed greater levels of soil organic matter, total nitrogen, and available phosphorus. Furthermore, studies in Nueva Ecija Province indicated that organic rice farms had higher levels of soil organic matter, microbial biomass, and microbial diversity than non-organic farms (Kai *et al.*, 2024).

Recent developments in soil health assessment technologies have highlighted the advantages of organic farming. A research study utilizing the Soil Fertility Index (SOFIX) methodology demonstrated significant improvements in key soil health indicators at various organic farms in Japan. The results showed significant increases in total carbon content, bacterial biomass, nitrogen cycling activity, and phosphorus cycling activity. These metrics are signs of enhanced soil fertility, increased microbial activity, and better nutrient cycling, all of which contribute to the long-term sustainability of agricultural productivity. The SOFIX methodology offers a systematic and quantitative approach to evaluating soil health, providing practical insights for farmers to improve their practices. By adapting organic farming techniques to suit the specific characteristics of their soil and environment, farmers can maximize productivity while preserving ecological equilibrium. This approach emphasizes the potential benefits of integrating advanced soil assessment tools with organic farming methods to establish sustainable and resilient agricultural systems. A study illustrated the significant impact of organic farming on enhancing soil microbial communities. Their study revealed that organic farms exhibited greater diversity and abundance of beneficial soil microorganisms, which are crucial for nutrient cycling and pest control (Kai and Kubo, 2020). Organic farming practices boost the activity of nitrogen-fixing bacteria and phosphate-solubilizing

microbes, resulting in improved soil fertility and plant growth (Kai and Adhikari, 2021). These findings underscore the mutually beneficial relationship between organic farming techniques and soil microbial health, highlighting the potential for long-term agricultural sustainability (Kai and Adhikari, 2021; Kai and Kubo, 2020).

8.7. Examination of the physical and chemical characteristics of soil

The examination of soil physical and chemical characteristics indicates that some factors, such as nitrate nitrogen, soluble phosphate, exchangeable potassium, and volumetric moisture content, meet the suggested criteria. However, the levels of essential macronutrients-total carbon (TC), nitrogen (TN), phosphorus (TP), and potassium (TK)-are below optimal for organically maintained soils. Particularly, the TC and TN levels were notably deficient compared to the recommended standards, indicating that there may be inadequate organic matter inputs or sluggish decomposition rates, potentially constraining microbial processes and nutrient access (Kubo *et al.*, 2017; Pholkaw *et al.*, 2020).

The findings from the nitrogen and phosphorus circulation study indicate a moderate level of microbial activity in the soil, with no significant variations observed among the crops tested. This suggests that while the nutrient cycling processes are operational, they may not be functioning at their full potential. Similar conclusions have been drawn by researchers who have observed that limited nutrient availability can inhibit microbial effectiveness, especially in organic systems where nutrient cycling relies heavily on microbial activity. Although the carbon-to-nitrogen (C/N) ratios generally fall within the recommended range, the low levels of total carbon (TC) and total nitrogen (TN) suggest that the organic material present may not be sufficient to sustain thriving microbial communities essential for effective nutrient cycling and soil quality (Lal, 2015; Mäder *et al.*, 2002).

These results underscore the necessity for further refinement of organic amendments and crop rotation methods to optimize nutrient cycling and enhance soil fertility. Previous research has underscored those organic farming systems, particularly those in the transitional phase, often encounter obstacles related to nutrient deficiencies as a result of decreased reliance on synthetic fertilizers. The relatively recent shift from conventional to organic farming practices in the study area may have led to the identified deficiencies in soil fertility. Increased organic material inputs, such as compost and green manure, are widely acknowledged as crucial tactics for enhancing nutrient availability and microbial activity in organic systems. Additionally, crop rotation techniques can assist in preserving soil fertility by averting nutrient exhaustion and bolstering a variety of microbial communities (Drinkwater *et al.*, 1998; Seufert *et al.*, 2012).

The findings of this study are consistent with prior research indicating the significance of soil management techniques, such as incorporating well-decomposed organic matter and implementing crop rotation, in enhancing soil quality and fostering sustainable agricultural methods. Subsequent studies should examine the enduring impact of these measures on soil health and crop productivity, paying particular attention to the resilience of organic farming systems in different environmental and management scenarios (Altieri, 2002).

8.8. Examination of soil biological processes and nutrient transformation

The examination of soil biological properties indicates significant constraints in microbial activity and nutrient cycling within the soils under study. The total bacterial biomass, a crucial factor for assessing soil microbial health, was found to be below the recommended level at the majority of sites. This deficiency suggests that microbial populations in these soils may not be functioning optimally, potentially impeding the soil's ability to effectively decompose organic matter and cycle nutrients. The inability to reach the recommended bacterial biomass levels at 10 out of the 12 sites

highlights a scarcity of microbial populations necessary for sustaining soil fertility in organic farming practices (Lal, 2015).

The values of nitrogen cycling activity identified in this study indicate deficiencies in nitrogen transformation processes. Out of 12 sites evaluated, 9 have values that fall below the recommended threshold, indicating that these soils may struggle to convert organic nitrogen into forms that are easily accessible to plants. This limitation could potentially impede plant growth and nutrient uptake. Research findings in the past have also demonstrated that the efficiency of nitrogen cycling in organic soils can be compromised by inadequate microbial activity, resulting in slower nutrient turnover and diminished nitrogen availability for crops (Lal, 2015; Mäder *et al.*, 2002). Phosphorus cycling, a vital process for facilitating the availability of phosphorus to plants, was found to be below optimal levels at certain locations. The recorded range of 3 to 26 points indicates that the release of phosphorus from organic matter is not at its peak in these soils, potentially hindering plants' ability to acquire this necessary nutrient. Reports have indicated deficiencies in phosphorus supply within organic farming systems, particularly in soils with limited microbial activity and inadequate inputs of organic matter. In order to remedy these shortcomings, customized strategies for soil management are imperative. The inclusion of higher amounts of organic materials like compost and green manure has the potential to bolster microbial communities and enhance the effectiveness of nutrient cycling. Furthermore, incorporating cover crops into the soil management plan can enhance microbial diversity and promote efficient nutrient cycling by offering organic material and fostering favorable soil environments. By making adjustments to soil pH and moisture levels, it is possible to create optimal conditions for microbial activity, thereby improving the processes of nutrient transformation (Altieri, 2002; Drinkwater *et al.*, 1998). In summary, the results of this research emphasize the importance of implementing specific soil management strategies to counteract the constraints on microbial activity and nutrient cycling. Enhancing soil microbial well-being through the use of organic amendments and various management techniques has the potential to increase nutrient availability and overall soil fertility, thus promoting more effective and enduring organic farming practices.

8.9. Relationship between total Carbon and total Nitrogen

The positive correlation noted between total carbon (TC) and total nitrogen (TN) in the soil samples of organic plots in the Philippines ($R2 = 0.76$) indicates that the organic inputs used, such as manure and unfermented organic materials, have a consistent carbon-to-nitrogen ratio. This discovery coincides with previous research that has documented similar ratios in organic farming systems, where organic materials are commonly utilized to improve soil fertility. The strong association between TC and TN in this investigation reflects the dedication of farmers to integrating organic inputs into the soil, a common practice in organic farming methods. Nevertheless, the relatively low levels of TC and TN in the soils, in comparison to recommended thresholds for optimal nutrient cycling efficiency, imply that these practices may not be adequate for fully restoring soil nutrients in the near term (Gomiero *et al.*, 2011). The decreased fertility observed in the organic plots in the Philippines is likely due to the recent shift from traditional farming methods, which involved the application of synthetic pesticides and chemical fertilizers. This transition took place around seven years before the study, potentially leading to a decrease in organic matter content and a reduction in microbial activity as the soil's biological and chemical characteristics were likely altered by the previous use of chemical inputs. Research indicates that soils transitioning from conventional to organic farming frequently display lower levels of nutrients and microbial biomass in the initial stages due to the lack of synthetic fertilizers and the time necessary for organic matter to build up and break down (Altieri, 2002; Drinkwater *et al.*, 1998; Gomiero *et al.*, 2011; Reganold *et al.*, 2001). The findings indicate that although the organic amendments employed in the research are in line with standard organic farming methods, there may be a need for further refinement of these inputs to achieve the necessary nutrient levels for sustainable productivity. Including more

organic material like compost and incorporating green manure crops could potentially boost the levels of total carbon and total nitrogen in the soil, leading to improved efficiency in nutrient cycling and microbial activity. Additionally, enhancing soil management techniques such as crop rotation and cover cropping could potentially enhance the overall fertility of the soil in the long term by increasing the availability of vital nutrients and supporting a more varied microbial population (Lal, 2015).

Ultimately, the direct relationship between total carbon and total nitrogen suggests that organic supplements are being utilized in accordance with organic agriculture standards. However, the inadequate nutrient levels that have been observed emphasize the necessity for enhanced strategies in soil management. Achieving sustainable enhancements in soil fertility will necessitate a more holistic approach, which involves incorporating supplementary organic materials, refining cultivation methods, and continually assessing soil condition. The connection between TC and TP is apparent in the organic plots, with a positive correlation coefficient of 0.18. It indicates a relationship between these two elements, although it is relatively weak in comparison to the stronger correlation seen between TC and TN. This discovery is consistent with prior research that has noted weaker associations between carbon and phosphorus, as opposed to carbon and nitrogen, especially in soils where phosphorus availability is affected by various factors beyond just microbial processes (Frossard *et al.*, 1995). In contrast to the nitrogen cycle, which is intricately connected to carbon through microbial interactions such as mineralization and immobilization, the availability of phosphorus in soil is more intricate. This complexity is dictated by various factors including mineral adsorption, chemical precipitation, and microbial immobilization. These processes have the potential to restrict phosphorus availability for plant uptake, potentially elucidating the weaker correlation identified in the present study. Specifically, phosphorus within soils is frequently bound to minerals such as iron, aluminum, or calcium, leading to a decrease in its bioavailability. Additionally, the decomposition rates of organic materials, which contribute to both carbon and phosphorus inputs, can exhibit considerable variation, thus resulting in increased variability in the C/P ratios across different field soils (Sharpley *et al.*, 1994). The results emphasize the necessity for precise soil management techniques to maximize phosphorus availability within organic farming systems. Utilizing methods such as applying phosphorus-rich organic amendments like bone meal or composted manure could enhance phosphorus cycling in soils with limited phosphorus availability. Furthermore, altering soil pH to boost phosphorus solubility and implementing crop rotation practices to enhance microbial diversity may aid in improving phosphorus cycling efficiency (Bünemann *et al.*, 2010; Ducousso-Détrez *et al.*, 2022). Additional investigation is required to explore the precise mechanisms that regulate phosphorus dynamics in these soil types. By pinpointing the essential factors that dictate phosphorus availability, such as mineral associations and microbial activity, valuable understanding can be gained on how phosphorus cycling can be improved in organic agricultural systems, thus harmonizing phosphorus inputs with carbon management strategies.

8.10. Analysis of bacterial biomass in relation to total Carbon

The relationship observed between total Carbon (TC) and bacterial biomass in upland soils in the Philippines displays a marked disparity compared to similar soils in Japan. The average TC content (14,891 mg kg^{-1}) and bacterial biomass (4.6×10^8 cells g^{-1}) in the Philippine soils were roughly 40% and 58% of the corresponding figures in Japan, respectively. This difference can be attributed to the relatively recent shift (approximately seven years ago) from conventional to organic farming practices in the research area. Previous research indicates that organic farming systems, particularly during the transition phase from conventional methods, typically demonstrate lower levels of soil organic matter (SOM) and microbial biomass in the initial stages due to decreased reliance on synthetic fertilizers and pesticides (Kai *et al.*, 2020). In the organic plots of the Philippines, the bacterial biomass observed corresponds to the anticipated levels for areas that have recently shifted

to organic practices. The decreased levels of total carbon align with the diminished inputs of organic matter commonly linked to the initial phases of organic agriculture. This discovery upholds the idea that the length of time organic practices have been in place has a notable impact on soil microbial communities, with organic systems that have been established for longer periods displaying enhanced microbial biomass and efficiency in nutrient cycling (Kai *et al.*, 2020; Lori *et al.*, 2017). Significant variations were not detected in total carbon, total nitrogen, total phosphorus, bacterial biomass, or nutrient cycling activities for tomato, eggplant, and lettuce across different cropping zones. This uniformity in soil properties and microbial activity indicates that the management practices employed have a greater impact than the specific crops being cultivated. The consistent use of organic amendments and crop rotation techniques likely played a role in maintaining this consistency, highlighting the significance of comprehensive soil management in organic agricultural systems (Durrer *et al.*, 2021).

These results underscore the importance of implementing continuous soil management techniques to improve microbial biomass and nutrient cycling, especially in soils that have been previously utilized for conventional farming practices. Utilizing organic additives, such as compost and green manure, along with adjustments to soil pH and moisture levels, can facilitate the restoration of microbial populations and enhance nutrient cycling processes. Additional research is necessary to investigate the sustained impacts of organic farming practices on soil microbial communities and nutrient dynamics, especially within farming systems transitioning from conventional methods to organic approaches.

8.11. Conclusions

Our research offers a thorough understanding of arbuscular mycorrhizal fungi (AMF) dynamics in both conventional and organic farming systems, shedding light on their crucial roles in nutrient cycling and storage of soil carbon. Particularly, organically managed fields exhibit notable advantages in terms of AMF activity, which is closely linked to improved soil nutrient levels and increased carbon storage. This distinction in AMF impact between farming systems underscores the need for the development of agricultural practices that promote and capitalize on the ecological functions of AMF, especially in organic systems where they play a vital role in achieving sustainability and boosting soil function. The findings of this study underscore the advantages of organic farming in enhancing soil fertility and carbon storage, offering valuable insights for the design of sustainable agricultural approaches. Subsequent research should focus on unraveling these intricate interactions over extended periods and in various environmental conditions, utilizing advanced molecular techniques to enhance our comprehension of how to tailor sustainable farming techniques for maximum ecological benefits and crop productivity. Forthcoming agricultural management strategies should prioritize the nurturing of AMF and other beneficial soil microbes to effectively sustain ecosystem services and enhance crop yields. These limitations are likely due to the recent shift from conventional farming, which historically relied on synthetic fertilizers and pesticides, to organic farming methods. To overcome these constraints in soil fertility and foster a more sustainable organic agricultural system, the implementation of targeted soil management practices is crucial. Important strategies include applying well-composted organic materials to restore soil organic matter, incorporating diverse crop rotations to improve nutrient cycling, and utilizing green manures to enhance soil structure and fertility. Moreover, regular monitoring of soil biological, chemical, and physical parameters through sophisticated analytical techniques can provide actionable information for optimizing soil management practices. By adopting these measures, organic vegetable farms can surmount existing challenges, improve soil health, and achieve more effective and sustainable production. These endeavors not only bolster the resilience of organic farming systems but also contribute to global efforts aimed at promoting environmentally sustainable and economically viable agriculture.

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Chapter 9

Organic Agriculture in the Twenty-first Century

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Organic Agriculture in the Twenty-first Century

Abstract

Although some may view organic agriculture as an inefficient method of food production with a history of controversy, organic foods and beverages are experiencing substantial growth in the global food industry. In this analysis, we evaluate the effectiveness of organic farming through the lens of four key sustainability indicators: productivity, environmental impact, economic viability, and social wellbeing. While organic farming typically yields lower crop output compared to conventional agriculture, it proves to be more profitable and environmentally sustainable. Additionally, organic products offer equally, if not more, nutritious content with minimal to no pesticide residues in comparison to conventionally grown produce. Furthermore, preliminary data suggests that organic farming systems provide enhanced ecosystem services and social advantages. Despite the potential for organic agriculture to contribute to the establishment of sustainable farming practices, it is acknowledged that a combination of organic and other innovative farming techniques is necessary to adequately address global food demands. Nevertheless, there are significant obstacles hindering the widespread adoption of these systems, necessitating a range of policy measures to facilitate their advancement and integration into mainstream agriculture.

Keywords: Organic, agriculture, twenty-first, century.

9.1. Introduction

Organic farming has been a topic of debate and is sometimes viewed as an inefficient method of food production. Despite this, the market for organic foods and beverages is experiencing rapid growth within the global food industry. This analysis focuses on the sustainability of organic farming by considering four main metrics: productivity, environmental impact, economic feasibility, and social welfare. Organic farming typically yields lower crop outputs in comparison to conventional agriculture. However, it has been found to be more profitable and environmentally sustainable, while also providing equally or more nutritious food products with reduced pesticide residues compared to conventional farming practices. Additionally, initial findings suggest that organic farming systems offer enhanced ecosystem services and social advantages. While organic agriculture presents an opportunity for creating sustainable farming practices, it is important to acknowledge that a combination of organic and innovative farming systems will be necessary to address global food security. Despite the potential benefits, barriers exist that hinder the widespread adoption of these systems, requiring a variety of policy tools to support their development and implementation. Organic agriculture has a controversial past, exemplified by the prevailing sentiments of farmers and researchers in the 1970s and 1980s. One indicative comment from that era was made by US Secretary of Agriculture Earl Butz in 1971, who infamously stated, "Before we revert to organic farming practices in the United States, a decision must be made on which 50 million Americans we are willing to allow suffering from starvation or hunger (Lockeretz, 2007). Some skeptics in the early 2000s viewed organic agriculture as driven by ideology and inefficient. They contended that organic farming requires more land to yield the same amount of food as conventional methods, potentially endangering natural habitats like forests, wetlands, and grasslands if implemented on a large scale. Critics also pointed out various shortcomings and inadequate solutions within organic agriculture. As a result, organic farming was perceived by some as an inefficient means of ensuring food security and a farming system that may lose relevance in the future (Emsley, 2001; Kirchmann and Thorvaldsson, 2000; Trewavas, 2001). However, there has been a consistent increase in the quantity of organic farms, the size of land dedicated to organic farming, the financial resources allocated to research on organic agriculture, and the market demand for organic products. The sales of organic food and drinks have experienced a rapid surge,

nearly quadrupling from 1999 to 2013, reaching a total of $72 billion (Figure 1); it is forecasted that this amount will double by 2018. Furthermore, recent global reports have acknowledged organic farming as a forward-thinking agricultural method that effectively addresses various sustainability objectives, playing a significant role in ensuring food security and ecological stability on a worldwide scale (Connor and Mínguez, 2012; McIntyre *et al.*, 2009; Pickett, 2013; Willer *et al.*, 2024).

Fig. 9.1. Annual global market for organic foods and land area of organic production (Reganold and Wachter, 2016).

In the nominal billions of US dollars, the sales of organic food have been on the rise, with contributions coming from North America, Europe, and the rest of the world. Additionally, there has been an increase in the total global land area dedicated to organic production, as illustrated by the blue line on the graph. Unfortunately, data on European and North American contributions was not available for the years 1998 to 2000, as indicated by the grey shading. In this analysis, we assess the effectiveness of organic farming systems through the lens of sustainability metrics and global challenges. We also delve into the obstacles hindering the adoption of organic farming systems and the necessary policy measures to address these challenges.

9.2. Organic practices and certification

Organic agriculture, also known as biological or ecological agriculture, integrates traditional conservation-focused farming practices with contemporary farming methods. It highlights the importance of crop rotation, natural pest management, crop and livestock diversity, and enhancing soil quality through the use of compost and organic matter. Organic farmers utilize modern machinery, advanced crop varieties, sustainable soil and water conservation techniques, and the latest advancements in livestock care and feeding. The spectrum of organic farming systems varies from stringent closed-loop systems that exceed organic certification requirements by minimizing external inputs to conventional systems that adhere to organic certification standards.

1. It is essential to maintain proper communication within a team to achieve success in any project.

2. Effective communication ensures that team members are aligned with the project's goals and objectives.

3. Clear and concise communication is key to avoiding misunderstandings that can lead to errors and delays in project completion.

4. It is important for team members to actively listen to each other and provide constructive feedback to foster collaboration and problem-solving.

5. Open communication channels within a team promote transparency and trust among members.

6. Team leaders play a critical role in facilitating communication by setting clear expectations and ensuring that information is shared timely and accurately.

7. Encouraging an environment where team members feel comfortable expressing their thoughts and ideas can lead to innovative solutions and improved performance.

8. Effective communication also involves understanding the different communication styles and preferences of team members to ensure messages are received and interpreted correctly.

9. Providing regular updates and progress reports to team members helps keep everyone informed and accountable for their respective tasks.

10. Utilizing various communication tools such as email, instant messaging, and video conferencing can enhance the efficiency and effectiveness of team communication.

11. It is important for team members to be attentive and responsive to communication from their colleagues to maintain a productive workflow.

12. Encouraging a culture of open and honest communication can help resolve conflicts and address issues before they escalate.

13. Effective communication enables team members to share knowledge and expertise, leading to continuous learning and improvement.

14. Team members should always strive to communicate with clarity and professionalism, regardless of the medium or platform used.

15. Poor communication within a team can result in misunderstandings, decreased morale, and ultimately hinder the project's success.

16. Building strong communication skills within a team can enhance collaboration, decision-making, and overall performance.

17. Feedback and communication should be a two-way process, with team members actively seeking input and providing insights to improve processes and outcomes.

18. Establishing a communication plan at the beginning of a project can help ensure that all team members are on the same page and working towards a common goal.

19. Team members should be encouraged to ask questions, seek clarification, and actively participate in discussions to promote a culture of effective communication.

20. In conclusion, effective communication is the cornerstone of successful teamwork and project management, fostering collaboration, innovation, and overall project success.

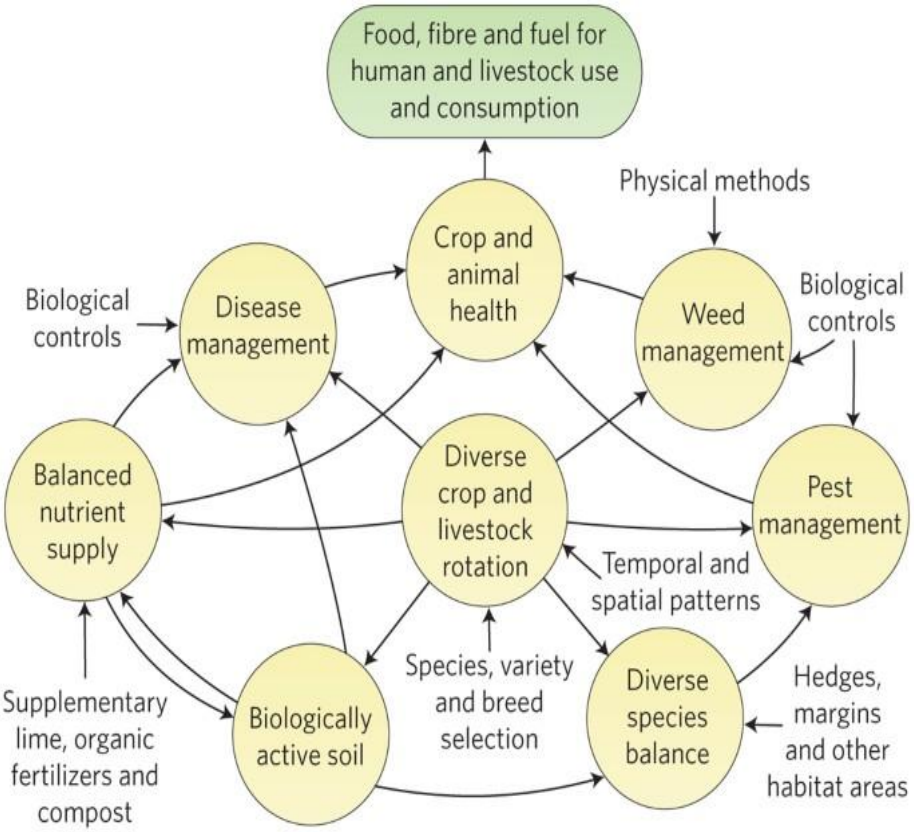

Fig. 9.2. Organic management practices (Reganold and Wachter, 2016).

Numerous farms in both developed and developing nations practice organic methods without official certification. However, there is a growing trend among farmers to adopt certified organic farming practices in order to validate their production methods, reduce dependence on non-renewable resources, access high-value markets and premium prices, and increase farm revenue. While the specific requirements for certification can vary among different certifying bodies, they typically emphasize the importance of maintaining soil health, implementing crop rotations, encouraging biodiversity among animals and plants, supporting biological processes, and ensuring the welfare of animals, while generally prohibiting practices such as irradiation, the use of sewage sludge, genetic modification, the prophylactic use of antibiotics, and the use of synthetic pesticides and fertilizers. These standards are continuously being updated to reflect advancements in technology and changes in socioecological conditions, with some requirements being based on scientific evidence and others influenced by philosophical beliefs. Due to the origins of most certification standards in affluent temperate countries, they may not always be suitable for application in other regions, particularly in developing nations. The strong demand for organic products in Europe and North America has led to the importation of organic goods from large farms in developing countries. While the premium prices received for such exports can benefit farmers, the limited access to these products for local consumers raises concerns regarding food security and social equity. Participatory guarantee systems, which rely on verification from local stakeholders, have emerged as a more regionally-focused alternative to traditional certification processes, potentially leading to the development of locally pertinent strategies for the production and consumption of organic products (De Schutter, 2008).

9.3. Sustainability of organic agriculture

Approximately 38% of the Earth's total land area is utilized for agricultural purposes. Despite its essential role in providing food and various commodities, agriculture is a significant contributor to

the emission of greenhouse gases, loss of biodiversity, contamination from agrochemicals, and degradation of soil quality. The majority of these adverse environmental impacts can be attributed to arable land, which accounts for approximately 12% of the Earth's land cover. The task of ensuring an adequate food supply for a projected global population of 9 to 10 billion people by the year 2050, while also safeguarding the environment, presents a formidable challenge. Embracing truly sustainable agricultural practices on a broad scale represents our most promising strategy for addressing this monumental challenge and securing the future of food production and ecosystem health. Growing concerns regarding the sustainability of conventional farming methods have fueled interest in alternative agricultural systems, such as organic farming, integrated farming, and conservation agriculture (Council *et al.*, 2010; Godfray *et al.*, 2010; Rockström *et al.*, 2009). Based on a report from the US National Academy of Sciences, the sustainability of a farm, whether organic or conventional, is contingent upon its ability to generate sufficient quantities of nutritious food, improve natural resources and the environment, maintain financial success, and promote the welfare of farmers and their communities. Over the last twenty years, organic farming has seen a significant increase in popularity, resulting in numerous research studies that examine various aspects of organic and conventional farming methods. The following section is dedicated to evaluating these comparative studies in relation to the four sustainability criteria mentioned above (De Schutter, 2008).

9.3.1. Production

Production involves the output of crops and animals as well as the quality of these products. Several individual research studies have examined the differences in yield between organic and conventional farming systems. The findings of these studies have been consolidated in meta-analyses or reviews, which suggest that organic systems typically yield 8 to 25% less than conventional systems. However, under specific growing conditions and management practices, organic systems can achieve yields that are comparable to conventional systems. According to a synthesis study, the highest yielding organic crops or crop groups include rice, soybeans, corn, and grass-clover, which yield only 6 to 11% less than conventional systems. On the other hand, fruits and wheat are among the lowest yielding organic products, with yields that are 28 and 27% lower than conventional systems, respectively (Amundson *et al.*, 2015; Badgley *et al.*, 2007; De Ponti *et al.*, 2012; Seufert *et al.*, 2012; Stanhill, 1990).

Another comprehensive analysis revealed that organic fruits, soybeans, and oilseed crops had the highest yields, while wheat and vegetables had the lowest, producing 37% and 33% less than conventional farming methods respectively. It was also noted that when organic crop rotations rely on green manure crops, overall food production throughout the rotation may be lower than suggested by yield comparisons alone. While meta-analysis is a valuable tool for identifying overarching trends that may not be immediately evident in individual field studies, it should be approached with caution as there is no one-size-fits-all farming system or practice. Nonetheless, these findings support the argument that the adoption of organic agriculture in agro ecological conditions where it thrives could help bridge the yield gap between organic and conventional farming. Furthermore, in regions experiencing more frequent and severe droughts due to climate change, organically managed farms have demonstrated a tendency to produce higher yields compared to conventional farms, which can be attributed to the superior water-holding capacity of organically managed soils (Crowder and Reganold, 2015; Lockeretz *et al.*, 1981; Lotter *et al.*, 2003; Ponisio *et al.*, 2015).

Improvements in management techniques and crop varieties for organic systems have the potential to narrow the yield gap. For instance, selecting wheat cultivars directly in organic systems has led to increased yields compared to selecting cultivars indirectly in conventional systems. Despite organic systems typically producing lower yields, organic foods contain significantly lower levels or no synthetic pesticide residues in comparison to conventionally produced foods. Research has shown that children consuming conventionally produced foods tend to have higher levels of

organophosphate pesticide metabolites in their urine when compared to children who consume organic foods. In 2012, the American Academy of Pediatrics highlighted the benefits of an organic diet in reducing children's exposure to pesticides and offered guidance for parents on choosing foods with minimal pesticide residues. While organic foods may provide advantages concerning synthetic pesticide residues, the health impacts of pesticide exposure through food consumption remain unclear. It is essential to improve the identification and consideration of organically certified pesticides in order to properly assess their impact on human health (Baker *et al.*, 2002; Barański *et al.*, 2014; Curl *et al.*, 2003; Foods, 2012; Lu *et al.*, 2005; Murphy *et al.*, 2007; Pussemier *et al.*, 2006; Siegrist *et al.*, 1998).

There have been several reviews or meta-analyses conducted on the scientific literature that compare the nutritional content of organic and conventional foods. Out of these studies, twelve have indicated that organic food may have higher nutritional value. The significance of these potential nutritional advantages is still a topic of ongoing debate (Brandt *et al.*, 2011; Dangour *et al.*, 2009; Forman *et al.*, 2012; Rembiałkowska, 2007). The remaining three studies all reached the same conclusion regarding the lack of consistent nutritional disparities between organic and conventional foods. Nevertheless, amongst these three studies, one in particular observed a notable finding: conventional chicken and pork products were determined to have a 33% higher chance of being contaminated with antibiotic-resistant bacteria when compared to their organic counterparts (Benbrook *et al.*, 2008).

9.3.2. Environment

Research and systematic analysis typically affirm the notion that organic farming practices are more ecologically sustainable in comparison to conventional methods. These comprehensive studies indicate that organic farming consistently results in higher levels of soil carbon, improved soil quality, and reduced soil erosion when contrasted with conventional approaches. Furthermore, organic farms are known to exhibit greater biodiversity in terms of plant species, various fauna (such as insects, soil organisms, and birds), and diverse habitats and landscapes. Various functional groups, including herbivores, pollinators, predators, and plant producers, tend to display higher levels of diversity within organic farming systems. A study encompassing multiple European countries revealed that insecticides and fungicides often have detrimental impacts on biodiversity, with insecticides specifically diminishing the potential for biological pest control in agricultural systems (Crowder *et al.*, 2010; Lynch *et al.*, 2012; Tuck *et al.*, 2014). Organic agriculture, due to its minimal use of synthetic pesticides, poses a significantly reduced risk of synthetic pesticide contamination in ground and surface waters. In terms of nitrate and phosphorus leaching and greenhouse gas emissions, organic farming systems demonstrate superior performance compared to conventional farming on a per unit production area basis. However, due to the lower land-use efficiency of organic farming in developed nations, this favorable impact is less pronounced and sometimes even reversed on a per unit product basis. A comprehensive meta-analysis of environmental quality indicators reveals that organic farms exhibit lower levels of nitrate leaching, nitrous oxide emissions, and ammonia emissions per unit field area, but higher levels of leaching and emissions per unit product (Geiger *et al.*, 2010; Skinner *et al.*, 2014). Excessive application of nitrogen and phosphorus fertilizers has been associated with significant deterioration of freshwater and marine ecosystems globally, resulting in eutrophication of freshwater bodies and the formation of hypoxic areas in coastal waters (Lee *et al.*, 2015).

Organic systems are typically more energy-efficient than conventional ones. In countries such as Germany, Italy, Sweden, and Switzerland, studies have shown that organic farms utilize significantly less energy per hectare compared to conventional farms. Additionally, 70% of organic farms and 30% of conventional farms were found to have considerably lower energy consumption per unit of output. The overall lower energy utilization and higher levels of soil organic matter in organic systems make them promising models for creating strategies to reduce fossil fuel emissions and

enhance soil carbon sequestration, which are crucial tactics in the fight against climate change (Lee *et al.*, 2015; Palupi *et al.*, 2012).

9.3.3. Economics

The global expansion of organic agriculture will largely hinge on its economic viability relative to conventional agriculture. The financial success of organic farming is influenced by several key factors such as crop yields, labor and overall expenses, premium prices for organic goods, the possibility of decreased income during the transition period to organic farming, typically lasting three years, and potential cost reductions from decreased dependence on non-renewable resources and purchased inputs (Halberg *et al.*, 2006; Steffen *et al.*, 2015). To the best of our understanding, only one comprehensive analysis has investigated the economic performance of organic versus conventional agriculture. This analysis integrates data from four decades of research encompassing 55 different crops cultivated on five continents. Including the actual price premiums associated with organic foods, organic agriculture was found to be considerably more profitable, with net present values 22 to 35% higher and benefit/cost ratios 20 to 24% greater than conventional agriculture. Despite price premiums ranging from 29 to 32%, the required breakeven premiums for organic profits to equal conventional profits were only 5 to 7%, even with organic yields being 10 to 18% lower. The magnitude of organic premiums and the variance between organic premiums and breakeven premiums remained steady throughout the 40-year period under review. The higher organic premiums in comparison to breakeven premiums suggest that organic agriculture could continue to thrive even if premiums decrease. The study also revealed that while total costs were similar, labor costs were notably higher (7 to 13%) in organic farming practices. While conventional agriculture has excelled in producing greater yields with fewer labor inputs, the additional labor required in organic agriculture was viewed favorably for its contributions to rural employment and development opportunities (Prihtanti *et al.*, 2014; Zentner *et al.*, 2011).

Few economic analyses have considered the negative impacts (such as environmental expenses) or positive impacts (such as ecosystem benefits) with their associated monetary worth in comparative studies between organic and conventional farming methods. Assigning a value to the adverse effects caused by farming activities, such as soil erosion or nitrogen seepage into water sources, would enhance the profitability of organic agriculture, as its environmental footprint is generally smaller than that of conventional farming. It has been estimated that transitioning to organic farming in the United Kingdom could reduce external production costs by 75%, from £1,514 million per year to £385 million per year. Several studies have examined the ecosystem services provided by organic and conventional farming practices. Some of these studies have considered the economic value of these services, revealing that conventional methods can diminish the capacity of farms to provide certain valuable ecosystem services in comparison to organic practices (Andersson *et al.*, 2012; Kremen and Miles, 2012; Sandhu *et al.*, 2015).

9.3.4. Wellbeing

The degree to which organic, conventional, and alternative agricultural practices contribute to social equity and quality of life for farm families and communities is not clearly understood due to limited research. Available data suggests that both organic and conventional farming methods need to make significant improvements in meeting social sustainability objectives. However, organic farming has demonstrated certain sociocultural strengths, such as fostering positive community economic development, promoting increased social interactions between farmers and consumers, and enhancing employment opportunities for farm workers along with fostering cooperation among farmers. While organic farming may entail more manual labor on the farm, it also decreases the risk of farm workers being exposed to harmful pesticides and chemicals. This exposure can pose serious health risks, particularly in underdeveloped countries where illness and even fatalities have occurred as a result of occupational and accidental exposure due to the impracticality and cost of using safety equipment (Gruère *et al.*, 2009; Sandhu *et al.*, 2010).

Organic certification programs have implemented objectives related to social welfare. The standards set by the International Federation of Organic Agriculture Movements (IFOAM) dictate that organic farmers should be able to provide fair wages for themselves and their employees, while also ensuring safe and respectful working environments. Additionally, animals that are certified organic must be raised with care in environments that allow for their natural behaviors and requirements to be met. For instance, regulations in the European Union, United States, and Japan regarding organic farming stipulate that livestock should have access to outdoor spaces or grazing areas whenever possible, and that any sick animals should receive necessary treatment, including the use of antibiotics if deemed necessary (Kumar *et al.*, 2023; Lindeberg, 2017). Organic agriculture has the potential to enhance food security by promoting a broader range of crop and livestock activities on the farm, thus expanding sources of income and enhancing dietary diversity. The methodology of organic farming involves diverse rotations of crops and livestock, fostering the integration of various agricultural enterprises and promoting the utilization of leguminous crops for enhancing biological nitrogen fixation. Through the cultivation of a wider variety of nutrient-rich foods, such as vegetables, and protein-rich foods, like legumes and meats, whether for local consumption or export, farmers can gain access to a more diverse range of foods. A study conducted in the Philippines, which monitored 840 small organic and non-organic farms, revealed that the increase in vegetable and protein consumption between 2000 and 2007 was significantly higher for organic farmers following diversified practices compared to their conventional counterparts (Bachmann *et al.*, 2009; Kodera, 2020; Parrott *et al.*, 2006).

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Chapter 10

Biodiversity of Organic Agriculture

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Biodiversity of Organic Agriculture

Abstract

Preservation of natural resources and biodiversity is a fundamental principle in organic agriculture. Organic farming practices, such as limiting the use of chemical pesticides and fertilizers, managing non-cropped areas with care, and promoting mixed farming, are particularly beneficial for wildlife on farmland. By incorporating methods that attract beneficial insects, provide habitat for birds and mammals, and enhance soil biodiversity, organic production systems can benefit from essential ecological services. Certified organic operations that adopt these practices can experience advantages such as reduced reliance on external fertility inputs, lower costs for pest management, access to cleaner water sources, and improved pollination services.

Keywords: Biodiversity, organic, agriculture.

10.1. Introduction

Conservation of natural resources and biodiversity stands as a fundamental principle in organic production. Organic farming incorporates three overarching management practices which include the restriction or decreased usage of chemical pesticides and inorganic fertilizers, the considerate management of non-cropped areas, and the preservation of diverse farming practices. These practices, which are mostly intrinsic to organic farming, greatly benefit wildlife in farmland. By employing methods that attract or introduce beneficial insects, offer habitat for birds and mammals, and create conditions that enhance soil biotic diversity, organic production systems are able to provide essential ecological services. Certified organic operations that adopt these production practices experience numerous advantages such as reduced dependence on external fertility inputs, decreased costs associated with pest management, access to cleaner sources of water, and improved pollination (Gamage *et al.*, 2023; Standard *et al.*, 2012). The majority of non-crop, naturally occurring species that have been observed in comparative studies of agricultural practices demonstrate a clear preference for organic farming due to higher abundance and diversity. Organic farms typically house approximately 30% more species compared to conventional farms. This preference is evident among various organisms such as birds, butterflies, soil microbes, beetles, earthworms, spiders, vegetation, and mammals. The absence of herbicides and pesticides in organic farming has a positive impact on biodiversity, leading to increased population density and overall fitness. Certain weed species found on organic farms attract beneficial insects that contribute to improving soil quality and controlling weed pests. Soil-bound organisms also benefit from organic farming practices, as there is a higher population of bacteria due to natural fertilizers like manure, while exposure to herbicides and pesticides is minimized. The enhanced biodiversity, specifically from beneficial soil microbes and mycorrhizae, has been suggested as a factor contributing to the high yields observed in organic plots, especially when compared to conventional fields over a 21-year period (Bengtsson *et al.*, 2005; Blakemore, 2000; Blakemore, 2018; Gabriel *et al.*, 2006; Hole *et al.*, 2005).

Organic agriculture contributes to human capital by fostering biodiversity. The inclusion of a variety of species in organic farms leads to a decrease in the need for human intervention, such as fertilizers and pesticides, thereby enhancing sustainability. The directive delineates the responsibilities of certified operations in submitting an Organic System Plan (OSP) to a certifier, certifiers in ensuring that the OSP outlines practices supporting natural resources and biodiversity conservation, and inspectors in conducting on-site inspections to verify the implementation of these production practices (Fließbach *et al.*, 2007; van Elsen, 2000). A diverse array of organisms derive benefits from organic farming, although it is uncertain whether organic methods offer superior advantages compared to traditional integrated agri-environmental programs. The promotion of

organic farming as a more biodiversity-friendly approach is met with skepticism, as the extent of the positive effects remains a topic of debate due to the species-specific and context-dependent nature of these effects. Current research underscores the importance of quantifying the comparative effects of local and landscape-level management on farmland biodiversity. There are four main considerations when evaluating the impacts of organic versus conventional farming on biodiversity: Firstly, the effectiveness of a holistic organic farming approach in enhancing biodiversity compared to targeted initiatives within conventional agriculture remains uncertain. Secondly, methodological challenges in comparative studies limit the ability to draw definitive quantitative conclusions. Thirdly, there is a lack of understanding regarding the biodiversity impacts of organic farming in pastoral and upland agricultural settings. Finally, the urgency for long-term, comprehensive studies is emphasized in order to address these issues and enhance our understanding of the role of organic farming in biodiversity conservation within agroecosystems (Henckel *et al.*, 2015; Hole *et al.*, 2005).

10.2. Labour standards

Organic agriculture is often perceived as a more socially just and economically sustainable option for farmworkers compared to conventional agriculture. However, there is a lack of social science research and consensus regarding whether organic agriculture truly offers better working conditions than conventional methods. Many consumers view organic and sustainable agriculture as synonymous with small-scale, family-owned operations, leading to the belief that purchasing organic products supports improved conditions for farmworkers. Organic agriculture typically requires more labor due to its reliance on manual techniques for fertilization and pest control. While there may be a lower risk of illnesses from chemical inputs, hired farmworkers are still susceptible to debilitating musculoskeletal disorders associated with agricultural tasks. Although the USDA certification mandates certain growing practices and ecological standards, they do not address labor practices. Independent certification programs like the Agricultural Justice Project, Domestic Fair Trade Working Group, and the Food Alliance have aimed to incorporate farmworker interests, but their effectiveness is limited by the voluntary participation of organic farms. Despite the potential benefits of enforcing labor standards for farmworkers, there is little enthusiasm for such social requirements within the organic community. Many in the organic industry argue that mandating labor standards is unnecessary, unacceptable, or economically unfeasible given market constraints (Brown and Getz, 2008; Getz *et al.*, 2008; Shreck *et al.*, 2006).

10.2.1. Europe

The EU-organic production-regulation is a component of the overarching regulatory framework established by the European Union to govern the production of organic agricultural and livestock products, as well as to provide guidelines for their labeling. Within the EU, organic farming and organic food are commonly referred to as ecological or biological practices. The latest data from the 2016 report "The World of Organic Agriculture", published by FiBL and IFOAM in 2016, indicates a rise in the number of farmers engaging in organic cultivation, an expansion of certified organic land, and a growing number of nations reporting organic agricultural activities (Lernoud and Willer, 2019; Robertson, 2025; Willer and Lernoud, 2017).

10.2.2. Denmark

Denmark has a longstanding commitment to transitioning traditional farming practices to organic methods, a movement that has been integrated into academic curricula at universities as early as 1986. The government initiated alternative measures and established a unique national certification for organic products beginning in 1989. Consequently, Denmark holds the distinction of being the pioneering nation in championing organic farming, advocating for the ideology, and overseeing the dissemination of organic goods (Ingemann, 2006; Noe, 2004). Today, the government is currently receiving applications for financial assistance during the transition period, as per Danish regulations which require farms to abstain from using traditional farming methods like pesticides for a certain

period before their products can be considered for organic certification. The financial aid provided for this purpose has seen a reduction in recent years, owing to the growing profitability of organic farming and the surpassing of some products in profitability compared to conventional farming in the local market. Ecological farming in Denmark places particular importance on reducing the usage of added nitrogen to farmland, offering farmers the opportunity to receive an additional subsidy for achieving this reduction through organic methods (Vos *et al.*, 2025). There are similarities to the extensive organic practices found in regenerative agriculture; however, not all aspects of regenerative agriculture are currently incorporated into the national strategy. These concepts are instead available as voluntary choices for individual farmers. As a result, international organic products do not meet the criteria for ecological farming and are therefore not eligible for domestic ecological product labeling. Instead, they are labeled with the standard European Union organic label (Daugbjerg and Schvartzman, 2022; Topay and Yeşilyurt, 2024).

10.2.3. Ukraine

The Ministry of Agrarian Policy and Food of Ukraine is the primary governmental body responsible for developing the regulatory framework and overseeing the organic sector in Ukraine, including maintaining state registers of certification bodies, operators, organic seeds, and planting material, as well as providing training for organic inspectors. This includes oversight of certification bodies, random inspections of operators, and monitoring of organic products in the market to prevent mislabeling and non-organic products from entering the market (ahrarnoi polityky ta prodovolstva Ukrainy, 2018; Melnyk and Ovander, 2021).

10.2.4. China

The Chinese government, particularly at the local level, has offered various forms of assistance for the advancement of organic agriculture since the 1990s. Local governments have acknowledged the potential of organic farming in fostering sustainable rural development. It is customary for local governments to assist agribusinesses in acquiring land by engaging in negotiations with local farmers regarding land leasing agreements. In addition, the government has set up demonstration organic gardens and provides training for organic food companies to obtain certifications. Furthermore, the government subsidizes costs related to organic certification, pest repellent devices, organic fertilizer, and other necessary resources. The government has also taken an active role in promoting organic products by hosting organic food expositions and providing support for branding initiatives (Chen, 2015; Scott *et al.*, 2018).

10.2.5. India

In the year 2016, the state of Sikkim in northern India successfully completed its transition to 100% organic farming. Several other states in India, such as Kerala, Mizoram, Goa, Rajasthan, and Meghalaya, have expressed their commitment to fully adopting organic farming practices as well. Additionally, the state of Andhra Pradesh in South India is actively promoting organic farming, with a particular focus on Zero Budget Natural Farming (ZBNF), which is a type of regenerative agriculture technique (Bishnoi and Bhati, 2017; Kumar *et al.*, 2017; Paull, 2017; Rose *et al.*, 2021). Current food production levels exceed the necessary requirements to feed the global population, with the ability to sustainably feed up to 10 billion people by the projected peak population (Devi et al., 2024; Holt-Giménez et al., 2012).

10.2.6. Dominican Republic

The Dominican Republic has effectively converted a significant portion of its banana crop to organic production. This country holds a majority share of 55% in the global market for certified organic bananas. In South Korea, a prominent shift in agriculture occurred during the 1960s and 1970s, notably through the "Green Revolution" initiative. This program led to reforestations and significant advancements in agricultural practices. In response to food shortages during Park Chung Hee's

presidency, the government in South Korea promoted the cultivation of rice varieties suitable for organic farming. Farmers in South Korea aimed to mitigate risks through strategic planning, such as by crossbreeding a rice variety known as Japonica with Tongil. Moreover, they reduced the use of fertilizers and implemented other economic measures to address potential risks (Burmeister, 1987; Moon, 2012). In contemporary society, there has been a significant transformation in organic farming and food policies, particularly since the 1990s. The revised guidelines primarily emphasize fundamental dietary advice regarding nutrient consumption and Korean-style eating patterns. This shift in focus is largely motivated by the fact that approximately 88% of nations worldwide are grappling with various forms of malnutrition. Subsequently, in 2009, the enactment of the Special Act on Safety Management of Children's Dietary Life introduced restrictions on foods that are low in energy and lacking in essential nutrients. Additionally, this legislation targeted other nutritional issues that Korean students may have been experiencing (Choi et al., 2017; Lee et al., 2014; Müller and Krawinkel, 2005).

10.2.7. Thailand

The Institute for Sustainable Agricultural Communities (ISAC) was founded in Thailand in 1991 with the aim of advocating for organic farming and other sustainable agricultural methods. The country has set a national goal through the National Plan for Organic Farming to achieve 1.3 million rai (2,100 square kilometers; 800 square miles) of organically cultivated land by 2021. Additionally, there is a target for 40% of the agricultural produce from these lands to be utilized within the country. Substantial advancements have been observed in this regard (Chitov, 2020; Pattanapant and Shivakoti, 2009):

- Numerous organic farms have emerged, cultivating a variety of crops from mangosteen to pungent beans.
- Several of these farms have also set up educational facilities to advocate for and disseminate their organic farming methods and expertise.
- In the province of Chiang Mai, there are a total of 18 organic markets, affiliated with the International Society of Organic Agriculture in Thailand (ISAC).

10.2.8. United States

The establishment of the United States Department of Agriculture Rural Development (USDARD) in 1994, a subsidiary of the USDA, was intended to promote development in rural areas through various programs. As part of its efforts, the USDARD introduced the Organic Certification Cost Share Program (OCCSP) to provide funding support to farmers involved in organic agriculture. In recent years, the United States has made considerable strides in the organic food industry, demonstrated by the doubling of organic farms from 2011 to 2016. Opportunities for employment in the field of organic farming possess the ability to produce a significant quantity of jobs, potentially contributing to the facilitation of the Fourth Industrial Revolution. Furthermore, sustainable methods employed in forestry, fishing, mining, and other conservation-focused endeavors hold the potential to generate a greater number of jobs in comparison to conventional fossil fuel and mechanized labor. Between 2000 and 2011, the land area allocated to organic farming in the United States saw an increase of 3.53 million acres (equivalent to 1,430,000 hectares). California led the nation in 2016 with the highest number of organic farms, totaling 2,713 active organic farms. Organically produced goods make up 4% of total food sales in the United States (Bialik and Walker, 2019; Boiko, 2025; Johnson, 2008; Squalli and Adamkiewicz, 2018).

10.2.9. Sri Lanka

Sri Lanka, like many other countries, shifted away from organic farming with the introduction of the Green Revolution, opting instead for a heavy reliance on chemical fertilizers. The government began offering subsidies for the import of artificial fertilizers to boost rice paddy production and encourage

farmers to transition from traditional varieties to higher yielding ones. Young farmers, motivated by short-term financial gains, embraced this shift despite concerns about its long-term environmental impact. Nevertheless, older and more experienced farmers expressed reservations about inorganic farming due to health risks such as the potential link to chronic kidney disease. Some of them reverted to organic farming or opted for insecticide-free fertilizers to cultivate their crops. A study conducted by researchers compared crop yields among farmers in Sri Lanka utilizing different farming methods, including organic farming, insecticide-free fertilizers, and pesticides for modern varieties. Surprisingly, no significant difference in yield production was observed, with organic farmers and users of insecticide-free fertilizers reporting fewer issues with pests like plant hoppers. However, many farmers continued to use insecticides as a precaution against potential damage to their crops, supported by the affordability and availability of agrochemicals in the market. While organic farming offers health benefits, it demands more labor and effort from farmers (Horgan and Kudavidanage, 2020; Qiao *et al.*, 2016; Sooriyakumar *et al.*, 2019; Weerahewa *et al.*, 2010).

Although this situation offered a significant opportunity for increased employment in Sri Lanka, the economic remuneration provided was insufficient to cover the living expenses of the workers. Consequently, many farmers turned to modern techniques to manage their households, particularly following the economic strains caused by the COVID-19 pandemic. Despite Sri Lanka grappling with the challenges posed by the pandemic, during the 2019 presidential election campaign, President Gotabaya Rajapaksa proposed a decade-long national transition to organic farming in a bid to position Sri Lanka as a pioneer in organic agriculture. This initiative resulted in a decree issued on April 27, 2021, prohibiting the import of synthetic pesticides and fertilizers, which sparked turmoil among farmers. While this move was motivated by concerns for the country's ecosystems and the well-being of its citizens, particularly in light of the prevalence of pesticide-related poisonings, it faced criticism from the agricultural sector. There were apprehensions that the mandate would negatively impact the yields of key crops, doubts about the domestic production capacity for organic fertilizers, and concerns regarding the cost and complexity of organic farming compared to traditional agricultural practices (Nordhaus and Shah, 2022; Parashar *et al.*, 2025; Priyadarshana, 2021; Van Der Hoek *et al.*, 1998; Wipulasena and Mashal, 2021). In September 2021, an economic emergency was declared by the government, attributing it to the ban's repercussions on food prices, the inflation caused by the devaluation of the Sri Lankan currency due to the collapsing tea industry, and a decrease in tourism resulting from COVID-19 restrictions. By November 2021, the nation had partially removed the prohibition on inorganic farming for specific key crops like rubber and tea, while also initiating compensation and subsidies for farmers and rice producers in an effort to mitigate losses. The former subsidies on imported synthetic fertilizers were not reinstated (Watt, 2021; Wipulasena and Mashal, 2021).

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Chapter 11

Using Legumes as Green Manure

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Using Legumes as Green Manure

Abstract

Legume-based green manures (LGMs) are cultivated crops intended to enhance soil quality and ultimately enhance the long-term productivity of agricultural yields. While historically focused on providing nitrogen (N) to the soil, these crops offer a wide array of potential advantages, including enriching soil health, reducing erosion, and fostering biodiversity on farmland. LGMs play a crucial role in organic farming systems where synthetic N fertilizers are prohibited. However, rising input costs, environmental concerns regarding intensive agrochemical use, and the recent "greening" initiatives of the European Common Agricultural Policy have prompted a renewed interest in broader applications of LGMs. In Europe, legume-based green manures encompass both annual and perennial plant species, either cultivated independently or as part of mixed cropping systems alongside varieties like grasses or brassicas. Commonly grown legumes include clovers such as red and white clover (*Trifolium* spp.), as well as species like *Medicago* spp. (lucerne/alfalfa and black medic), trefoils (*Lotus* spp.), vetches (*Vicia* spp.), lupins (*Lupinus* spp.), additional forage legumes, and grain legumes tailored to specific regional objectives and limitations. In organic farming rotations, LGMs are cultivated in lieu of cash crops to optimize soil fertility.

Keywords: Legume-based green manures (LGMs), biodiversity, fertilizers.

11.1. Introduction

Green manure/cover crops (GMCCs) are plants that are used to cover and enhance the soil, as well as to benefit other agricultural plants and the land's ecology. Although GMCCs can be made from a variety of plants, the legumes—plants in the Fabaceae family—are the subject of this paper. They have a reputation for working with soil microbes to transform atmospheric nitrogen into "fixed" nitrogen that plants can absorb. The term biological nitrogen fixing refers to this process. Growing conditions on the land available to small-scale farmers are frequently challenging. For example, farm fields may be too wet, dry, steep, eroded, acidic, alkaline, saline, or infertile for the best growth and yield of food plants, depending on the region. Whenever feasible, land that is not ideal for growing crops should be put to other uses, including providing grazing for animals. Still, a lot of farmers are forced to grow their basic crops on less-than-ideal soils. Nitrogen is one of the nutrients that is most frequently lacking on marginal or degraded land. Legumes may frequently flourish in soils that lack nitrogen because of their capacity to use nitrogen from the atmosphere. Extensive root systems seen in many tropical legumes allow them to extract nutrients and moisture from the soil's depths. Tropical legumes are very varied, with some suited to more arid regions and others to humid conditions. Tropical legumes are known for their ability to thrive in a variety of challenging growth environments because of these factors. For farmers to eventually produce enough food for their family, soil maintenance is essential. This in turn is heavily reliant on preserving soil organic matter. Numerous soil processes that are connected to organic matter, including as aeration, drainage, nutrient retention, and microbial nutrient cycling, affect crop growth (Arshad *et al.*, 2016; Arshad *et al.*, 2019). Continuous application of plant-based mulch to a field is one of the principles of conservation agriculture (Figure 11.1). Mulch prevents soil erosion, inhibits weeds, and restores soil organic matter. However, the majority of farmers lack sufficient crop residue to cover the soil, particularly when cultivating impoverished soils and needing to remove some of the residue to feed livestock.

Fig. 11.1. Legume mulch made from the leftovers (right) of harvested or dead plants and the leaf litter of living plants (left). Reference regarding the use of green manure (Hartwig and Ammon, 2002).

Any solution will probably have several different aspects. Knowing the benefits of organic mulch, farmers may choose to leave some of their agricultural remains on the field. They might also be able to provide a small quantity of animal dung. The addition of tropical legumes to their primary grain crops could provide more mulch. Numerous legumes are used as dry bean crops, or pulses, to supplement farmers' food supplies. Livestock can also be fed most legumes. Just keep in mind that the nutrients found in any plant parts that are harvested for food, feed, or other purposes won't be put back into the soil. Because they shade the ground, legumes with thick leaf canopies inhibit weed growth. By doing this, they also shield soils from erosion and high heat. In the heated tropics, less light exposure helps sustain an environment that supports soil life that would not otherwise be able to thrive on contrast to compost piles, which require watering and the transportation of the completed compost to the field, legumes, which are grown directly on farmers' fields, also facilitate the application of organic matter.

Many European intensive agricultural regions are seeing a decline in livestock farms and an increase in stockless organic farming systems. Creating an organic arable farming system that produces high yields and is self-sufficient in nitrogen is crucial but difficult. Stockless organic agroecosystems are even more challenging to manage sustainably, with growing challenges in achieving adequate crop output and N cycling while preserving environmental health. Legumes are recommended as one of the essential components of stockless organic farming systems for nitrogen supply, reducing reliance on external nitrogen inputs (Autret *et al.*, 2019; Crews and Peoples, 2005; Migliorini *et al.*, 2014; Watson *et al.*, 2017).

Europe's temperate broadleaf and mixed forest biome is characterized by seasonal vegetation, and low temperatures and little daylight limit crop cultivation during the cool season. Adding green matter to the soil rather than removing it after the crop growing season has been proposed as a way to boost soil organic carbon (SOC) stocks. However, this may result in gas emissions from the soil that isn't maintained with a cover crop and nutrient loss from leaching.

The potential rate and duration of decomposition may reveal whether the material has the capacity to enhance nutrient loss throughout the crop growing season, the non-growing season, or the full crop rotation. Organic materials break down into simpler organic particles through a process known as decomposition. For the recycling of legume N, the procedure is crucial and a component of the nutrient cycle. The process of mineralization during decomposition refers to the transformation of organic materials into soluble inorganic forms that enhance plants' ability to absorb nutrients. Immobilization's opposite is mineralization. The decomposing bacteria take nitrogen in the form of

ammonium or nitrates after the mineral nitrogen is immobilized when the C:N ratio of the decaying organic matter is greater than 20:1 (Cabrera *et al.*, 2005; Chatterjee and Acharya, 2020; Fu *et al.*, 2019; Johnson *et al.*, 2007; Liu *et al.*, 2014).

Lower C:N ratios lead to mineralization through the simultaneous release of labile inorganic N fractions, which raises the soil's total mineral N content (NO_3-N and NH_4-N). Both plants and the environment can absorb or lose the mineral N in the soil, which lowers air quality by increasing greenhouse gas (N_2O) emissions and lowers water quality by allowing N to seep into groundwater. Thus, it is crucial to investigate the breakdown of organic matter in particular sites and soils using both quantitative and qualitative methods (Maraldo *et al.*, 2015; Zhang *et al.*, 2007; Žydelis *et al.*, 2019).

The breakdown rate is predetermined by plant material alone. The primary biotic elements are the straw's physical and chemical properties, including its lignin to N ratio, cellulose, hemicellulose, lignin, and nutrient content, as well as its C:N ratio. Furthermore, the chemical characteristics of plants influence the metabolism of decomposers and command the way communities work. Legume residues with lower C:N ratios decompose more quickly than cereal residues, but they also boost dry matter yield and N uptake by the subsequent crop. However, rapid bulk breakdown of legumes is the result of a relatively narrow C:N ratio. In the first two to three months after being added to the soil, red clover decomposes extremely quickly, whereas other crops take longer to disintegrate (Abiven *et al.*, 2005; Austin and Ballaré, 2010; Cai *et al.*, 2019; Ibewiro *et al.*, 2000; Kriaučiūnienė *et al.*, 2012; Powers and Salute, 2011; Sanaullah *et al.*, 2010).

New technical approaches recommend bulk processing legumes to reduce N losses from narrow C:N ratio legumes, particularly during the non-growing season, and to synchronize the nutrient supply with ecological needs. These processed organic manures were once known as cut-and-carry fertilizers or mobile green manures. Choosing the right plant species for silage or compost can help regulate C:N ratios, avoid nutrient excesses or losses, and time nutrient supplementation for two years in the crop cycle with higher humus content for a lasting impact.

But the way these manures are processed and the chemical makeup of the component legume plants—which can change depending on the local environment and growing conditions—have a significant impact on their nutrient composition. The usefulness and impact of these processed plant-based manures are therefore unpredictable, and they ought to be examined in relation to particular farming systems.

In contrast to granulated cattle manure and legume mulch, our theory suggests that processed legume manures can sustain crop productivity while simultaneously increasing biomass output efficiency, N usage efficiency, and the synchronization index between crop N supply and demand (Arlauskiene *et al.*, 2013; Carter *et al.*, 2013; De Notaris *et al.*, 2018; Sørensen *et al.*, 2013; Tripolskaja and Šidlauskas, 2010; Van der Burgt *et al.*, 2013).

11.2. N and C in legume green manures

Green manures made from processed legumes can be identified by their varying chemical compositions and C:N ratios (Figure 11.2). The C:N ratio of fresh red clover biomass was the narrowest. The N concentration of fresh red clover biomass was comparable to that of granulated cattle dung and red clover with straw compost; however, the phosphorus and potassium contents were higher. The biomass of fresh red clover had a lower C:N ratio since it was planted as a wheat intercrop and did not yield large amounts of C or biomass. Prior to fermentation, the C content of the red clovers utilized for the process was higher since they were grown independently. The ensiled red clovers' C:N ratio increased and their higher C content was maintained through silage fermentation.

This biomass did not differ considerably from the solo fresh red clover after processing since the composting of red clover and straw biomass reduced the C:N ratio.

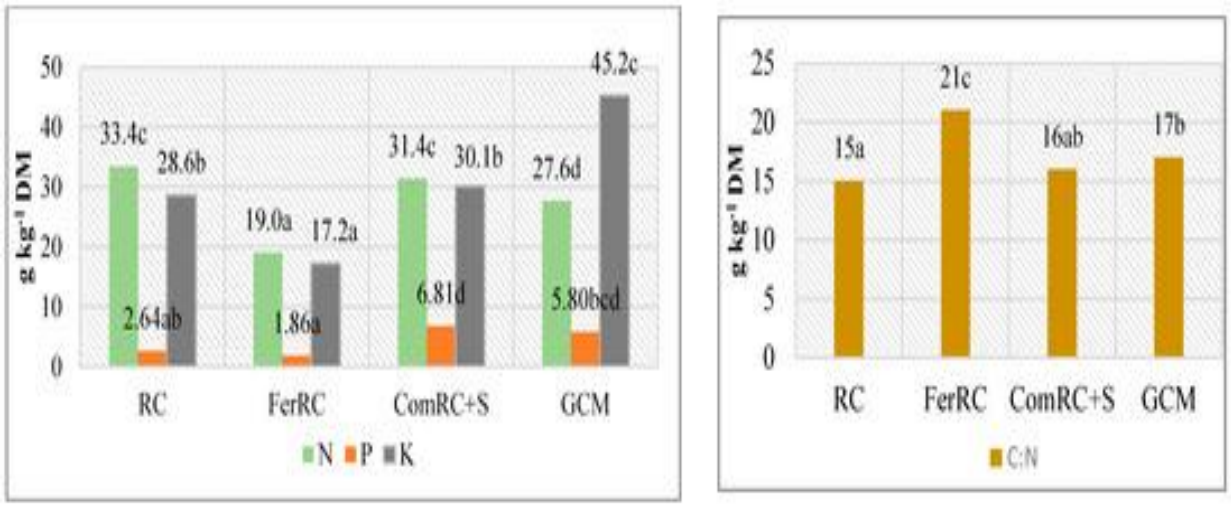

Fig. 11.2. C:N ratio and chemical makeup of the green manures employed. Notations. RC stands for fresh red clover biomass, FerRC for fermented red clover, ComRC + S for composted red clover and straw, and GCM for granulated calf manure. There is no difference in the means of the identical items followed by the same letters in the same section ($p \leq 0.05$) (Toleikiene *et al.*, 2024).

11.3. C Release during the green manure decomposition

Depending on the season, processed legume green manures were utilized as organic fertilizer. In the spring, additional green manures were added to the soil, and in the fall, fresh red clover biomass was ploughed down. It was discovered that new red clover biomass lost 65.6% of its initial C throughout the first non-growing season (October–April) (Figure 11.3). The amounts of undecomposed C that green manures retained after the first crop growing season varied significantly (ranging from 19.2 to 67.4% DM).

Over the first growing season, granulated cattle manure released the least quantity of carbon (C), while fermented and composted red clovers released comparable amounts. In both treated two-year periods, the release of carbon to the soil was gradual for granulated bovine dung and compost made from clover and straw, while 91% of the carbon was rapidly released and stabilized in a brief one-and-a-half-year period by fresh red clover biomass. A stable C value of 8.5% of the total incorporated C was its value.

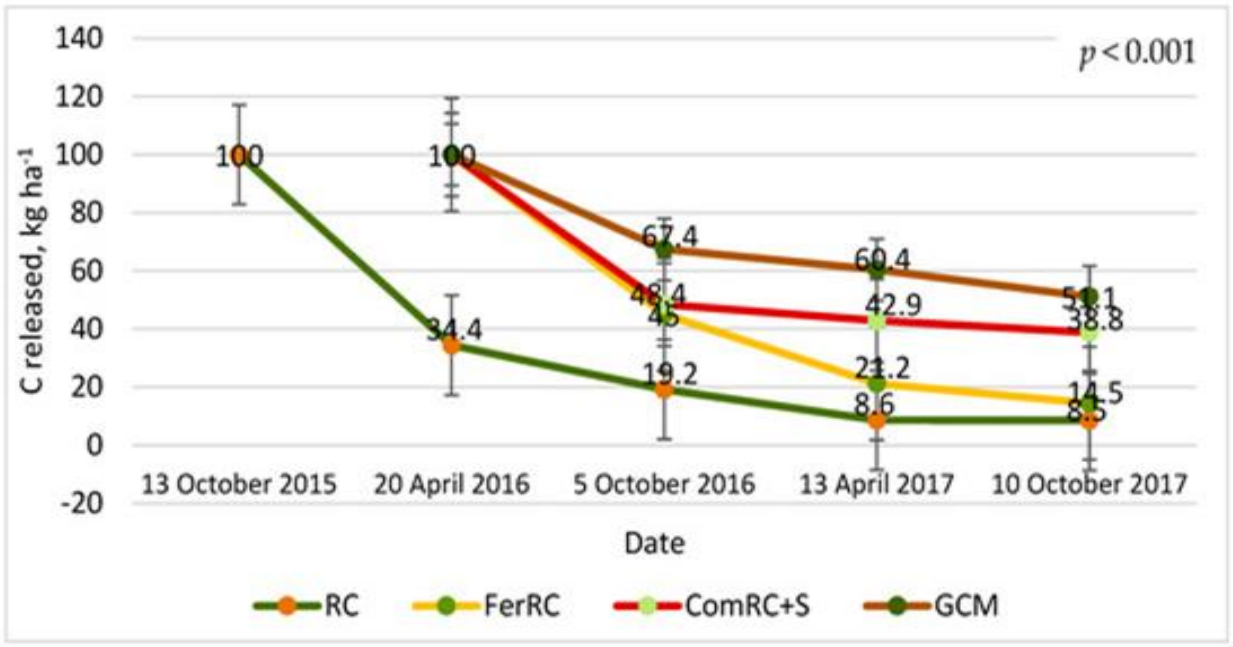

Fig. 11.3. A two-year decomposition period showing the dynamic of total carbon remaining in green manures.

Notes: Granulated cattle manure (GCM); composted red clover and straw (ComRC + S); fresh red clover biomass (RC); and fermented red clover (FerRC). A whisker illustrates the data's fluctuation (Toleikiene *et al.*, 2024).

11.4. N release during the decomposition

During the 2-year decomposition period, fresh red clover biomass's N concentration was the greatest and changed the most between 2.5 and 4.8% DM. During various decomposition periods, the C:N ratio ranged from 10.3 to 25.4; nevertheless, there was no discernible difference between treatments.

Throughout the two-year period, the total N release for fresh red clover biomass was significantly the greatest at 67.6 kg ha^{-1}, with the highest effects occurring during the first crop growing season (19.2 kg ha^{-1}) and the first non-growing season (37.6 kg ha^{-1}) (Figure 11.4). Fermented red clover, red clover compost with straw (21.4–21.8 kg ha^{-1}), and granulated bovine manure (7.9–10.2 kg ha^{-1}) all released a statistically similar ($p < 0.001$) amount of nitrogen throughout the first crop growth season.

Fresh and fermented red clover biomass showed a significant loss of nitrogen (10.6–14.0 kg ha^{-1}) during the second non-growing season. Both fermented red clovers and granulated cattle dung showed positive N release during the second crop season (3.4–4.7 kg ha^{-1}).

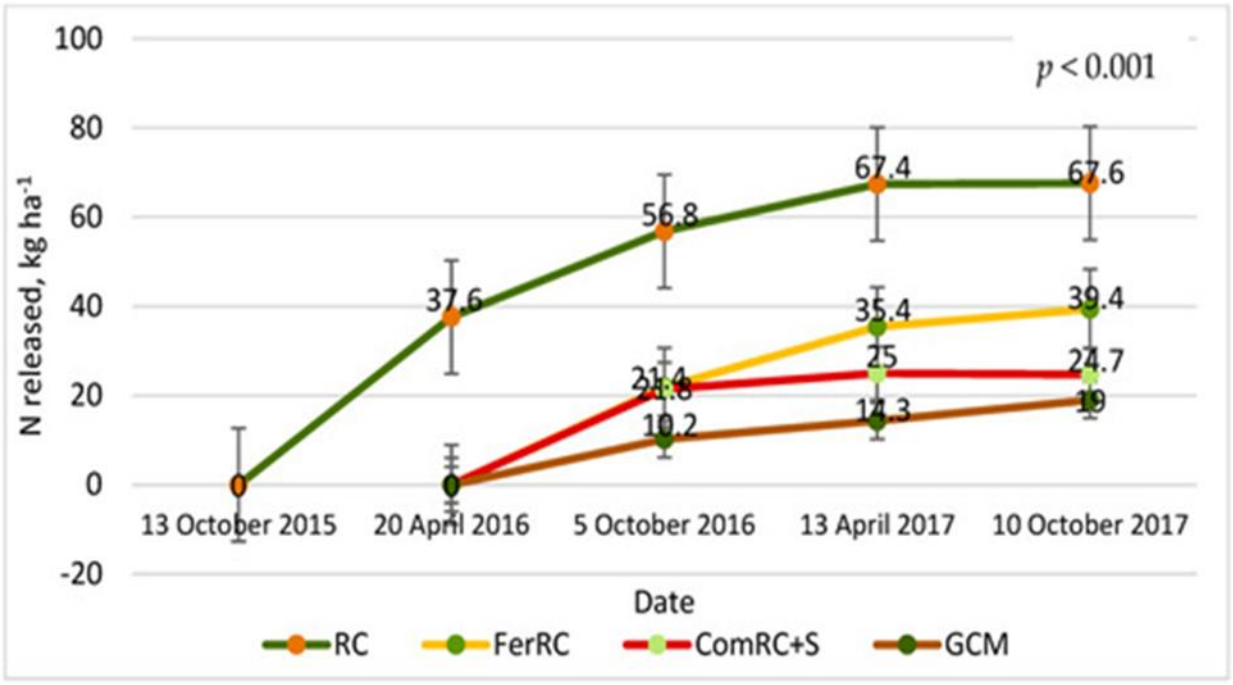

Fig. 11.4. The dynamic total N release from legume green manures during the crop rotation's two-year duration.

Notes: Fresh red clover biomass is called RC; fermented red clover is called FerRC; composted red clover and straw is called ComRC + S; and granulated cattle manure is called GCM. The data variation is displayed by whiskers (Toleikiene *et al.*, 2024).

11.5. Mineral N changes in the soil

Green manures made from legumes were mineralized, and the nitrogen from the legumes was absorbed into the soil at different rates as N-NH_4 and N-NO_3 minerals. A year following the addition of legume green manures, the N-NH_4 content was four times lower than the N-NO_3 content and did not differ substantially across treatments. Two additions were found to have greater levels of N-NH_4 in soil that was 0–30 cm deep: granulated cattle manure (+89%) and compost of red clover and straw (+144%). New red clover biomass and fermented red clover, on the other hand, exhibited N-NO_3 levels that were 160% and 298% greater than the control, respectively.

In the second year following amendment inclusion, fresh red clover biomass and granulated cattle manure showed the lowest N-NH_4 and N-NO_3 leaching to the deeper soil layer (30–60 cm) among the applied green manures.

11.6. The effect of legume green manures on crop productivity

Analyzing the duration of the effect of legume green manures, a correlation was noticed between green manure features and the Cereal quality and productivity two years after applying green manure. The yield, total biomass, protein content in grain, total N accumulated in straw, grain, and total plant of spring wheat showed a positive and significant correlation ($r = 0.47–0.78$, $p < 0.05$) with the total amount of N incorporated into the soil with legume green manures in the first year following the spring application of green manure. The decomposition rate of green manures during

the first year of vegetation was favorably linked ($r = 0.55–0.71$, $p < 0.01$) with the spring wheat indexes, in addition to the total N of green manures.

The biomass, protein content, total N of straw, and aboveground biomass of spring wheat all rose linearly with the higher rate of decomposition of green manures, particularly for fresh and fermented red clover.

Additionally, the pace of decomposition modified the amount of nitrogen released by green manures within a certain crop vegetation time lag. As a result, the amount of nitrogen released during the first year of vegetation had a stronger correlation with spring wheat indices than the initial total amount of nitrogen added with green manures. Mineral N in the deeper soil layer (30–60 cm depth) was shown to have a very high positive connection with the spring wheat variables previously discussed.

The larger N leaching possibility was conditioned by the higher rate of decomposition and higher N release, which could be explained by the strong positive association between total N, decomposition rate, and seasonal N released by legume green manures with mineral N in the 30–60 cm depth of soil.

The yield of spring barley in the second year following the application of legume green manures showed a positive and medium-strong correlation ($r = 0.42$, $p < 0.05$) with the total quantity of nitrogen added to the soil. In the meantime, the C:N ratio of legume green manures was better reflected in total biomass ($r = 0.40$, $p < 0.05$). The spring barley's protein content and thousand kernel weight were associated with the amount of nitrogen released during the second year of vegetation.

In the first year, the impact of legume green manure was frequently strong ($r = 0.62–0.88$, $p < 0.05$), whereas in the second year, it was frequently of moderate strength ($r = 0.40–0.65$, $p < 0.05$). Because there was no discernible relationship between the variables of spring barley in 2017 and the total N accumulated in the straw of spring wheat in 2016, the residual effect of the first-year grown spring wheat was minimal in the third year.

11.7. C and N role in the decomposition

The pace at which various organic compounds in the soil decompose (Didion *et al.*, 2016) and the processes of N mineralization and immobilization (Chatterjee and Acharya, 2020) are both largely determined by the C:N ratio. Lower C:N ratios than those of non-legume crops are a characteristic of legume wastes (Arlauskiene *et al.*, 2013; Tripolskaja *et al.*, 2013; Zander *et al.*, 2016). Our study found that red clover had the narrowest C:N ratio (14.8–22.0) of any forage legume. The C:N ratios of red clover are 12 (Jensen *et al.*, 2012), 20.5 (Zhang *et al.*, 2007), and 15.4–27.4 (Nemeikšienė *et al.*, 2010), which are in line with previous scientific findings.

Fresh red clover biomass stores a lot of nitrogen, but the release process is hard to regulate (Brozyna *et al.*, 2013; Frøseth and Bleken, 2015). For this reason, processing legume mass was utilized to stop N losses and synchronize the supply of nutrients (De Notaris *et al.*, 2018; Tripolskaja and Šidlauskas, 2010). Our analysis revealed that all legume-based green manures had narrow C:N ratios (Cai *et al.*, 2019; De Notaris *et al.*, 2018; Ibewiro *et al.*, 2000; Kriaučiūnienė *et al.*, 2012; Powers and Salute, 2011; Sanaullah *et al.*, 2010; Tripolskaja and Šidlauskas, 2010) following processing (Brozyna *et al.*, 2013; Didion *et al.*, 2016; Frøseth and Bleken, 2015; Iannetta *et al.*, 2016; Knacker *et al.*, 2003; Metzger *et al.*, 2005; Nemeikšienė *et al.*, 2010; Tripolskaja *et al.*, 2013; Zander *et al.*, 2016).

11.8. Decomposition rates of legume fertilizers

Decomposition rates can vary by up to 64%, which can be explained by the quality of organic materials (Cleveland *et al.*, 2014). Among the most common plants, red clover is ploughed in the fall to improve soil fertility (McKenna *et al.*, 2018; Sarunaite *et al.*, 2013). Red clover manure's C:N

ratio is only 15 and it contains a lot of labile components. First to break down are the organic molecules in plant material that are readily degradable and labile (Keuskamp *et al.*, 2013). The likelihood of N losses increased when fresh red clover mass was added prior to the non-growing season (Tripolskaja and Šidlauskas, 2010).

Fresh red clover mass experienced significant losses during the first non-growing season, including a loss of 37.6 kg ha^{-1} of N and 65.6% DM of its initial mass. The deeper layer of 30 to 60 cm of soil saw a 90% rise in mineral N levels as a result, demonstrating the leaching process in this treatment. Low temperatures during the non-growing season, 0–4 °C, preserve the same decomposition patterns as 8.5–15 °C, according to previous study (Frøseth and Bleken, 2015). In the second non-growing season, only fresh and ensiled red clover mass had a greater loss of nitrogen (10.6–14.0 kg ha^{-1}). A reduced rate of decomposition was seen in the non-growing season for both composted red clover and straw debris. Faster decomposable material reacts to management factors more strongly (Cleveland *et al.*, 2014; Keuskamp *et al.*, 2013; McKenna *et al.*, 2018; Sarunaite *et al.*, 2013).

Processed legume material was added to the soil in the spring to align the nutrient supply with ecosystem requirements. Fermented red clover mass and compost released 21.4–21.8 kg ha^{-1} and granulated bovine dung released 7.9–10.2 kg ha^{-1} of nitrogen during the first crop growing season, which was considerably similar ($p < 0.001$). This demonstrates the distinctive ability of ensiling to retain legume nitrogen during the vegetative season (Benke *et al.*, 2017; Carter *et al.*, 2014) and the fact that it is competitively priced with fertilizers derived from animals (Sørensen *et al.*, 2013).

During the second crop season, both fermented masses and granulated cattle manure showed positive N release (3.4–4.7 kg ha^{-1}), which is consistent with this theory. This shows that the second benefit of ensiled material is that it has a long-lasting favorable impact on the two crop growth seasons that follow in the rotation (Benke *et al.*, 2017; Keuskamp *et al.*, 2013).

11.9. Mineralization of organic fertilizers

Research on the processes of fermented legume mineralization in soil is lacking. Although there is a reduced danger of N losses because of low pH and little ammonium, it is said to have more accessible N for plants (Carter *et al.*, 2014; Möller, 2018). Comparing granulated cattle dung to fermented and green organic fertilizers, the former changes the chemical makeup of the soil by breaking down easily degradable organic materials and forming more stable organic molecules. Only 10–15% of the compost's bulk breaks down annually in the soil, indicating that it decomposes slowly (Möller, 2018; Rong *et al.*, 2018).

11.10. Correlation with crop productivity

The literature has not thoroughly examined and contrasted processed manures because ensiling and other processing methods are more frequently used in cattle feed (Luciano *et al.*, 2019). Numerous studies have been conducted on the chemical makeup of processed legume green manure; nevertheless, the impacts on the yield of farmed cereals, particularly two years after fertilization, are either negligible or restricted to pot experiments (Benke *et al.*, 2017).

Furthermore, the amount of N released from green manure during the specific year of vegetation had a stronger correlation with cereal productivity indexes than the overall amount of N mixed with manures from the start, demonstrating the critical necessity of timing the release of nutrients. For instance, in our study and in certain other investigations, the performance of the legume compost treatment was comparatively poor throughout the crop rotation (Farahzety and Aishah, 2013). Fundamental physical and chemical changes brought forth by composting significantly lower the amount of N available in the soil (Sikora and Enkiri, 2000). Due to the varied timing of N availability in the soil, cattle dung was also linked to a smaller increase in winter wheat grain yield, protein content, and stored N when compared to fresh red clover manure (Farahzety and Aishah, 2013; Luciano *et al.*, 2019; Olesen *et al.*, 2009; Sikora and Enkiri, 2000).

11.11. Legume green manure and intercropping

Recently, bioenergy crops have garnered a lot of interest in the United States as a potential replacement or addition to the fossil fuel supply. Searches for alternate energy sources have been pushed by dependence on foreign oil supply and rising oil prices. For instance, a variety of solutions have been explored, including cellulosic bioethanol; consequently, bioenergy crops are increasingly being incorporated into US cropping systems. Plant breeders have recently taken advantage of sorghum's exceptional genetic variety, and the crop has drawn a lot of interest as a possible feedstock for ethanol.

Photoperiod-sensitive cultivars increase biomass yield and vegetative development when planted at higher latitudes. High biomass sorghum is a desirable bioenergy crop for East Texas and the humid Southeastern United States due to its high dry matter (DM) yields with minimal inputs in warm, dry regions (Davis *et al.*, 2009; Fingerman *et al.*, 2010; Lal, 2009; Murray *et al.*, 2008; Rocateli, 2010; Rooney, 2004; Rooney *et al.*, 2007).

Removing plant biomass to produce bioethanol may result in a number of soil issues. Removing much of the plant biomass generally upsets established mass balances of carbon and plant nutrients when compared to conventional cropping systems. By removing the plant material from the system, vital nutrients that would otherwise be returned to the soil and released gradually throughout decomposition are eliminated (Hons *et al.*, 1986). Likewise, fixed plant C is eliminated, which is bad for soil organic C (SOC) preservation. Adding plant residue directly increased SOC (Havlin *et al.*, 1990; Mazzoncini *et al.*, 2011). By bringing more plant biomass back into the soil, intercrops or green manure added to rotations may help reduce SOC losses (Havlin *et al.*, 1990; Hons *et al.*, 1986; Mazzoncini *et al.*, 2011; Rocateli, 2010; Rooney *et al.*, 2007).

In addition to adding more carbon to the soil, legumes also provide fixed nitrogen to cropping systems, making them excellent green manures and intercrops (Žydelis *et al.*, 2019).

The majority of legume N needs can be met by symbiotically fixed nitrogen with the aid of Rhizobium bacteria. After that, legume N can be added to the soil directly through root exudates and senescence, or legume biomass can be added as green manure to save input costs by substituting the N fertilizer needed by non-leguminous crops (Kramberger *et al.*, 2009; Laberge *et al.*, 2011; Neely *et al.*, 2018; Redmon *et al.*, 1995; Seo *et al.*, 2006).

Fall plantings of cool-season annual legumes can provide organic nitrogen before summer crop planting dates. In a sandy loam soil in Georgia, it has been demonstrated that crimson clover, a cool-season legume, may replace up to 120 kg N ha^{-1} of fertilizer for grain sorghum. According to a North Carolina study, Wagger found that a following crop of corn (*Zea mays* L.) utilized roughly one-third of the nitrogen that was supplied by hairy vetch (*Vicia villosa* Roth) and crimson clover (Wagger, 1989). Up to one-third of the nitrogen from legumes may be stored in more resistant organic matter and mineralized in subsequent growing seasons, providing long-term soil N status, even though N use efficiency may seem low in the first year (Boquet and Dabney, 1991; Evers *et al.*, 1994; Hargrove, 1986; Neely *et al.*, 2024; Wagger, 1989).

Although warm-season annual legumes can provide significant amounts of biomass and nitrogen, they must be inter-planted with other warm-season crops or cycled for green manure. Due to competition for scarce water and nutrient resources when intercropping, or the loss of cropping seasons when rotating, primary crops may experience production limits (De Barros *et al.*, 2007). In fact, when cowpea and maize were inter-planted on a sandy loam soil in Brazil, the cowpea maintained higher transpiration rates, grew deeper roots, and outperformed maize under poor soil fertility (Boe *et al.*, 1991; De Barros *et al.*, 2007; Smith *et al.*, 2020).

In order to improve the sustainability of biomass production, the main objective of this study was to determine the most effective way to incorporate legumes into high-biomass sorghum production systems, given their contributions of nitrogen and carbon. For the Pineywoods Vegetative Region of

East Texas as described previously (Gould, 1962), cowpea and red clover were determined to be the most suitable crops to represent warm- and cool-season annual legumes, respectively, based on earlier studies (Evers *et al.*, 2000; Kerby *et al.*, 2006).

11.12. Conclusions

The fresh red clover biomass had the narrowest C:N ratio and a high N content. It lost 37.6 kg ha^{-1} of N and 65.6% DM of its initial C during the first non-growing season, which lasted four months after inclusion. In the 30–60 cm deep subsurface, the amount of mineral N was 90% higher, indicating strong mineralization and a greater potential for N leaching.

In red clovers, fermentation increased the C:N ratio while maintaining a higher C content. Ensilage slows down the release of carbon to the soil during all treatment two-year periods. Fresh red clover biomass, meanwhile, rapidly released 91% of C. Technologically processed legume biomass greatly improved the synchronization index between crop N supply and demand, increased N use efficiency by 15%, and raised biomass output efficiency by 16%. Red clover fermentation produced the maximum synchrony index, but fresh red clover biomass was characterized by a low synchronization between the rotation's crops' N supply and N demand.

Compared to granulated cattle manure, processed legume green manures failed to meet the NUE and were able to reduce the favorable impact on spring wheat productivity in the first year. Fermented red clover, on the other hand, considerably raised the spring barley grain production in the second year and outperformed granulated cattle manure in terms of total synchronization index. This shows that employing fermented red clover instead of granulated animal dung is more environmentally friendly.

Cereal productivity showed a substantial correlation with the amount of N integrated into the soil, the pace of decomposition, and the amount of nitrogen released on a periodic basis. Furthermore, there was a positive and significant correlation ($r = 0.47–0.78$, $p < 0.05$) between the soil's total N amount integrated with legume manures and the rate of decomposition and the total biomass, protein content in grain, total N accumulated in straw, grain, and spring wheat plants.

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Chapter 12

Environmental Indicators for Organic Farming

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Environmental Indicators for Organic Farming

Abstract

Environmental indicators serve as valuable tools for monitoring environmental changes, evaluating environmental performance, and advising policymakers. A wide range of environmental indicators, including those specific to agriculture, are currently in use or under development. This special compilation of technical papers delves deeper into the scholarly research on environmental indicators, focusing on their application to pressing contemporary issues in various domains. These include the use of model-based indicators to detect phosphorus runoff from arable land, the examination of antioxidants related to the glutathione-ascorbate cycle as early indicators of toxicity in mangroves, and the evaluation of biobeds containing organic matrices to reduce herbicide dispersion from agricultural fields and mitigate on-farm pollution. With case studies demonstrating the interdependence regarding agricultural water, soil, and air quality, along with the application of model-generated indicators, the introductory review provides an introduction of environmental indicators, specifically in agriculture. Furthermore, gaps in current knowledge and suggestions for future research directions are explored. While environmental indicators, especially those tailored to agriculture, have proven effective at the field, catchment, and local levels as indicators of system performance and response, there is a need for ongoing refinement and development to better meet community expectations in terms of providing a comprehensive understanding of pertinent issues and enabling national or international comparisons.

Keywords: Environmental indicator, organic farming.

12.1. Introduction

We used the more comprehensive data from Food Wastage Footprint because FAOSTAT only offers a limited amount of information on food wastage statistics. The distribution of food wastage among commodity groups as well as areas globally is provided by this data, which is after that extrapolated to include all commodities and nations within such corresponding regions and groupings. All phases regarding the value chain are covered by the wastage data, such as post-harvest handling, agricultural production, distribution, processing, consumption, and disposal (including greenhouse gas emissions from the anaerobic decay of discarded biomass). At primary commodity level, these numbers are combined to calculate wastage shares. Assumptions of 25% and 50% reductions in wastage are made in scenarios pertaining to wastage reduction, which results in proportionate drops in the shares of wastage for each commodity. The impacts of waste reduction ranging from 0% to 50% can be evaluated using such scenarios. The production regarding each commodity declines in tandem with the reduction in wastage, which lowers the demand for inputs and the accompanying environmental effects. Agri-Environment Indicators (AEIs) are essential for understanding the intricate relationship between environmental factors and agricultural practices. These indicators not only quantify the environmental consequences of agricultural operations but also underscore the positive contributions of ecosystems to agricultural production and societal well-being. The impact of climate change on crop yields is a pressing concern that must be addressed (Asseng *et al.*, 2015; Martin-Rios *et al.*, 2023; Muller *et al.*, 2017b). The impact of climate change on crop yields was examined in a number of recent papers, with a primary focus on important crops including maize, wheat, soy, and rice. On the other hand, various other commodities are not adequately assessed. We need to perform a sensitivity analysis on the effect of climate change on crop yields since the results get much more complicated when CO_2-fertilization is taken into account. Our research spans a pessimistic scenario of no additional yield gains above the baseline to an optimistic view of no influence on yields. Although some research points to possible yield declines, we have decided not to include such risk in our scenarios. An intermediate scenario that

predicts yield increases at 50% of the reference scenario has been developed instead, representing extreme viewpoints of full climate change impact and no climate change impact. We have assumed that the effects of climate change will not have an impact on animal yields because of the lack of available data (Asseng *et al.*, 2015; Challinor *et al.*, 2014; Müller *et al.*, 2010; Müller and Robertson, 2014; Porter, 2022).

In addition, we constructed hypothetical situations in which organic farming experiences fewer negative impacts from climate change compared to conventional farming. This premise is based on the assertion that organic farming is more resilient to climate change than conventional farming, although there is limited evidence to support this claim and no definitive conclusion can be drawn. We created a simulation to illustrate this point, assuming that the impact of climate change on organic crop yields would only be 60% of that on conventional crop yields. However, the outcomes of this simulation are presented in supplementary figures rather than in the main content of the research paper (Muller *et al.*, 2017a; Scialabba and Müller-Lindenlauf, 2010). Land occupancy is typically used to evaluate the amount of cropland and grassland utilized for agricultural purposes. When it comes to cropland, the measurement of land occupancy considers both the areas that have been harvested and the cropping intensities, which indicate the frequency of harvesting on a particular hectare. Due to the presence of fallow areas, cropping intensities are often less than one, resulting in land occupancy values that are higher than the harvested areas.

Grassland areas are typically thought to be consistent under all conditions. But it's crucial to remember that a lot of grazing lands and grasslands are presently dealing with serious social and environmental issues. It might be essential to appropriately address such issues if the emphasis of ruminant production were to move to such areas (Roy *et al.*, 2015). The shift from arable to non-agricultural land, like forests, is the main emphasis of land use changes. In spite of its origin, the cropland occupation indicator evaluates the total land demand under different conditions. Assuming comparable patterns regarding sourcing land as in baseline, the deforestation indicator, on the other hand, looks at how such land demand affects forests in nations, in which deforestation is an issue. The difference between nitrogen outputs and nitrogen inputs is referred to as N-surplus. Crop residues, organic fertilizers, seeds, mineral nitrogen fertilizers, and nitrogen fixation are examples of inputs for crops. These inputs are assigned to various crops according to their nitrogen requirements in relation to the total nitrogen demands regarding all crops, which are established depending on the nitrogen resources that are available. When calculating N-surplus, nitrogen from atmospheric deposition is not taken into account. The quantity of nitrogen that a crop absorbs during its growth phase, such as the amount of nitrogen found in yields, crop wastes, and emissions, like ammonia, nitrous oxide, and nitrate, is known as its total nitrogen output. Since using mineral nitrogen fertilizers is prohibited, organic crop activities could just use organic nitrogen inputs such as nitrogen fixation, manure, and crop residues.

In livestock, nitrogen inputs are feed, whereas nitrogen outputs are manure products and manure emissions, like ammonia, nitrous oxide, and nitrate. The investigation of nitrogen sources includes all pertinent flows and compounds, with a special emphasis on volatilization, direct emissions, and leaching of nitrogen compounds such as ammonia, nitrous oxide, and nitrate produced by manure management and using fertilizers. The calculations' emission factors adhere to the recommendations made in IPCC 2006 report (Tier 1). SOL-model's results for the base year's worldwide aggregate N-surplus as well as subcategories, such as N-fixation are consistent with previous research (Bouwman *et al.*, 2013; Steinfeld *et al.*, 2006). There have been no systematic differences between conventional and organic livestock methods in terms of nitrogen surplus, other from the difference in yield production. All nitrogen outputs and inputs from grasslands and croplands are included in nitrogen surplus, which is shown as a global average per hectare, giving an overall average for such regions. As a result, direct comparisons to cropland values stated in the literature might not be appropriate. Using per-hectare figures highlights our emphasis on assessing the viability regarding organic farming from an agricultural standpoint, especially in light of the supply of nitrogen that is a concern in organic production. Studies indicate that nitrogen excess for

some cereals can be decreased by 50–70% without affecting yields, which helps determine the ideal surplus range between 10 kg/ha and 5 kg/ha. Even higher reduction rates might be attained, according to estimates on possible nitrogen input reductions as well as excess nitrogen proportions; the model's selected ideal range corresponds to a reduction of 60–80% when put to comparison with the reference scenario.

As a result, while evaluating the agricultural viability regarding changes in nitrogen surplus levels in various scenarios, we have chosen to aim for this considerably greater range of 60–80% reduction in nitrogen surplus (Good and Beatty, 2011; Mueller *et al.*, 2014). The literature has addressed the problem of organic agriculture's perhaps insufficient nitrogen supply. The use of fallow land, increased cropping intensities, and intercropping for the production of legumes have all been suggested as solutions to this problem. Yet, because the model required several questionable assumptions, such as the availability of water as well as the suitability of areas for off-season legume planting, such concepts were not included. There is disagreement over the validity of this assessment, especially with regard to the assumption that legumes will be grown alongside other crops on all available land. This might necessitate an extra 1360 million hectares of land, assuming a nitrogen fixing rate of 100 kg N/ha. Furthermore, a lot of criticism was leveled at the analysis of such approach. The literature has addressed the problem of organic agriculture's perhaps insufficient supply of nitrogen.

Furthermore, there was a great deal of criticism directed at the examination of this method (Müller *et al.*, 2010; Porter, 2022). P-excess: P-excess can be defined as the difference between P inputs and outputs with regard to nitrogen. P_2O_5 is used for measuring P-flows. Manure, animal feed, crop residues, and agricultural yields are examples of outputs and inputs that include mineral P fertilizer, P_2O_5. It is crucial to recognize that large quantities of P are fixed in soils in the case when assessing P-excess; in other words, the excess is simply a "potential loss" that might materialize, for example, through erosion, instead of actual environmental losses. SOL model's conclusions about the reference year's overall P balance are consistent with previous research (Bouwman *et al.*, 2013). The 'cumulative energy demand' (CED) methodology is used to evaluate the effects of non-renewable energy use, with renewable energy sources deliberately excluded. Without taking into account improvements in energy efficiency, it has been anticipated that the percentage regarding non-renewable energy used for electricity as well as fuels might stay constant across all scenarios (Frischknecht *et al.*, 2007). LCA-databases like ecoinvent 2.0 database and other pertinent sources provided the inventory data for particular activities, like differentiating between energy consumption in organic and conventional practices. Farm activities are linked to energy consumption, which includes energy use for a number of things, like crop protection, seeds, mechanization, fertilization, fencing, organic fertilization, stables, and roughage storage facilities. The ecoinvent 2.0 database and other relevant sources provided information on animal production. The amounts of fertilizer used for each crop in each nation are used to specifically model the energy consumption for fertilizer production. Ecoinvent 2.0 and SALCA inventories have been followed while modeling energy carrier inputs.

Transportation energy consumption was left out of the analysis due to a lack of trade-related data. It is crucial to highlight that the absolute figures on energy consumption might be subject to bias because of the aging data within ecoinvent 2.0, yet, the relative variations between scenarios are substantially less impacted by such data discrepancies (Nemecek *et al.*, 2005; Nemecek *et al.*, 2007; Schader, 2009; Schader *et al.*, 2013). Greenhouse gas emissions: Tier 1 and Tier 2 techniques are used in GHG emissions estimates, which are based on the procedures described in 2006 IPCC Guidelines. The ecoinvent 2.0 databases as well as several Life Cycle Assessment (LCA) studies provide information on emissions from infrastructure and agricultural inputs. FAOSTAT provides emissions from agriculturally managed organic soils as well as deforestation. Assumptions were established about feeding rations and shares in different manure management systems for the two types of production systems, with no differentiation made between emission factors for conventional and organic systems (Schader, 2009). With regard to greenhouse gases (GHGs),

especially 297 t CO_2e/t for N2O and 25 t CO_2e/t for CH_4, the Global Warming Potentials (GWP) as specified by IPCC2006 100a Tier 1 method have been applied. IPCC Tier 1 techniques were used for calculating emissions from fertilizer application as well as manure management. To take into consideration the effects of different feeding approaches, enteric fermentation emissions were evaluated with the use of Tier 2 approach. Utilizing ecoinvent 2.0 and other data sources, GHG emissions from the production of mineral fertilizers and pesticides were calculated. When aggregating emissions across common categories, SOL-model findings for total GHG emissions in the base year closely matched those found in existing literature. Emissions from buildings and processes have been calculated using process-specific conversion factors and respective CED-values obtained from ecoinvent 2.0.

SOL-model results as well as the literature references showed differences in enteric fermentation emissions, with SOL-model agreeing more closely with FAOSTAT data on this subject (Baeumer, 1992; Board, 2005; Chandrasekaran, 2010; Gattinger *et al.*, 2012; Geisler and Vearasilp, 1988; Gerber *et al.*, 2013; Gomiero *et al.*, 2011; Kissinger *et al.*, 2012; Pimentel *et al.*, 1995; Tubiello *et al.*, 2013; Wood and Cowie, 2004). Water use: AQUASTAT data and information on irrigated areas for various crops were used to calculate the amount of irrigation water consumed per ton of irrigated produce. It has been anticipated that the irrigation values per ton of production were comparable for conventional and organic production. According to AQUASTAT, the main causes of the disparities between the two systems are variations in crop distribution and yields with varying crop-specific irrigation values. Pesticide use: An effect assessment model has been created to measure pesticide use because there is a dearth of reliable data on its usage in various nations. The three main components of the model are pesticide laws in a particular nation, farmer access to pesticides, and the intensity of pesticide use by crop and farming system. Experts with experience in different nations and pesticide impact measurement techniques evaluated each element on a scale of 0 to 3. Deforestation: FAOSTAT data on deforestation from 2005 to 2009 have been contrasted with variations in each nation's agricultural land areas throughout the same time frame. Deforestation values in various scenarios were calculated using such comparison, which attributed 80% of deforestation to agriculture. An initial estimate of deforestation pressure has been required because of a lack of worldwide data, despite the fact that assuming continuous deforestation pressure per country in the year 2050 is a solid assumption. A ratio of deforested areas to total agricultural land area has been calculated for the base year in cases where information on changes in agricultural land areas for 2005–2009 was not available. For estimating deforestation values, this ratio was after that applied to the total areas of agricultural land under various scenarios. Deforestation values have been set to zero in situations where the total forest area increased.

The decline in deforestation rates in a reference scenario is explained by modeling deforestation in connection to changes in agricultural land areas. It captures the influence of land expansion on forests through assuming comparable dynamics as observed in baseline. This method complements the variable measuring land occupation, in spite of its source in a specific country. Yet, since a sizable amount of the additional land could probably originate from forests, the amount of deforestation might be underestimated for nations with notable increases in land occupation. Data on the suitability of forests, grassland, and other regions for crop production might be necessary for a more thorough examination regarding the dynamics of deforestation with rising cropland demand, but this is outside the scope of the presented work. Soil Erosion: The amount of soil loss (measured in tonnes per hectare annually) as a result of water erosion was the main focus of the soil erosion data analysis, which was conducted on a national level. Because of a lack of data, wind erosion was not taken into account. To differentiate between crops that posed lesser and higher risks of soil erosion, the rates regarding soil erosion per hectare were after that compared with a soil vulnerability score tailored to each crop. Permanent grasslands received a score of 0 on this index, crops with brief intervals of bare fallow received a score of 1, and crops with longer periods of bare fallow, like beets or maize, received a score of 2. Expert input and previously published literature were used to create this classification. Additionally, organic agricultural methods are anticipated to reduce soil erosion rates due to their generally greater amounts of soil organic matter (Baeumer,

1992; Chandrasekaran, 2010; Gattinger *et al.*, 2012; Geisler and Vearasilp, 1988; Gomiero *et al.*, 2011; Herrero *et al.*, 2013; Pimentel *et al.*, 1995).

12.2. Quality of water resources

In recent years, the quality of both surface water and groundwater has generally met the required threshold concentrations in many areas where monitoring stations are in place. However, elevated levels of nitrate in groundwater persist, largely due to inadequate implementation of sound agricultural practices. Certain regions characterized by intensive agriculture exhibit consistently high nitrate levels, indicating poor groundwater and irrigation water quality. According to the Agricultural Report of 2005, analysis of 183 samples of irrigation water in 2004 revealed that 63% exceeded the limit concentrations for nitrate, with pollution levels ranging from 2 to 17 times the prescribed limits. Additionally, most river streams downstream of settlements lacking proper wastewater treatment facilities exhibit elevated levels of nitrogen compounds and phosphates, particularly during low flow conditions (Pistalov and Sotirov, 2023). In recent years, there has been a decrease in the presence of synthetic substances such as pesticides, cyanides, and other chemicals, excluding petroleum products. The quality of water used for irrigation is crucial for both traditional and organic farming practices, especially in environments where expansion is challenging. Moreover, the excessive introduction of biogenic substances into river water poses a threat to aquatic ecosystems, including major water sources like the Black Sea and Danube River. To comply with the standards set by the EU Water Framework Directive, it is imperative to enhance monitoring of industrial, livestock, and domestic waste discharged into rivers, as well as adopt a more balanced and prudent approach to using mineral fertilizers.

12.3. Air quality and greenhouse gas emissions

Methane, ammonia, and carbon dioxide are the main greenhouse gases released by agricultural activities. Emissions of carbon dioxide are caused by the direct use regarding fuels in production processes as well as the carbon footprint of the resources used, like chemicals and machinery. Factors like erosion, soil management practices, burning of agricultural waste, fallow land, and deforestation contribute to increased carbon emissions and reduced sequestration. Methane sources primarily originate from animal husbandry activities, involving fermentation and microbial processes within the digestive systems of animals, as well as anaerobic decomposition of plant matter in manure. Nitrogen oxide emissions result from denitrification and nitrification processes, along with animal husbandry practices. Agriculture can potentially offset more greenhouse gas emissions than it produces through its operations, according to studies (Smith *et al.*, 2007; Tsigas *et al.*, 1997). As a result, it's critical to discuss greenhouse gas emissions in agriculture in the larger framework of how the sector could either contribute to or reduce such emissions. Examples include the production of biogas to reduce emissions, as well as biofuel production, which emits fewer harmful substances than traditional petroleum products. The data from the European Environment Agency (EEA) illustrates the industry's contribution to overall greenhouse gas emissions, showing a decline from 12.2% to 7.3% between 1990 and 2007. This downward trend is attributed to the industry's economic crisis and the increasing emissions from other sectors of the economy. Agriculture is an important source of nitrogen oxide, accounting for 60% to 70% of total nitrogen emissions, and methane emissions make up about 15% to 25% of the country's total emissions. Figure 12.1 displays the quantities of greenhouse gases, including methane and nitrogen oxide, measured in millions of tons of carbon equivalent (Borgan *et al.*, 2011; Kitou *et al.*, 2009).

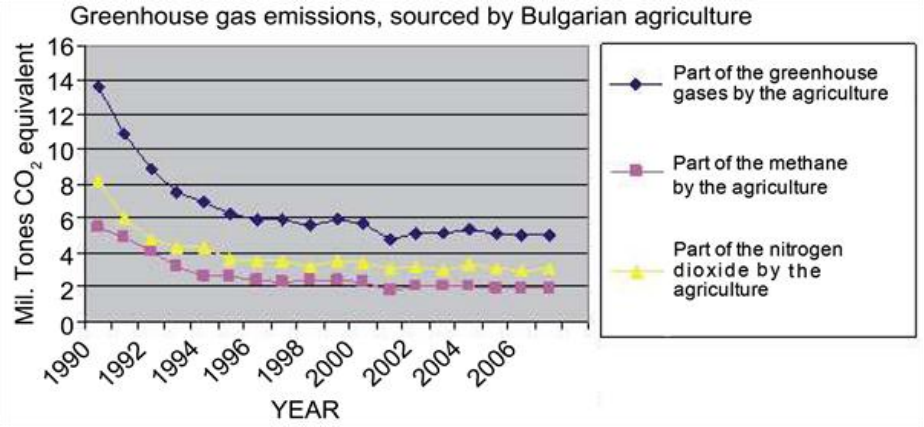

Fig. 12.1. Greenhouse gas emissions, sourced by Bulgarian agriculture (Pistalov and Sotirov, 2023).

There is a declining trend in greenhouse gas emissions, primarily due to a deceleration in the economic expansion of the sector, a decrease in ruminant populations, and a reduction in the utilization of mineral fertilizers. In order to proactively address this issue, more effective measures to mitigate emissions are necessary, including enhanced fertilization techniques, adherence to the stipulations of the Nitrates Directive, and the prevention of pollution from improper manure storage or usage. A survey conducted in Kyustendil municipality revealed that between 30% and 40% of the farms examined pose potential hazards due to their failure to meet manure storage requirements.

According to the 2005-2008 National Action Plan on Climate Change, policy instruments aimed at reducing emissions in the agricultural sector include: the management of manure (supported by financial incentives and advisory services) to achieve a 0.07 Mt greenhouse gas emissions reduction by 2010; the enhancement of fertilization practices (assisted by legal and financial mechanisms) and the reduction of water consumption for irrigation (supported by financial allocations from the SAPARD Program and the State Fund for Agriculture) to achieve a 0.17 Mt reduction in greenhouse gas emissions.

12.4. Efficient use of natural resources

Extensive agriculture is widely regarded as being more environmentally sustainable than intensive agriculture. Within the framework of the Common Agricultural Policy (CAP) and its reforms, there is a focus on agricultural practices that prioritize environmental conservation. While not entirely disregarding intensive agriculture, the adverse impacts associated with it are taken into consideration. Currently, Bulgaria's level of production intensification is relatively low, negatively impacting the productivity and competitiveness of agricultural goods. Enhancing intensive agricultural practices in accordance with good agricultural principles could align with environmental standards and ultimately enhance economic performance within the agricultural sector.

12.4.1. Environmental risks in arable land use

The distribution between arable and fallow lands within utilized agricultural areas (UAA) serves as an indicator of the potential environmental pressures that may be faced during the processes of cultivation, production, and harvesting. Research has shown that larger arable areas are more vulnerable to environmental risks, given that they are often reliant on single crops, leading to increased susceptibility to pests and necessitating higher pesticide usage. Additionally, the use of large-scale machinery can result in soil compaction. Arable land encompasses the combined area under crop rotation, annual grass mixtures, cereal and legume crops, and fallow land. Over the period of analysis from 1998 to 2007, there has been a noticeable decrease in arable land of

approximately 10% or 334,386 hectares (Figure 12.2). This drop represents a reduction of more than 25% compared to the levels observed in 1989 when arable land covered around 4.1 million hectares. Despite this decline, the proportion of arable land in UAA has remained relatively stable at approximately 60% during the same timeframe, largely influenced by the concurrent decrease in UAA.

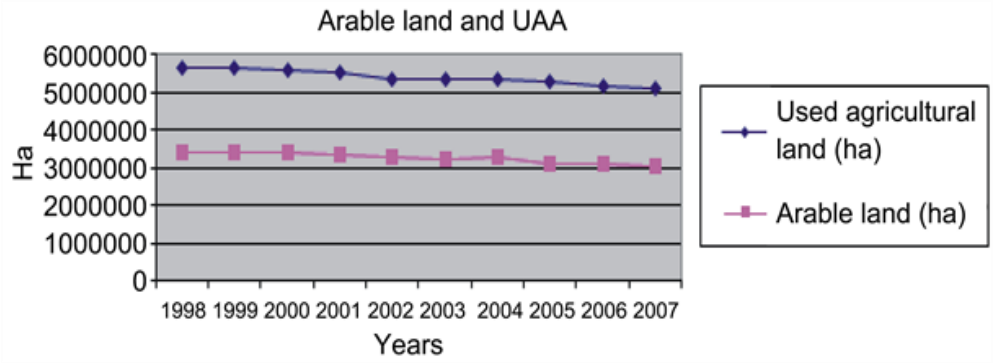

Figure 12.2. Arable land and UAA (Source: MAF) (Pistalov and Sotirov, 2023).

The decline in arable land area may be seen positively from an ecological standpoint for certain types of land, but not economically or socially. Abandoned land near arable areas often attracts pests and become dumping grounds. Energy crop programs are expected to turn such lands into potential biomass sources, including for second-generation biofuels that don't conflict with food production.

The composition of agricultural crops plays a significant role in determining the ecological condition of the land being utilized. Extensive farming practices are considered more environmentally friendly, whereas intensive agriculture poses greater risks to the environment. The crop structure influences the ecological status through specific farming techniques and intensification factors like mineral fertilizers, pesticides, irrigation, and mechanization.

In our country, cereal crops and oilseed crops dominate the agricultural landscape, necessitating the use of significant amounts of artificial fertilizers and mechanization. While the area dedicated to cereals decreased slightly and oilseed crops increased marginally from 1998 to 2007, there was an overall reduction in the combined area of these two crops (Figure 12.3). Cereals and oilseeds cover about 82% of arable land, utilizing over 70% of mineral fertilizers, mainly nitrogen, and more than half of pesticides. Poor fertilization practices and the need to mitigate the effects of climate change are expected to impact the environmental sustainability of this production pattern. Learnings from developed countries warn that monoculture, limited crop rotation, and intensive farming techniques contribute to the depletion of soil organic matter and economic fertility. Consequently, monocultural farming in our country, coupled with inadequate fertilization and neglect by large-scale tenants, poses a potential threat to soil resources. The composition of cultivated crops can serve as an effective economic indicator for assessing the specialization of production and economic efficiency within specific crops. When combined with other indicators, such as the dynamics and structure of agricultural imports and exports, it can reveal missed production opportunities, whether due to imports or untapped export potential for agricultural products. A persistent issue in the agricultural sector is the inability to meet the population's demand for certain products, particularly fruits and vegetables, which have consistently remained low in availability. Despite investments made through programs like Sapard in recent years, this is mainly due to reductions in cultivated areas, lower yields, and inadequate investments. The utilization and treatment of wastewater within the agricultural sector have been on the rise in recent years, with an annual volume reaching 258,022 thousand cubic meters. Although the sector's share of total water usage has increased slightly to

2.7% - 5.2%, there has also been a noticeable increase in wastewater generated by the agricultural sector, indicating a 25% rise in 2007 compared to 2000 (Figure 12.4). The disposal of wastewater from the agricultural sector, as shown by NSI data from 2000-2005, reveals that over half of the water used is released untreated, a figure that has increased to two-thirds by 2007. This trend poses environmental challenges and may hinder compliance with regulations such as the Water Framework Directive and the EU Nitrates Directive in the future. Addressing this issue will require significant investments, potentially sourced from the Rural Development Program, private funding, or through public-private partnerships.

12.5. Energy efficiency of agriculture

This indicator serves dual environmental and economic purposes by providing insight into energy usage within agricultural production processes. According to data from the National Statistical Institute (NSI), a decrease in the agricultural sector's gross domestic product (GDP) has led to a slight decline in energy efficiency, as measured by the ratio of GDP to oil consumption. In contrast, the industrial sector has improved its energy efficiency by reducing energy consumption per unit of GDP by half. In a broader context, this indicator can be viewed as a measure of energy intensity, specifically examining the relationship between the age of equipment and fuel/lubricant consumption, which in turn impacts greenhouse gas emissions. Despite efforts to modernize equipment through programs like SAPARD, outdated machinery continues to dominate, negatively impacting environmental sustainability and energy efficiency.

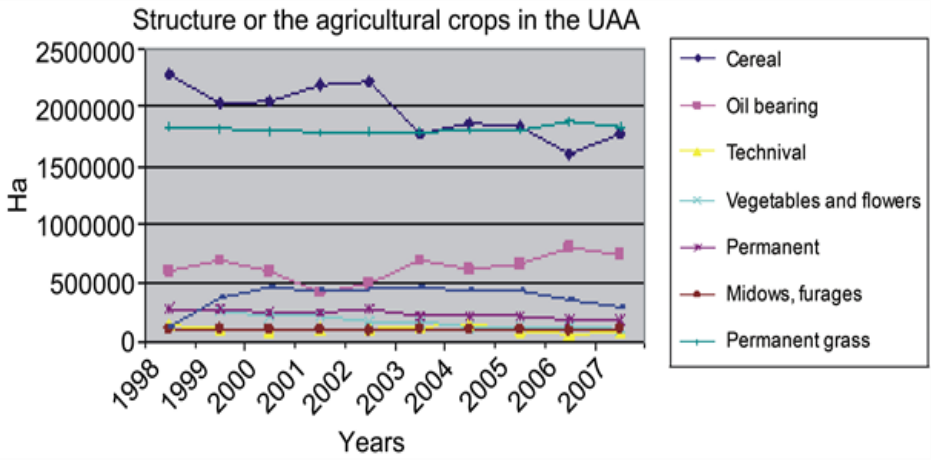

Figure 12.3. Structure of agricultural crops in the UAA (Source: MAF) (Pistalov and Sotirov, 2023).

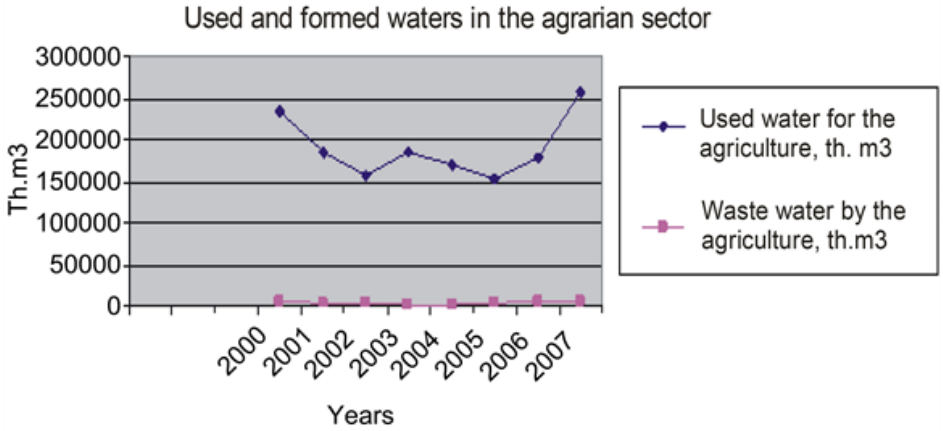

Figure 12.4. Used and formed waters in an agricultural sector (Source: NSI) (Pistalov and Sotirov, 2023).

12.6. Composting and production of renewable energy

Bulgaria has significant potential for cultivating "energy crops" to be used in renewable energy production. Estimates suggest that there is a substantial amount of biomass available, in the form of plant waste left over after each year's harvest, totaling between 4.6 and 5.2 million units. This resource remains largely untapped, but it could be used for the production regarding second generation ecobriquettes and biofuels. It is worth noting that the common practice of burning this biomass directly in the field is in conflict with modern European regulations that prohibit such methods due to their detrimental effects on soil fertility and the potential spread of toxic substances like furans. With the increasing costs of traditional energy sources and the necessity of meeting the EU's renewable energy objectives, there is an opportunity for the agricultural sector to attract private investments and become more competitive. For instance, investments in projects that involve the utilization of waste biomass, through initiatives such as the Joint Implementation Facility and the Green Investment Facility under the Kyoto Protocol, could yield promising returns (Ratarova and Ferdinandova, 2008). The growth of energy crops for biofuel production, such as rapeseed, exemplifies a more comprehensive utilization of arable land. The rapid expansion in these fields is not without scrutiny. For instance, in Bulgaria, the cultivation of rapeseed surged sevenfold between 2000 and 2007, reaching 54,707 hectares. This winter-spring crop effectively utilizes seasonal moisture and has a market demand in Bulgaria and the EU. However, its competitiveness in the market leads to debates regarding financial support.

The potential for biogas production in Bulgaria faces challenges and is primarily constrained by the fragmented nature of livestock farming. Investing in farms that reach optimal European standards is essential to comply with the Nitrates and Groundwater Protection Directive and to achieve greenhouse gas reduction goals in the agricultural sector. The current situation indicates that only a limited number of larger livestock farms are able to access the necessary funding to harness the energy potential of animal waste.

12.7. Impact on species diversity and landscape

These are two relatively recent indicators that have been observed within the agricultural sector. They have become mandatory following the establishment of the NATURA 2000 ecological network and the assessment of lands with high nature value in Bulgaria. These indicators are incorporated into agri-environmental measures as part of the Rural Development Program, as well as in other European biodiversity conservation programs such as the LIFE + instrument. A survey conducted among farmers in the Kyustendil region revealed a lack of awareness regarding where they can obtain information about whether their lands are within the ecological network territories or designated as high nature value lands. This information is crucial for them to apply for compensation through the Rural Development Program. Within the framework of DPSIR analysis, indicators for evaluating habitats, biodiversity, and landscapes are utilized during the "State" phase in specific local areas and in the "Impact" phase for the broader EU environment. The conservation and preservation of landscapes should be viewed not only as a component of environmental sustainability but also as a key aspect for generating alternative income through the development of tourism and recreational activities. Similar to the support provided for species diversity conservation, financial assistance is also available for landscape preservation under the relevant measures of the Rural Development Programme. During the first half of the period 1998-2007, aside from isolated pilot projects focused on agri-environmental schemes, targeted programs with allocated budgets and expected outcomes were not readily available. However, the implementation of the National Rural Development Plan (NRDP) in conjunction with the SAPARD Programme led to a shift towards integrating environmental considerations into agricultural policy. This resulted in funds allocated for

agri-environmental measures amounting to 2.8% of the total program budget. In Bulgaria, agri-environmental measures covered just 0.7% (32,000 ha) of arable land in 2006, in stark contrast to the 20% coverage in other EU member states.

12.8. Investments in the agricultural sector for environmental protection

This represents a significant metric; however, there remains an insufficient amount of comprehensive data available for accurate assessment. While there has been an increase in investment in environmental initiatives from 1.3% to 2.7% of gross domestic product between 2000 and 2007, the proportion allocated to environmental projects in the agricultural sector has only seen a slight rise of 12% to 15%, as reported by the Ministry of Environment and Water. Particularly lacking are investments in ecological projects related to fertilizer sites and wastewater treatment at livestock farms (Azarov *et al.*, 2025; Pistalov and Sotirov, 2023).

12.9. Assessment of critical ecological points

The topic at hand revolves around the utilization of mineral fertilizers, pesticides, irrigated lands, manure, and areas dedicated to organic farming.

12.9.1. Utilization of mineral fertilizers

The usage of mineral fertilizers (as depicted in Figure 12.5 and Figure 12.6) witnessed a significant decrease by over five times during the period of 1989-1998. This decline can be viewed in two aspects; on one hand, it serves as a positive environmental indicator in reducing pressure on the environment, but on the other hand, such a sharp decline negatively impacts productivity. This can be attributed to the financial constraints faced by farmers in procuring mineral fertilizers during the initial period, coupled with the rapid escalation in their prices compared to agricultural products, rendering their usage economically unviable. The period from 1998-2007 experienced a slight uptick in the utilization of nitrogenous fertilizers. It is essential to consider the qualitative aspect of this indicator as well, including the usage of mineral fertilizers per unit area and the proportion of active substances. The data indicates a prevalent practice of unbalanced fertilization in the country, with nitrogen taking precedence. While the optimal ratio of nitrogen, phosphorus, and potassium stands at 1:0.8:0.4, the actual ratio is 1:0.17:0.08, i.e., considerably lower for phosphorus and potassium by five times each. Over-reliance on nitrogen fertilizers elevates the risk of nitrate pollution in soil, water, and production, converting the agricultural sector into a source of unused nitrogen compounds, thereby disrupting the climate. Unbalanced fertilization exerts a detrimental impact on soil fertility and contravenes soil conservation imperatives.

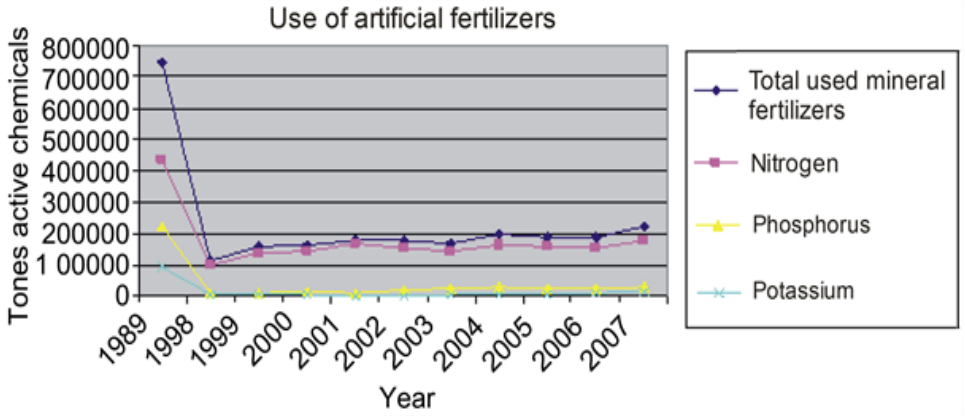

Figure 12.5. Use of artificial fertilizers (Pistalov and Sotirov, 2023).

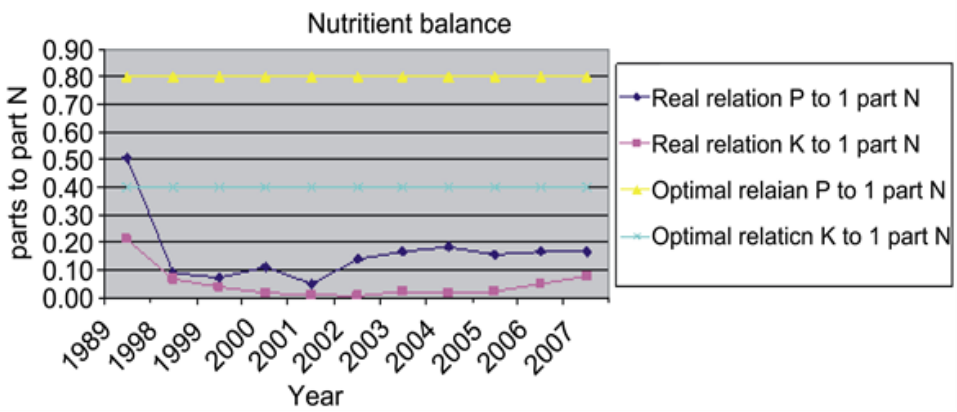

Figure 12.6. Nutrient balance (Pistalov and Sotirov, 2023).

12.9.2. Areas with an established irrigation network

We will place additional emphasis on this particular indicator, given its significant economic importance. It is worth mentioning that irrigation, beyond its environmental repercussions, also yields a substantial influence on the economic and social sphere by promoting job creation and ensuring stability in crop yields that are typically susceptible to fluctuations due to natural climate variations and global warming. Any fluctuations in production can lead to price instability, causing social unrest and a rise in prices (Ciavatta *et al.*, 2022; Štefanová and Šálek, 2014).

12.9.3. Good agricultural practices

Good Agricultural Practices (GAPs) can provide a framework for evaluating whether agricultural activities align with environmental criteria. When considering an environmental indicator such as "Good agricultural practices", it is essential to establish specific mandatory conditions:

- This indicator differs from typical quantitative measures and instead offers a more comprehensive assessment that encompasses a diverse set of considerations. It is classified as a qualitative dimension, reflecting the extent to which Bulgarian agriculture adheres to modern agro-ecological standards and the Common Agricultural Policy (CAP).

- Due to the broad scope they encompass, GAPs address various sectors and can be integrated with existing agri-environmental indicators.

- GAPs serve as a valuable tool for gauging institutional efficiency, ensuring compliance with regulations, and promoting environmental preservation within a sustainable framework.

- The adoption of GAPs also indicates the level of ecological consciousness and forward-thinking within the agricultural sector.

Organic farming is recognized as a form of good agricultural practice, and when evaluated in terms of the proportion of land dedicated to organic farming compared to total agricultural land, it offers a basis for international comparison.

Furthermore, additional activities like organic farming, preservation of endangered local breeds, and management of semi-natural habitats are also highlighted within the scope of GAPs (Amekawa, 2009; Gravani, 2009).

12.9.4. Areas under organic farming

Organic farming, as previously stated, is considered a beneficial agricultural practice supported by various global and Bulgarian publications that highlight its advantages. Instead of delving further into this topic, a specific quantitative measure that illustrates the prevalence of organic farming is

the proportion of agricultural land devoted to organic production within the total agricultural acreage (UAA). Eurostat reports that in 2007, only 0.4% of the UAA was dedicated to organic agriculture, a figure that appears quite minimal when considering the environmental, social, and economic conditions present in Bulgaria. These conditions include the purity of natural resources, extensive traditional farming methods, high levels of rural unemployment leading to available labor, market assistance through CAP measures, and the strong institutional backing seen in initiatives like "The National Plan for the Development of Organic Agriculture in Bulgaria 2005-2013". This plan aimed at increasing organically managed land to 8% of the UAA, highlighting the lack of alternative income sources in certain areas (Agapieva, 2015; Jancsovszka-Puskás, 2015; Malik *et al.*, 2001; Mitova, 2021).

12.10. Conclusions

The analysis of environmental indicators at the sectoral level yields several key conclusions:

- Agricultural activity has resulted in good overall condition of natural resources due to changes in systems and agricultural production, reduced pressure from other sectors of the economy, industry stagnation post-1990, and the implementation of sustainable agriculture principles in accordance with the CAP.

- Despite positive aspects, significant issues remain, particularly in terms of industry's negative impact on agricultural resources and potential threats such as erosion, acidified soils, salinization, nitrate pollution, water pollution from slurry discharge, pesticide contamination, heavy metal and radionuclide contamination, and pollution risks from anthropogenic waste.

- There is also a risk of land degradation, abandonment of businesses and arable land, deterioration of crop structures towards more intensive and monocultural production, inefficient manure use, low energy efficiency, underutilized potential for energy crop growth, deteriorated meliorative networks, and insufficient knowledge and implementation of sustainable agriculture principles.

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Chapter 13

The Role of Tissue Culture in Organic Farming

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The Role of Tissue Culture in Organic Farming

Abstract

There is a sizable worldwide industry devoted to multiplying, sourcing, and marketing indigenous planting material as a result of the growing demand for it for ecological restoration as well as rehabilitation in agro-silvo-pastoral ecosystems. Disease-free, high-quality, and genetically consistent plants can be produced quickly using Plant Tissue Culture. The growing need for planting material as well as reforestation initiatives can be met through micropropagation. Yet, in comparison with more conventional approaches that include seeds, suckers, and cuttings, in vitro plant propagation turns out to be an expensive procedure. Therefore, it is crucial to put measures into place that reduce production costs without the need to sacrifice plant quality. To do this, the culture media's composition could be improved. Adding organic growth enhancers to the culture media could increase the production of leaves, shoots, and roots as well as encourage tissue growth. The maturation and formation of cultures are accelerated by organic supplements, yielding robust plants. In contrast to callus and somatic embryogenesis, plant re-generation from meristems (axillary buds and shoot tips) is a reliable technique to create genetically consistent plants; nonetheless, in vitro culture settings could introduce mutations. Thus, it is considered crucial for propagation purposes to discover somaclonal differences early in plant growth. DNA-based molecular markers should be utilized in order to verify the genetic stability of plants that had been regenerated in vitro. In addition to highlighting the value of the use of PCR-based molecular markers like ISSR, RAPD, SCoT, and SSR, this study aims to present an updated summary of research developments in the incorporation of organic growth enhancers to boost in vitro tissue culture protocols.

Keywords: Organic growth additives; plant propagation; molecular markers; genetic stability.

13.1. Introduction

Global agro-silvo-pastoral ecosystems have suffered as a result of human activity as well as climate change. The requirement for native plant materials has increased due to global efforts to restore eco-systems, and present production methods are unable to supply this need. To sustain or rebuild adaptive, resistant and robust ecosystems and communities, native species must be used in initiatives of restoration. For addressing marginal and degraded rangelands' rehabilitation, it is becoming increasingly important to create approaches for large-scale planting of particular genotypes of pastoral, medicinal, and forest species (Baughman *et al.*, 2022; De Carlo *et al.*, 2021; Hudson *et al.*, 2014; Louhaichi *et al.*, 2021; Ouled Belgacem and Louhaichi, 2013; Pedrini *et al.*, 2020; Yirdaw *et al.*, 2017). For propagation of clonal plants, in vitro tissue culture regeneration is acknowledged as a very successful technique. The many variables that interact with one another make it difficult to create effective plant tissue culture protocols. Important elements including the culture conditions, plant raw material, and media composition affect the quality of the end product that has been obtained from any plant cell culture procedure. The morphogenesis and growth of plant tissues in culture are significantly influenced by the choice of growth regulators as well as nutritional elements. Plant micropropagation media contain various additives and components that should be carefully chosen for each situation based on the species, cultivar, or type of explant. The optimal growth of tissues in vitro requires the presence of adequate concentrations of nutritional needs. Macronutrients, micronutrients, sugars, vitamins, gelling agents, amino acids, and growth regulators are among the ingredients frequently found in micropropagation media (Chimdessa, 2020; Häkkinen *et al.*, 2018; Hameg *et al.*, 2020; Khorsha *et al.*, 2016; Moraes *et al.*, 2020). Yet, such substances are expensive and may be hazardous if utilized in inadequate amounts. As a result, several studies were conducted to examine how the composition regarding culture media might be changed by adding inexpensive organic

substances in place of more expensive ones, all while preserving the quality of the plants that are grown. The maturation and growth of plants have been demonstrated to be greatly aided by various organic growth supplements, including banana pulp, tomato juice, yeast extract, coconut water, potato homogenate, papaya juice, and pineapple pulp. Complex combinations regarding organic nutrients as well as growth promoters are offered by such organic growth supplements (De Stefano *et al.*, 2022; Häkkinen *et al.*, 2020; Huh *et al.*, 2016; Kassanuk *et al.*, 2020; Manawadu *et al.*, 2014; Thejaswini and Narasimhan, 2017; Wu *et al.*, 2014). Beyond their use as a carbon source, organic growth additives provide a multitude of natural vitamins, fiber, phenols, proteins, hormones, minerals, and lipids, which further supports their inclusion in the culture medium. With an emphasis on the use of organic growth additives and the need to use PCR-based molecular markers in order to confirm genetic stability of plants that are re-generated in vitro. The presented work explores the changes made to the composition regarding culture media for the propagation of plant tissues (Khorsha *et al.*, 2016). The sources used in this debate were found via a thorough keyword-based search on reliable platforms like Scopus, JSTOR, onlinelibrary, Science Direct, Springer, and Google Scholar, all of which were current as of July 2022.

13.2. Fruit, vegetable, and plant extracts

Distinct plant species have distinct nutritional requirements, which impact the development and growth of plant tissues. Nutrients that are needed by tissues in different regions of a plant could differ to ensure optimal growth. To determine their effect on growth promoting, culture media are generally supplemented with various organic extracts or substances, which include pineapple pulp, tomato juice, coconut milk, banana homogenate, and papaya juice (Häkkinen *et al.*, 2018).

Three species of Daphne, *Daphne tangutica*, *Daphne caucasica*, and *Daphne jasmine* have successfully undergone micropropagation on MS media that is supplemented with organic growth supplements that include pineapple pulp and coconut water. Using 5 different organic growth supplement kinds, the in vitro re-generation procedure for Celosia sp. had shown that young coconut juice (YCJ) at a 70mL/L concentration produced the greatest shoot re-generation rate, at 14.21 shoots. Furthermore, it was discovered that 50 mL/L of tomato and banana juices greatly accelerated the regeneration of shoots in stem segments, yielding 9.57 and 9.28 shoots per explant, respectively. Papaya juice had the maximum shoot regeneration rate at 10.5 shoots, even at a lower concentration of 20 mL/L. Green gram, rice flour, banana fruit, ground pumpkin, ground spinach leaves, orange juice, ground carrot, ground potato tubers, coconut milk, coconut water, and other organic growth supplements were all assessed (Häkkinen *et al.*, 2020; Manawadu *et al.*, 2014; Moraes *et al.*, 2020). The best results for enhancing Raphanus sativus's in vitro regeneration process were seen in Murashige and Skoog (MS) medium that has been supplemented with 10% orange juice, which produced the most shoots per explant (12 shoots). Coconut water (CW), banana powder (BW), and potato dextrose (PD) have been added to the basal seed sowing medium for the establishment of *Epidendrum nocturnum*. At 60 and 90 days after seeding, respectively, the maximum germination percentages (71% and 76.75%) were obtained when 10 mL/L of CW has been added to the culture medium. Furthermore, the media that contained 5g/L BW + 5mL/L CW showed better results in terms of fresh weight (0.08 g), plant length (19.80mm), and root number (2.1). With the use of a one-quarter strength MS medium in asymbiotic seed culture, a research was carried out for the purpose of evaluating effects of different organic additives (like birch sap, CW, BW, and maple sap) on *Cypripedium macranthos* in vitro germination, seedling growth, and protocorm formation. In the case where 100mL/L of coconut water has been added to basal medium, the highest percentages of germination and protocorm formation (70.8% and 74.2%) have been obtained. Additionally, percentages of germination and protocorm formation had surpassed 65% and 68% when 100mL/L of birch sap or maple sap was added. Knudson C medium that has been supplemented with organic growth additives (like banana pulp, tomato juice, and coconut water) at different concentration levels demonstrated notable protocorm development when exposed to 25g/L of banana pulp in comparison to other supplementations in case when investigating the in vitro propagation of Dendrobium lowii. With all

protocorms successfully forming shoots and 93.30% of protocorms establishing roots, this treatment had the greatest value of growth index of 593.30 (Huh *et al.*, 2016).

13.3. Amino acids, polyamines, and proteins

For cell repair and growth, the majority of plants can generate the amino acids they need. Promoting cell proliferation as well as tissue development, on the other hand, requires supplementing the culture media with amino acids from external sources. In contrast to inorganic nitrogen, amino acids are absorbed easily through plant tissues and cells. Elshahed and Saad claim that plant cells are more effective at absorbing and using nitrogen from organic sources than from inorganic ones. In vitro propagation of a number of the plant species, including Fragaria x Ananassa duch cv. Chandler, *Rosa centifolia*, *Oryza sativa*, *Hibiscus moscheutos*, and *Carica papaya*, has shown the efficacy of utilizing amino acids as a source of organic nitrogen in order to promote tissue regeneration and growth (Akhtar *et al.*, 2016; Banani Deka and Anania Arjuna, 2014; Bhausaheb Pawar *et al.*, 2015; Bindu and Podikunju, 2017; El-Sharabasy *et al.*, 2015; Greenwell and Ruter, 2018; Saad and Elshahed, 2012). The quantity and type of amino acids that have been utilized in the medium have a major impact on the development and growth of numerous shoots, as shown previously (Baskaran *et al.*, 2012). The effectiveness regarding three nitrogen sources—casein hydrolysate (CH), adenine sulfate (Ads), and putrescine (PU)—in promoting Chlorophytum borivilianum shoot multiplication in vitro was examined in a previous study (Khatri *et al.*, 2019).

13.4. Essential oils

One of the major problems with tissue culturing in vitro is microbial contamination. One potential alternative technique for plant tissue culture is the use of plant extracts, like essential oils, for explant sterilization and the development of a sterile culture medium in place of autoclaving. Another barrier to efficient in vitro propagation is oxidative browning, which is brought on through polyphenols accumulation as well as oxidizing in culture media. Controlling phenolic oxidation, which causes enzymatic browning, and inhibiting microbial growth are essential for successful establishment of in vitro tissue cultures. The efficacy regarding *Thymus vulgaris* as well as *Rosmarinus officinalis* essential oils for controlling enzymatic contamination and browning in *Aloe vera* cultures was examined in a research (Hamdeni *et al.*, 2022). Following 4 weeks of culture with the use of concentration levels of 0.05%, 0.075%, and 0.10%, *R. officinalis* produced the best survival rate of explants (100%) without any symptoms of browning, despite restricting explant growth utilizing Thymus vulgaris essential oil. The media that contains 0.075% and 0.10% of *R. officinalis* had the lowest infection incidence (10%). With 0.10% *R. officinalis*, the mean number of leaves in each explant has been the highest at 3.71, and with 0.05%, the largest length of the leaf has been 3.18cm. In order to produce sterile conditions in the medium, Taghizadeh et al. found that adding carvacrol, eugenol, or thymol at 0.01% and 0.50%, respectively, resulted in efficiently inhibiting the growth of bacterial and fungal contaminations without requiring the medium and vessels to be autoclaved. Bacterial and fungal infections in *Cynodon dactylon* nodal explants were successfully managed by the antiseptic characteristics of carvacrol and thymol (at 200mg/L each and exposed for 60min to 120min) (Deein *et al.*, 2013).

13.5. Marker-assisted genetic stability assay

Ecosystem services, biodiversity, and human well-being are all seriously threatened by the negative effects of overexploiting natural resources. To keep ecosystems functioning and to stop the loss of genetic resources as well as habitats, it is necessary to support conservation initiatives. Utilizing micropropagated plant materials is an appropriate technique for restoration of biodiversity in endangered, rare, and threatened plant species through reintroduction, conservation, and recovery initiatives in situations where maintaining the authentic genetic pool is crucial (Arneth *et al.*, 2020; Bakhshipour *et al.*, 2019; Priyanka *et al.*, 2021). While several DNA molecular markers were produced lately to verify genetic stability, the most sophisticated and dependable solutions

with high rates of repeatability are start codon targeted (SCoT) and inter-simple sequence repeats (ISSR) markers. Furthermore, because of their strong discriminatory power, sensitivity, and co-dominant inheritance nature, SSR markers had attracted a lot of interest in the evaluation of genetic stability. Organic growth additives, like polyamines, proteins, amino acids, and extracts of fruits and plants have been shown to promote cell proliferation, tissue development, and morphogenesis, according to a number of authors. It is yet unknown, nevertheless, if plants cultivated in vivo and regenerated in vitro have genetic stability (Bednarek *et al.*, 2021; Elyazid *et al.*, 2021; Hussien *et al.*, 2022; Jaiswal *et al.*, 2021; Nowakowska *et al.*, 2022).

13.6. RAPD analysis

As a nitrogen source, 400mg/L Gln has been added to MS medium to improve the somatic embryos from *Sterculia alata*'s optimal development and maturation. In genetic analysis, 181 amplification bands have been detected with the use of 25 RAPD primers, with an average of 7.24 bands in each primer. The addition of 10mg/L of CH to MS medium produced the greatest rate of multiplication of 5.08 and improved elongation of the shoots, yielding a mean shoot length of 2.94cm for *Prunus salicina*, 14 of 16 RAPD used primers had produced 43 fragments of amplification with sizes that range between 200bp and 1500bp. All of the plants that have been evaluated showed monomorphic banding profiles that have been similar to parent plants. The addition of the polyamines (Spd & PU) to *Phoenix dactylifera*'s MS medium could help produce genetically stable plants (Abdelsalam *et al.*, 2021; Samarina *et al.*, 2019; Zhang *et al.*, 2021).

13.7. SSR analysis

When Gln (150mg/L) and CH (100mg/L) have been added to the nutritional media, Musa AAB variety Chenichampa showed the highest induction of somatic embryos (85%), surpassing the control condition (Natarajan *et al.*, 2020). Ten SSR primer tests revealed no genetic differences between the plants generated from embryogenic cell suspension as well as their parent plant. Adding CH (100mg/L) and Gln (500mg/L) to *Stipagrostis pennata* culture media resulted in maximum production of embryogenic callus (Asadi-Aghbolaghi *et al.*, 2021). Single amplification bands of 185bp, 412bp, 243bp, and 210bp were found for 1, 3, 7, and 8 primers, respectively, while testing with ten SSR primers. In the case when evaluated using SSR primers, the incorporation of Gln and CH as organic growth supplements in regeneration protocols showed genetic stability, confirming the protocols' dependability.

13.8. RAPD and ISSR analyses

Using ISSR and RAPD analysis, the genetic stability of the in vitro re-generated plants of *Valeriana jatamansi* and *Ranunculus wallichianus* on MS medium that has been supplemented with 10% CW was verified. The quantity and length of shoots and roots (13, 19.6, 6, and 7.5 cm) increased when CW was added to the propagation procedure for *Valeriana jatamansi*. Only 5 ISSR and 10 RAPD primers out of 10 ISSR and 35 RAPD primers that were tested displayed banding patterns that were comparable between mother plant and in vitro plantlets. The addition of CW to MS medium produced shoot length (9.2 cm), highest re-generation response (97%), and number of shoots (11.10shoots/ culture) in the case of *Ranunculus wallichianus*. On average, 6 and 5 bands per primer, with sizes that range between 200bp and 1500bp and 200bp to 1000bp, were produced by 9 RAPD and 8 ISSR primers, respectively, according to the analysis. Significant efficacy was demonstrated by the addition of plant extracts like SSE to culture medium, which led to dose-dependent increases in root biomass as well as shoots and root length. With 11 and 26 monomorphic amplicons, respectively, only 2 out of 6 RAPD primers and 4 out of 11 ISSR primers produced stable amplicons (Pandey *et al.*, 2020; Srinivasan *et al.*, 2021; Vasudevan *et al.*, 2017).

13.9. SCoT and RAPD analysis

Using SCoT and RAPD markers, it has been shown that Citrullus lanatus as well as Pisum sativum plants grown in vitro have genetic stability when the Spd and PU polyamines have been added to their nutritional media. Citrullus lanatus showed higher shoot induction response (93%), shoot elongation (6.3 cm), and shoot number (46.43shoots/explant) under the addition of 10 mg/L of Spd and PU. Furthermore, the greatest rooting percentage (95%) as well as the production of 23.03 roots per shoot with a length of 4.32cm were noted, 9 RAPD and seventeen SCoT primers produced forty-one and forty-seven monomorphic fragments, respectively, with sizes ranging from 200bp to 180bp and 300bp to 2000bp. However, Pisum sativum showed the greatest number of roots (33.66 roots/shoot) with 30mg/L of PU and the largest number of multiple shoots (65.10 shoots/explant) when treated with 20mg/L of Spd. Thirty-four and thirty-eight monomorphic fragments, ranging from 400 to 600 and 100 to 500 bp, respectively, were obtained using nine RAPD and seventeen SCoT primers (Ajithan *et al.*, 2019; Muthukumar *et al.*, 2020).

13.10. Regulation of plant growth in cell and tissue culture

Plant regeneration and plant tissue culture are crucial components regarding plant biotechnology, which spans numerous industrial and scientific sectors. Our knowledge of the mechanisms governing plant regeneration in vitro has greatly expanded as a result of recent developments, which have also accelerated the development of specific tools and techniques to optimize this process. Both plant scientists and industry have taken notice of this development, which emphasizes the continual need to improve protocols for choosing and regenerating superior genotypes in order to increase reproducibility. In such context, a careful fine-tuning procedure is essential. The application and development regarding cell as well as tissue culture methods often result from empirical study, and plant tissue culture includes a variety of regenerative pathways. The optimal nutritional balance and the development regarding competent cells capable of molecular and epigenetic re-programming for the induction of stem cells are two important elements that determine plant tissue culture success. Another crucial factor is the precise temporal and spatial control of endogenous hormone distribution and production. Although new methods that use data-driven modification of the composition of the culture media have produced encouraging results, quick improvements in culture techniques could be achieved by utilizing what is already known about classical plant physiology. Additionally, the authors' practical experience—which comes from their more than 30 years of research in this area—informs the insights offered in this debate (Lee *et al.*, 2022; Zhou *et al.*, 2023).

13.11. Organizer cell type that controls plant regeneration

Plants, which are immobile, evolved a complex system of signals and structures in order to control and coordinate their growth. Stem cell niches are one such process that, in some conditions, could result in the development regarding a new organ or even a new plant. Although a great deal of research was done on the stem cell niches found in plant roots as well as shoots, the idea of plant tissue culture was emerged of this discovery and phenomena. The idea of organizer cell type formation, which controls plant cell fate and affects responses in shoot pathways in vitro, is put forth in this study. This supports the hypothesis put forth by Latest research has shown that WOX-5 could initiate TAA1-mediated auxin production, providing strong evidence for the link between auxin as well as WOX5 pathways. As a result, auxin synthesis and accumulation are highly important for the regeneration of plant. Through accumulation of auxin in pericycle cells at xylem pole, which is made possible by active and xylem-mediated auxin transport mechanisms that promote the formation of stem cells, the stem cell niche is created in roots (Ramírez-Mosqueda, 2022; Reyna-

Llorens *et al.*, 2023; Smetana *et al.*, 2019). A distinct mechanism is involved in shoot stem cells. Within an auxin gradient, the organizer cell niche—a collection of small cells emanating from the callus or the surface of an organ—is in charge of making its own auxin. These cells, which are distinguished through active WUS, have a distinct nuclear profile with small nucleoli as well as compact nuclei, as well as elevated histone acetylation. They also show signs of relative dormancy. Competent cells in plant organs that aren't connected to xylem or vasculature and can't promote auxin transport in the same way could give rise to organizer cells. The only plant that can produce xylem is the root. This suggests that generating ectopic expression of WUS could be a feasible approach for enhancing plant regeneration, as it highlights the critical involvement of a particular gene set in plant regeneration (Ramage and Williams, 2002; Singhal *et al.*, 2023).

13.12. Organogenesis

Using small plant tissue explants from original plant, organogenesis is one of the popular micropropagation techniques for large-scale plant propagation. With the help of growth regulators, such plants are cultivated in sterile conditions. The process of micropropagation could be classified into three distinct phases, each requiring specific conditions: The first is the formation regarding a "organizer cell" for shoot formation; the second is the growth regarding new shoots through the establishment of auxin gradients as well as cell specification; the third is the induction of roots from developed shoots through creating a temporary auxin concentration peak in xylem-adjusted cells, activation of cell cycle, and directional auxin transport; and the fourth is the activation of multiple cell fate-specific auxin bio-synthesis path-ways with specific cells' chromatin organization. It was demonstrated that raising the propagation ratio and improving tissue response can be achieved by growing mother plants on optimum culture media (Zhang *et al.*, 2023).

13.13. Somatic embryogenesis

The technique of inducing embryos from somatic plant cells is known as somatic embryogenesis. This developmental pathway could be activated with the use of some of the auxinic herbicides, like 2,4-Di-chlorophenoxyacetic acid (2,4-D), Dicamba, Picloram, at elevated doses. In addition to acting as growth regulators, such synthetic auxins interact with F-box proteins including transport inhibitor response 1 (TIR1), promoting endogenous auxin production while somewhat impeding its outward movement. The competent cells, which have normal nuclear structures as well as ploidy levels, have the ability for synthesizing auxin (via the TAA1-IPA pathway), which causes auxin to initially accumulate and the formation regarding a "organizer cell" that subsequently divides peripherally to form globular structures covered in an epidermal layer (Bevan *et al.*, 2021; Li *et al.*, 2021; Séré and Martin, 2020).

13.14. Haploid induction *in vitro*

The doubled haploid system is a vital component of breeding operations since it is thought to be the most effective and rapid method for producing homozygous hybrids. The most popular method for achieving this is microspore embryogenesis, which was effectively used on a number of significant crops, including pepper, barley, rice, rapeseed, wheat, and sugar beet. The physiological mechanisms that underlie microspore embryogenesis are very similar to those of conventional somatic embryogenesis. These mechanisms include the impact of stressors, interactions with auxin, and subsequent epigenetic changes that promote the shift from gametophytic to sporophyte path-ways (Murashige and Skoog, 1962).

13.15. Protoplast culture

Somatic hybridization, which includes asymmetric somatic hybridization, and cell totipotence study are the two main goals of plant protoplast culture. For breeding across species or genera that are not susceptible to traditional sexual hybridization techniques, somatic hybridization is very

important. Protoplasts could also be a useful tool for testing a variety of gene constructions in short-term tests, including state-of-the-art methods, such as CRISPR for targeted gene editing. Furthermore, in such case, there is no need for plant regeneration (Fan *et al.*, 2021; Johnson *et al.*, 2022; Page *et al.*, 2021; Zarei *et al.*, 2023).

13.16. Macro elements

While carbon (C) is taken from the air and converted through photosynthesis, plants in their natural habitat rely on their roots to absorb six key macro nutrients (Ca, P, Mg, K, N, and S). On the other hand, plants might require extra carbon supplementation in a controlled laboratory environment. We will then go over the functions and optimal concentrations of such vital plant nutrients.

13.16.1 Carbon

One of the main components of almost every important molecule in a plant's structure, including the cell wall, DNA, proteins, and RNA, is carbon (C). From the very beginning of seedling development, plants could be susceptible to fatality from a lack of carbon. The regeneration regarding plants in a controlled environment may be facilitated by several carbohydrate types, such as glucose, sucrose, and maltose. Because it is affordable and resistant to autoclaving, sucrose is the most popular choice among these (Utsumi *et al.*, 2017).

Although glucose is the main source of carbon that plants need in their natural habitat, directly utilizing it for in vitro plant re-generation has significant downsides. At a pH of 5.6, glucose is known to be chemically unstable in solution and has the capacity to spontaneously open its rings to create lactic acid. The significance of using newly filter-sterilized glucose is highlighted by the fact that this process is particularly expedited under autoclaving conditions. On the other hand, sucrose is more resistant to autoclaving, yet it could caramelize if heated for an extended time period. Depending on the particular needs of plant tissue culture, the right amount of sucrose should be used; 1% is ideal for photosynthetic plants, while 6% is advised for embryogenic callus. For the early growth stages of in vitro plant development, sucrose concentrations between 2% and 6% are generally used. It is important to remember that such concentrations encourage in vitro plant growth by acting as both osmotic agents and a vital supply of metabolic carbon (Abel *et al.*, 2002; Xu *et al.*, 2020).

13.16.2 Nitrogen

It is commonly advised that nitrogen be the second most concentrated element in growth media following carbon because it is thought to be crucial for optimal plant nutrition. The development regarding proteins as well as other vital biological molecules depends heavily on such element. The way nitrogen is delivered to plants is a crucial consideration, and the pH levels dictate the particular advantages. While nitrate should be converted to ammonium by enzymatic activities involving nitrate as well as nitrite reductase, ammonium immediately contributes to metabolic processes. Excessive ammonium application to plant cells has been shown to cause nitrogen overload and fast absorption. Recent studies have linked auxin signaling, epigenetic changes in plant growth, and nitrogen signaling pathways. For most plant species, a 5–6:1 nitrogen to phosphate (N:P) ratio is advised for shoot development and 10–12:1 for overall growth of the plant. The recommended optimal nitrogen content is approximately 15 mM N (Askari and Ghahremani, 2023; Lambers, 2022; Sun and Payn, 1999).

13.16.3 Potassium

The third most important ion required for plant growth is potassium. Potassium, unlike nitrogen, plays an important role in the growth of the plants rather than acting as a structural component. It facilitates the transport regarding auxin by functioning as a symporter with hydrogen. In the year 1962, the relationship between potassium and auxin distribution has been first reported. Further research on potassium nutrition showed that different potassium transporters cause a

significant disturbance in auxin distribution when there is a potassium deficit (Abel *et al.*, 2002; Johnson *et al.*, 2022; Utsumi *et al.*, 2017; Xu *et al.*, 2020).

13.16.4 Phosphate

The 4th element in the traditional formula of plant nutrition, phosphate (P), is essential for both structural components, like DNA and phospholipids as well as metabolic processes like ATP/ADP transitions and phosphorylation/dephosphorylation. Phosphate is not often fixed within membranes and is more prone to change than nitrogen. The effects of phosphate feeding on plant tissue culture (PTC) processes have been the subject of numerous research; yet, it is advised to maintain an optimal P concentration (2–3mM) and to follow the designated N:P ratio for nitrogen component (Askari and Ghahremani, 2023; Puri *et al.*, 2022).

13.16.5 Calcium

In the modulation regarding different kinases, structure of cell walls, and reactions to external stimuli, Ca functions as a well-established signal transducer. Its involvement in several signaling pathways accounts for its importance in plant tissue culture. Similar to phosphorus, calcium is normally found in culture media at concentrations between 2 and 3 mM. The calcium source that is used is essential to the proper regeneration regarding plants in vitro. Researchers are examining the effects of either depleting or providing extra calcium chloride ($CaCl_2$), which is typically used as the main source of calcium in MS culture medium. As a result, chloride (Cl) becomes a prominent anion adjacent to nitrate and has a number of negative impacts on plant tissue culture formation (see the chloride section for more information). It is therefore recommended to select for calcium nitrate [$Ca(NO_3)_2$] as the source of calcium, whereas making modifications to other components regarding the media for maintaining a low concentration of chloride, treating it as a minor nutrient (Sun and Payn, 1999; Troyanos *et al.*, 1997).

13.16.6 Magnesium and Sulphur

Because sulfur (S) and magnesium (Mg) are key cofactors and structural components in vital activities including amino acid synthesis as well as thiol formation, deficiencies in these components in soil could seriously impair plant development. Magnesium sulfate ($MgSO_4$) can be defined as an optimal salt for plant tissue culture since both elements should be present at concentrations of about 1.5 mM. As demonstrated in Prunus micropropagation, magnesium excess and deficiency could significantly impair plant growth and cellular function (Liang, 2022; Sági-Kazár *et al.*, 2022).

13.16.7 Iron

One essential macroelement that plants need for a number of physiological functions is iron. In the electron transport chains of respiration and photosynthesis, it plays a critical role in electron transfer reactions. Usually found in iron(II) sulfate heptahydrate form, the optimal iron concentration in growth medium falls between 70μM and 100μM. Yet, iron is frequently better used in a chelated form, like ethylenediamine di-2-hydroxyphenyl acetate ferric (FeEDDHA) or ferric ethylenediaminetetraacetic acid (FeEDTA), because of its limited solubility and availability to plants. The latter has demonstrated improved stability over a range of pH values and encouraging outcomes in a number of plant species, which include walnut, date palm, and hazelnut. The complex relation between iron availability as well as physiological responses in plants is highlighted by the fact that excessive iron levels could cause iron stress, which can affect processes, such as embryogenesis. It's also important to keep in mind that iron might readily precipitate in a culture medium, thus managing it during plant growth requires cautious attention. For a thorough grasp of this aspect, additional information about plant medium preparation is provided in the section that follows (Al-Mayahi, 2021; Bolaños *et al.*, 2023; Glinushkin *et al.*, 2023).

13.17. Microelements

13.17.1 Boron

Intercellular communication as well as its structural contribution to the cell wall is the two main fundamental functions of boron (B). Maintaining membrane integrity, promoting root elongation, enabling seed production, and controlling sugar metabolism are all included in such roles. The effects of boron deficiency were extensively studied in the year 1920, but a more recent study emphasized its molecular involvement in fruit development and its relationship to auxin transport as well as metabolism. Mature cells accumulate B, a non-reusable element, in their robust cell walls. Since a certain minimum concentration of B in meristematic cells is essential for starting cell division, lower levels of boron could be advantageous throughout the early shoot induction phase in plant tissue culture (PTC). However, because B is essential for many cell maintenance, hormonal processes, and plant growth aspects, reaching this vital threshold is difficult. It is advised to maintain a constant concentration of boron throughout all PTC phases since growth inhibition and aberrant meristem formation are two of the first indications of boron shortage (Alejandro *et al.*, 2020; Chen *et al.*, 2023; Thakur *et al.*, 2023).

13.17.2 Manganese

With regard to plant systems, manganese is a metal and one of the essential cofactors for oxygen-evolving complex (OEC), which affects functions including photosynthesis. As demonstrated in Nicotiana plants, there is little difference between toxicity and deficiency, and changes in Mn levels, whether excessive or insufficient, could have a substantial effect on plant development. Because manganese has such a complex influence, it is best to avoid changing its levels unless you are explicitly researching its impacts. Higher Mn concentrations might help during the start phase, but too much Mn is usually quite harmful. The ideal source of Mn is manganese chloride ($MnCl_2$), which guarantees that both ions are kept at micronutrient levels. The optimum Mn content in growth media normally falls between 20 and 100 µM (Mendel and Kruse, 2012; Santandrea *et al.*, 1998).

13.17.3 Molybdenum

Plants need trace amounts of the vital micronutrient molybdenum (Mo). Mo-containing enzymes participate in the redox processes of carbon, sulfur, and nitrogen. Until Mo is incorporated to a complex to form a cofactor, it is not biologically active. Mo is usually present in traditional culture media at values between 0.2 and 1 µM. The effects of either excess or insufficient molybdenum levels are not well studied in the literature. Consequently, it is advised to keep Mo concentrations between 0.5 and 1 µM (Attar *et al.*, 2020; Festa and Thiele, 2011).

13.17.4 Copper

Originally identified in the year 1939, copper (Cu) serves as a cofactor in various plant processes. In plants, Cu also functions as an epigenetic regulator. Instead of the lower concentration of 0.1 µM commonly seen in callus media, the ideal concentration of Cu is usually between 1 and 2 µM. Across several plant species, a greater copper concentration of 20 mg/L (80 µM) was linked to favorable results in plant regeneration. In plants, elevated Cu stress levels (20–30 µM) could stimulate cell proliferation as well as plant regeneration (Pasternak, 2020; Phogat *et al.*, 2023; Tsui, 1948).

13.18. Organic components

13.18.1 Bacto-Tryptone

Because it successfully inhibits ion precipitation, bacto-tryptone, sometimes referred to as casein hydrolysate, is an essential component of culture media. We used this compound in our experiment just because it inhibited precipitation, not because it contained nitrogen or was a combination of

amino acids. A dosage of 100 mg/L (or a maximum of 13mg of nitrogen) and a low amino acids' concentration —which could be ignored as one of the sources of nutrients—are what we recommend (Wang and Yang, 2021).

13.18.2 Ascorbic acid

Ascorbate, often known as ascorbic acid (ASC), is a small antioxidant molecule with special properties. The mature organs associated with plastids (APX) in plants contain the majority of ascorbic acid, whereas the meristematic zone has a low quantity of this nutrient. Throughout plant development, mutants lacking in ascorbate biosynthesis do not show any discernible phenotypic alterations. ASC suppresses cell proliferation while protecting mature cells from damage and excessive phenolic compound accumulation throughout the growth of callus, according to research on the effects of manipulating endogenous ASC levels in addition to exogenous ASC exposure in vitro. There are particular implications when ASC is added directly to culture medium. ASC has a brief half-life of a few hours at a pH of 5.6, after which it transforms into dehydroascorbate (DHA) and then oxalic acid. In addition to that, plant cells are unable to easily absorb ASC due to its high charge. Ascorbate is first converted to DHA through oxidation, which plants could then absorb. It is quickly absorbed by plant cells after being absorbed as a neutral molecule, and DHA-reductase quickly transforms it back into ASC. Because the pH is about 7, ASC becomes stable once it is within the cytoplasm. It is advised to use short-term incubation (up to 6hr–10hrs) of explants/callus in a solution containing DHA (300–500 μM) in order to avoid the possible degradation of the products of ascorbic acid. Plants/callus should then be transferred to a new medium free of DHA (Brahmachari *et al.*, 2018; Eeuwens, 1976; Kiferle *et al.*, 2021; Riyazuddin *et al.*, 2023).

13.18.3 Glutathione

One thiol compound that is well-known for its antioxidant qualities is glutathione (GSH). Apart from its antioxidant function, GSH was discovered to be essential for controlling the auxin response. There are several isoforms of GSH in plants, and each one may have a distinct purpose. GSH was demonstrated to dramatically improve cell cycle progression and encourage plant regeneration in Fabaceae species. With the use of GSH in plant tissue culture (PTC) requires adjusting the pH level after administration since, at millimolar concentration levels, GSH functions as a strong buffer in a 4–4.50 pH range (Chen *et al.*, 2016; Franco-Navarro *et al.*, 2016).

13.18.4 Amino acids

All 20 amino acids should be added to the solution in minimum levels, according to some authors. There are, however, additional optimal options to take into account. Since glutamine is an epigenetic modulator, we suggest using it at a 20mg/L concentration or higher out of all the amino acids. This particular dosage was frequently used to promote embryogenesis in a variety of plant species. In addition, some plant species might benefit from the presence of tryptophan, a precursor to hormone auxin (Dalton *et al.*, 1983; Osiecki *et al.*, 2010; Potters *et al.*, 2010).

13.18.5 Sodium (Potassium) humate

Through reducing a variety of stressors, humic acid helps to increase plant productivity in soil. There is comprehensive information accessible on this subject. At a concentration of 5–15mg/L, the neutralized sodium (potassium) salt of humic acid is used in tissue culture mainly to promote explant rooting. It is highly suggested to use this method because it has been shown to be extremely successful in promoting root development as well as growth in several difficult species (Golubitskii *et al.*, 2007; Ndakidemi *et al.*, 2014; Pasternak *et al.*, 2014).

13.18.6 Vitamins

Vitamins are necessary compounds that plants utilized and synthesized. More than 80 years ago, the first reports of vitamins' effects on plant health were made. Research has shown that plants

cultivated in vitro benefit greatly from the addition of exogenous vitamins. Among all the vitamins, B6 and B1 are thought to be especially important and are frequently used in studies on plants (Ndakidemi *et al.*, 2014; Pasternak *et al.*, 2020; Pawar *et al.*, 2015).

13.19. Conclusions

In response to the increasing need for planting materials, the latest results presented in the presented study show that organic growth supplements could enhance micropropagation techniques to generate genetically consistent plants. Yet, understanding the connection between such supplements' mode of action and structure is crucial. Finding the right growth enhancers for different plant species may be made possible by cooperation between chemists, biotechnologists, and biologists. This method, which involves large-scale cultivation of specific genotypes of agricultural, medicinal, and forest plants, may prove to be an effective means of reviving damaged ecosystems and reestablishing biodiversity.
Only endogenous auxin may cause polarity and be transported in a specific direction among all the phytohormones. With cytokinin possibly inciting auxin production, this explains why auxin is thought to be a key player in regulating plant development in lab setting. Along with the auxin canalization process, the auxin biosynthesis pathway as well as cell type determine the impact of endogenous auxin. In the case when auxin production and canalization are balanced, auxin canalization within vascular tissue promotes the formation of roots, while effective auxin transport via carriers results in the formation of shoots. Furthermore, auxin accumulation is essential for starting shoot organogenesis, and stress-induced auxin efflux inhibition is a key factor in this process. Through various canalization mechanisms, auxin influences both shoot as well as root growth, making it a significant regulator of plant development in vitro. IPA-mediated auxin bio-synthesis is required for start of organizer cells, and stressors facilitate the early phases of this induction while impeding shoot growth.

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Chapter 14

Organic Farming and Organic Agriculture Techniques

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Organic Farming and Organic Agriculture Techniques

Abstract

The aim of organic agriculture is to play a role in promoting sustainability. The concept of sustainability in agriculture incorporates the effective utilization of agricultural resources to meet human needs, while also preserving or improving environmental quality and safeguarding natural resources for future generations. Sustainability within organic farming must be viewed comprehensively, considering ecological, economic, and social dimensions. Organic yields tend to be 20% lower in developed countries compared to high-input systems, but can be as much as 180% higher than low-input systems in arid/semi-arid regions. In areas with high humidity, the yields of rice paddies are similar, but the productivity of main crops may decrease for perennial plants, although agroforestry can provide additional benefits. The operating costs in organic agriculture, including expenses for seeds, rent, repairs, and labor, are notably lower than those in conventional production. These costs range from 50-60% for cereals and legumes, to 20-25% for dairy cows, and 10-20% for horticulture products. This cost difference is primarily due to reduced expenses on synthetic inputs, lower irrigation costs, and labor costs which encompass both family labor and hired workers. However, the total costs end up being only slightly lower than conventional methods, as fixed costs like land, buildings, and machinery increase due to new investments during the conversion process, such as establishing new orchards and animal houses, as well as obtaining certification.

Keywords: Organic Farming, Organic Agriculture, Techniques.

14.1. Introduction

Organic farming, also referred to as organic agriculture, ecological farming, or biological farming, is an agricultural approach that prioritizes the utilization of naturally occurring, non-synthetic substances like compost manure, green manure, and bone meal. This method places particular focus on practices such as crop rotation, companion planting, and mixed cropping. Furthermore, organic farming promotes the use of biological pest control methods, such as the cultivation of insect predators. Overall, organic agriculture can be described as an integrated farming system that aims for sustainability and the improvement of soil fertility and biological diversity, while typically prohibiting the use of synthetic pesticides, antibiotics, artificial fertilizers, genetically modified organisms, and growth hormones (Barton, 2018; Gorb *et al.*, 2020; Palaniappan and Annadurai, 2018; Paull, 2019). Organic agriculture emerged at the onset of the 20th century as a response to the rapid transformations in farming practices. As of 2019, certified organic agriculture encompassed a total of 70 million hectares (equivalent to 170 million acres) worldwide, with Australia alone accounting for more than half of this considerable expanse. The established standards for organic farming are meticulously crafted to permit the utilization of naturally-occurring substances while strictly curtailing or banning synthetic substances. For example, naturally-derived pesticides like garlic extract, bicarbonate of soda, and pyrethrin (naturally sourced from the Chrysanthemum flower) are permissible, while synthetic fertilizers and pesticides, notably glyphosate, are categorically prohibited. In rare circumstances, the use of synthetic substances like copper sulfate, elemental sulfur, and veterinary drugs might be sanctioned. Prohibited practices encompass the employment of genetically modified organisms, nanomaterials, human sewage sludge, plant growth regulators, hormones, and antibiotics in the rearing of livestock. At its core, organic agriculture is underpinned by foundational values such as the promotion of health, the well-being of all living creatures and the environment, ecological soundness, and equitable practices (Paull, 2010).

Organic agricultural practices are subject to international regulation and enforcement by transnational entities like the European Union, as well as individual countries, largely in accordance with the guidelines established by the International Federation of Organic Agriculture Movements (IFOAM). Established in 1972, IFOAM serves as a global umbrella organization for organic farming groups, with regional divisions including IFOAM Organics Europe and IFOAM Asia. The market for organic products has experienced significant growth since 1990, reaching a total of $150 billion globally in 2022, with North America earning over $64 billion and Europe generating EUR 53 billion. This surge in demand has led to an expansion of organically managed farmland, which saw a 26.6 percent increase from 2021 to 2022 (Geier, 2007; Nuijten *et al.*, 2020; Nuijten *et al.*, 2016). Organic agriculture has the potential to positively impact biodiversity and environmental conservation at the community level. However, the lower yields associated with organic farming compared to conventional intensive farming may result in an increased demand for converting non-agricultural land for agricultural purposes in order to maintain production levels. This conversion process can lead to a loss of biodiversity and adverse climate effects (Fargione and Tilman, 2002).

14.2. Crop diversity

Organic agriculture advocates for crop diversity through the promotion of polyculture, planting multiple crops in the same area. The cultivation of a variety of vegetable crops fosters a broader range of beneficial insects, soil microorganisms, and other elements that contribute to the overall well-being of the farm. A diverse array of crops aids in the flourishing of the environment and safeguards species from the risk of extinction. The field of Agroecology has illuminated the advantages of polyculture, a practice commonly utilized in organic farming. Agroecology is a scientific discipline that utilizes ecological principles to examine, design, oversee, and assess agricultural systems that are both productive and resource-efficient, while also being culturally sensitive, socially equitable, and economically sustainable (Barbieri *et al.*, 2017; Gawdiya *et al.*, 2025; Gliessman, 2018; Lorenz and Lal, 2023; Scialabba and Müller-Lindenlauf, 2010).

Integrating a variety of crops into organic farming methods offers numerous advantages. One such benefit is the enhancement of soil fertility through the stimulation of beneficial soil microorganism growth. Additionally, this practice aids in diminishing pest and disease challenges by fostering a more varied and robust agroecosystem. Furthermore, the inclusion of crop diversity can enhance the nutritional value of food by offering a broader spectrum of essential nutrients (Watson *et al.*, 2002).

14.3. Soil management

Organic agriculture depends more on the natural decomposition of organic matter than traditional farming, utilizing methods like green manure and composting to replenish soil nutrients depleted by previous crops. This biological process, facilitated by microorganisms like mycorrhiza and earthworms, releases nutrients essential for plant growth throughout the entire growing season. Farmers employ various techniques to enhance soil fertility, such as crop rotation, cover cropping, minimal tillage, and application of compost. The reduction of fuel-intensive tillage not only minimizes the loss of soil organic matter into the atmosphere but also facilitates carbon sequestration, leading to a decrease in greenhouse gas emissions and contributing to mitigating climate change. Decreasing tillage practices may also enhance soil structure and minimize soil erosion risks. Plants require a wide array of nutrients in varying quantities to thrive. Ensuring an adequate supply of nitrogen and ensuring its availability to plants when they require it most poses a challenge for organic farmers. Crop rotation and the use of green manure from leguminous plants aid in nitrogen supply by fixing atmospheric nitrogen through symbiosis with rhizobial bacteria. Intercropping, utilized for pest and disease management at times, can also enhance soil nutrients, although competition between legumes and crops may arise, and necessitating wider spacing between crop rows. Incorporating crop residues into the soil can enhance nitrogen availability as

different plants leave varying amounts of nitrogen behind, potentially supporting synchronization efforts (Kremer and Li, 2003).

Organic farmers utilize animal manure, as well as processed fertilizers like seed meal and mineral powders such as rock phosphate and green sand, a natural source of potassium. Adjustments to soil pH may be necessary in certain instances, with options for natural pH amendments including lime and sulfur. In the United States, some compounds like iron sulfate, aluminum sulfate, magnesium sulfate, and soluble boron products are permitted for use in organic farming practices (Szykitka, 2009). Mixed farms that incorporate both livestock and crops have the ability to function as ley farms, where the soil is enriched by cultivating nitrogen-fixing forage grasses like white clover or alfalfa, allowing for the cultivation of cash crops or cereals once the fertility of the land has been established. In contrast, farms that do not have livestock, known as "stockless" farms, may encounter challenges in maintaining soil fertility and may need to rely heavily on external sources such as imported manure, grain legumes, and green manures. However, grain legumes may have limited nitrogen-fixing capabilities due to being harvested. Horticultural farms that specialize in growing fruits and vegetables in protected environments tend to be even more dependent on external inputs for soil fertility. The transportation of manure can be expensive and impractical over long distances due to its bulkiness. Organic farms may face challenges in sourcing manure if a significant number of farms transition to organic management (Code, 2018; Eise and Foster, 2018; Geiger and Biellier, 1993; Wolde and Tamir, 2016).

14.4. Weed management

Organic weed management is focused on the suppression of weeds rather than their complete elimination, achieved through methods such as enhancing crop competition and utilizing phytotoxic effects on weeds. In organic farming, a combination of cultural, biological, mechanical, physical, and chemical strategies are employed to control weeds without the use of synthetic herbicides. Adherence to organic standards requires the rotation of annual crops, prohibiting the repeated cultivation of the same crop in a single location without an intervening different crop. Organic crop rotations commonly involve the use of cover crops that suppress weeds and crops with varying life cycles to deter weeds associated with specific environments. Ongoing research aims to develop organic techniques that enhance the growth of natural microorganisms capable of inhibiting the growth or germination of common weeds. To improve crop competitiveness and reduce weed pressure, cultural practices such as selecting competitive crop varieties, planting at high densities, maintaining tight row spacing, and delaying planting until the soil is warm to promote rapid crop germination are commonly employed on organic farms. Mechanical and chemical methods for controlling weeds on organic farms are categorized into a few main groups: (Marking and Bills, 1976; Panov *et al.*, 2005; Pottorff, 2010).

• Soil cultivation involves the process of turning the soil to mix in crop residues and soil amendments, eliminate existing weed growth, and create a suitable seedbed for planting. It also includes soil turning post-seeding to eradicate weeds, particularly for row crops.

• Removing the top growth of weeds is achieved through mowing and cutting.

• Heat-based methods such as flame weeding and thermal weeding are utilized to eradicate weeds.

• Mulching serves as a barrier to prevent weed emergence by utilizing organic materials, plastic films, or landscape fabric.

• Certain naturally derived chemicals like concentrated vinegar, corn gluten meal, and essential oils are permitted for herbicidal purposes. Additionally, there are select bioherbicides formulated from fungal pathogens. However, organic herbicides and bioherbicides currently have a limited role in organic weed management strategies.

• Weed control can also be achieved through grazing, with examples such as the utilization of geese to weed various organic crops like cotton, strawberries, tobacco, and corn. This practice has roots in

the historic tradition of using cotton patch geese in the southern U.S. before the 1950s. Similarly, some rice farmers introduce ducks and fish into wet paddy fields to consume weeds as well as insects (Edwards-Jones and Howells, 2001; Glynne-Jones, 1998; Sherer *et al.*, 2003).

14.5. Controlling insects/pests

Organisms that pose challenges on farms, besides weeds, encompass arthropods (such as insects and mites), nematodes, fungi, and bacteria. Various strategies are employed, including but not limited to:

Beneficial predatory insects, such as minute pirate bugs, big-eyed bugs, and ladybugs (although the latter tend to fly away), are examples of natural predators that feed on a wide array of pests. Lacewings are also effective in this regard, although they have a tendency to fly away. Predatory mites are another effective means of controlling pest mites. Praying mantids, while slower and less voracious, do contribute to pest control efforts. Parasitoid wasps are selective in their prey, which limits their effectiveness outdoors due to susceptibility to wind. Organic farms utilize naturally derived insecticides, which include *Bacillus thuringiensis* (a bacterial toxin), pyrethrum (derived from chrysanthemum), spinosad (a bacterial byproduct), neem (extracted from a tree), and rotenone (obtained from legume roots). However, less than 10% of organic farmers regularly apply these pesticides, with a 2003 survey indicating that only 5.3% of vegetable growers in California use rotenone and 1.7% use pyrethrum. It is important to note that these natural pesticides may not always be safer or more environmentally friendly than synthetic pesticides, and in some cases, they can be harmful. Organic pesticides must be naturally derived, despite some controversy surrounding certain substances. For instance, rotenone, copper, nicotine sulfate, and pyrethrums are among the contentious natural pesticides. Rotenone and pyrethrum, in particular, are controversial due to their mode of action on the nervous system, which is similar to many conventional insecticides. Rotenone, in particular, is highly toxic to fish and can elicit symptoms resembling Parkinson's disease in mammals (Caldwell *et al.*, 2005; Trewavas, 2004). Although pyrethrum, also known as natural pyrethrins, is more effective in controlling insects when combined with piperonyl butoxide to slow down the degradation process of the pyrethrins, organic regulations generally do not allow the use of the latter substance. Naturally derived fungicides that are approved for use on organic farms include *Bacillus subtilis*, *Bacillus pumilus*, and *Trichoderma harzianum*. These fungicides are particularly effective against root diseases. The use of compost tea, which contains beneficial microbes that can combat plant pathogens, may vary in effectiveness due to differences in formulations and preparation methods, potentially leading to inconsistent results or the growth of harmful microbes. Certain naturally derived pesticides are prohibited for use on organic farms, such as nicotine sulfate, arsenic, and strychnine. On the other hand, organic standards allow the use of synthetic pesticides like insecticidal soaps and horticultural oils for insect control, as well as Bordeaux mixture, copper hydroxide, and sodium bicarbonate for managing fungal diseases. It is worth noting that copper sulfate and Bordeaux mixture, despite being approved for organic use in some regions, may pose environmental challenges compared to certain synthetic fungicides that are not permitted in organic farming. Concerns about copper accumulation in the soil from repeated applications of copper sulfate or copper hydroxide as fungicides are addressed in organic standards to prevent toxic levels of copper from building up in the soil. There are environmental implications associated with the use of certain substances on organic crops that can impact various organisms in the ecosystem (Authority, 2018; Forbes and Ramkrishnan Balasubramanian PHD, 2019; Niggli, 2007; Toomey, 2014).

14.6. Livestock

Livestock and poultry farming, aimed at producing meat, dairy, and eggs, is a traditional agricultural practice that complements crop cultivation. Organic farms strive to offer animals natural living conditions and organic feed. The certification process ensures that livestock are raised in accordance with USDA organic guidelines, which mandate that all animal feed be certified organic.

Organic livestock are permitted to receive medical treatment when ill, but growth-promoting drugs are prohibited. Their diet must be organic, and they must have access to pasture. In the past, horses and cattle played an essential role on farms as sources of labor for hauling and plowing, fertility through manure recycling, and fuel in the form of food for both farmers and other animals. While many modern small-scale farms may not include livestock, domesticated animals are considered valuable components of organic farming practices, contributing to the sustainability and self-renewal of the farm operation (Amaditz, 1997; Ritchie, 2017).

14.7. Genetic modification

One of the key principles of organic farming is the deliberate avoidance of genetically modified plants and animals. During IFOAM's 12th Scientific Conference held on 19 October 1998, a significant declaration known as the Mar del Plata Declaration was issued. This declaration, supported by more than 600 delegates from over 60 countries, unanimously voted to prohibit the use of genetically modified organisms in organic food production and agriculture. Despite strong opposition within the organic farming community against the use of transgenic technologies, researchers such as Luis Herrera-Estrella and Ariel Alvarez-Morales advocate for the integration of such technologies into organic farming as a crucial step towards achieving sustainable agriculture, especially in developing regions. Organic farmer Raoul Adamchak and geneticist Pamela Ronald also argue that many biotechnological applications in agriculture align with organic principles and have greatly enhanced sustainable farming practices. While genetically modified organisms are specifically banned in organic farming, there is growing concern about the cross-pollination of genetically modified crop varieties with organic and heirloom seed stocks. This poses a significant challenge in preventing these altered genomes from contaminating the organic food supply. Additionally, varying regulations across countries further complicate the availability and distribution of GMOs, as discussed in the article detailing the oversight of genetically modified organism releases (Clark and Tilman, 2017).

14.8. Economics

The field of agricultural economics that focuses on organic farming examines the comprehensive impact of organic farming on society, including social costs, opportunity costs, unintended consequences, information imbalances, and economies of scale. Factors such as labor input, carbon and methane emissions, energy consumption, eutrophication, acidification, soil health, impact on biodiversity, and land use differ significantly among farms and crops, challenging direct comparisons between the economic aspects of organic and conventional agriculture. Within the European Union, organic farmers receive higher subsidies through agri-environmental and animal welfare programs compared to conventional growers (Lampkin and Sanders, 2022; Lernoud and Willer, 2018; Sandu, 2022).

14.9. Productivity

Various studies that have compared yields have produced mixed results. These discrepancies can often be attributed to differences in study designs, such as variations in the crops being studied and the methodologies used to collect results. A meta-analysis conducted in 2012 discovered that productivity levels tend to be lower in organic farming when compared to conventional farming. However, the extent of this difference can vary depending on the specific context and may sometimes be minimal. Although organic yields may be inferior to conventional yields, a separate meta-analysis published in Sustainable Agriculture Research in 2015 suggested that certain on-farm organic practices could help bridge this gap. Effective weed management and the application of manure in combination with legume forages/cover crops were identified as strategies that could enhance organic corn and soybean productivity (Fließbach *et al.*, 2004).

14.10. Profitability

In the United States, organic farming has been demonstrated to yield 2.7 to 3.8 times higher profits for farmers compared to conventional farming, when factoring in prevailing price premiums. A 2015 meta-analysis spanning five continents found that globally, organic farming can be 22-35% more profitable for farmers than traditional methods. The profitability of organic agriculture can be explained by several factors. Firstly, organic farmers avoid using expensive synthetic fertilizers and pesticides. Furthermore, organic produce currently commands a price premium over conventionally grown produce, allowing organic farmers to earn higher revenue from their crops. The price premium associated with organic food is a key element in the economic success of organic farming. In 2013, there was a 100% price premium for organic vegetables and a 57% price premium for organic fruits, based on wholesale prices from the United States Department of Agriculture's Economic Research Service. Price premiums are not limited to organic versus nonorganic crops, and can vary based on the sales venue, whether it be farmers' markets, grocery stores, or wholesale to restaurants. Many farmers find direct sales at farmers' markets to be the most profitable, as they receive the full markup, although this approach is also the most demanding in terms of time and labor (Moyer, 2013).

In recent years, there has been a noticeable decrease in organic price premiums, which diminishes the financial motivation for farmers to adopt or continue organic production techniques. Research spanning 22 years conducted at the Rodale Institute indicates that, considering current yields and production expenses in the United States, a premium of just 10% is necessary for organic farming to be economically competitive with conventional methods. Another study revealed that on a worldwide level, price premiums of only 5-7% were sufficient to reach parity with conventional agriculture. The absence of a price premium results in a varied level of profitability for farmers (Martin and Severson, 2008; Post and Schahczenski, 2012; Reganold *et al.*, 2001).

14.11. Capacity building in developing countries

Organic farming has the potential to enhance ecological sustainability, particularly in developing nations. By incorporating organic principles, utilizing local resources such as indigenous seed varieties and natural fertilizers, cost-effectiveness can be achieved. The expanding local and international markets for organic products offer significant growth opportunities, providing innovative producers and exporters with the chance to enhance their income and living standards.
Organic agriculture requires a substantial level of knowledge and expertise. Efforts are currently being made globally to enhance capacities, including the development of localized training materials, although the impact has been limited so far. By 2007, the International Federation of Organic Agriculture Movements had made available more than 170 free manuals and 75 online training opportunities. In a joint statement in 2008, the United Nations Environmental Programme (UNEP) and the United Nations Conference on Trade and Development (UNCTAD) emphasized that organic farming could contribute more effectively to food security in Africa compared to conventional production methods. They also noted that organic or near-organic practices had led to a significant increase in yields, while also improving soil fertility and drought resistance in the long term (Dimitri, 2010; Dimitri and Oberholtzer, 2008; Greene, 2012; Vogel, 2014).

14.12. Millennium development goals

The significance of organic agriculture (OA) in advancing the Millennium Development Goals (MDG), particularly in poverty alleviation efforts amidst climate change challenges, is demonstrated through its positive impact on various aspects of the MDGs, including both monetary and non-monetary elements. These benefits are anticipated to persist beyond the MDG era. Documented in a compilation of case studies from selected regions in Asian nations by the Asian Development Bank Institute (ADBI) and released by ADB in Manila, it illustrates how OA contributes to enhancing incomes, improving farmers' well-being by reducing chemical exposure, embedding sustainable

practices into rural development strategies, enhancing access to clean water and sanitation, and fostering global partnerships for development by involving small-scale farmers in value chains (Lockie *et al.*, 2006; Vogel, 2014). A relevant study conducted by ADBI also examines the expenditures associated with OA initiatives and places them within the context of achieving the MDGs. Findings indicate significant variability among the case studies, suggesting a lack of clear patterns in the costs of implementing OA. The costs are contingent upon the effectiveness of the OA implementation programs. The least expensive programs were more than ten times cheaper than the most costly ones. Nonetheless, a deeper analysis of the benefits derived from OA implementation demonstrates that the costs per individual lifted out of poverty were substantially lower than the projections of the World Bank, which are based on overall income growth or the specific costs associated with achieving certain measurable MDGs (e.g., education, health, and environmental objectives) (Markandya *et al.*, 2015; Marshall, 1991; Pretty *et al.*, 2008; Setboonsarng, 2015).

14.13. Externalities

Agriculture is associated with adverse impacts on society, such as the utilization of public land and resources, loss of biodiversity, soil erosion, pesticide use, nutrient contamination, and various other challenges. Conversely, there are positive impacts of agriculture such as fostering self-sufficiency, promoting entrepreneurship, instilling a sense of environmental stewardship, and enhancing air quality. The differences in externalities between organic and conventional farming methods depend on the implementation practices and the type of crops grown. While organic farming typically requires more land, it generally consumes less energy during production. Evaluating and comparing these externalities can be complex, as it involves considerations of per unit area measurements versus per unit of production, as well as analyzing individual plots versus entire farm units. Assessing biodiversity levels in agriculture can vary significantly across different studies, farms, and groups of organisms. Studies have found that birds, predatory insects, soil organisms, and plants tend to positively respond to organic farming practices, while non-predatory insects and pests do not show the same improvement. A review conducted in 2005 revealed that the benefits of organic farming on biodiversity were more pronounced at smaller scales such as individual plots and fields, rather than across entire farms situated in similar landscapes (Bengtsson *et al.*, 2005; Hansen *et al.*, 2001). Other research endeavors that have sought to evaluate and contrast traditional and organic methods of agriculture have revealed that organic practices result in a lesser decline in biodiversity compared to conventional methods, requiring lower energy input and generating less waste per unit area. When the calculations are based on unit output, however, the energy efficiency and waste production of organic techniques do not demonstrate the same advantages. Studies examining various farms have indicated that the actual leaching rates per hectare are substantially reduced on organic fields in comparison to conventional ones, potentially by as much as 57%; nevertheless, the leaching rates per unit of output are depicted as being relatively similar or slightly elevated. In terms of carbon dioxide emissions, organic farming systems exhibit a lower range of 40 to 60% per hectare than their conventional counterparts, yet on a per-unit output basis, organic systems tend to exhibit higher carbon emissions (Ritchie, 2017; Williams *et al.*, 2006).

14.14. Issues

When comparing the environmental impact of organic agriculture to conventional agriculture, a value of 1.0 indicates that both systems have an equal impact, with values exceeding 1.0 suggesting that organic systems have a higher impact. In most aspects, organic farming tends to have a more negative impact compared to conventional farming, excluding the impact on biodiversity. A meta-analysis conducted in 2017 revealed that biological agriculture requires more land per yield unit, has a higher potential for eutrophication and acidification, and lower energy requirements when compared to conventional agriculture. However, both systems exhibit similarly high levels of greenhouse gas emissions. A study conducted by Cranfield University from 2003 to

2005 on behalf of the Department for Environment, Food and Rural Affairs in the UK highlighted the challenges in comparing global warming potential, acidification, and eutrophication emissions between organic and conventional farming. It was observed that organic production often leads to increased burdens, such as nitrogen leaching and N_2O emissions, despite lower primary energy use in most organic products. Notably, N_2O emissions significantly contribute to global warming potential, except in the case of tomatoes. Interestingly, organic tomatoes consistently show increased burdens, except for pesticide use. While some emissions may be lower per area in organic farming, the overall need for field area is consistently higher, ranging from 65 to 200% more compared to non-organic farming, with bread wheat and potatoes requiring the most additional space (Meemken and Qaim, 2018; Wainwright *et al.*, 2014).

14.15. Environmental impact and emissions

Researchers at Oxford University conducted an analysis of 71 peer-reviewed studies and discovered that organic products may have a negative impact on the environment in some instances. It was found that organic milk, cereals, and pork result in higher greenhouse gas emissions per product compared to conventional products, while organic beef and olives tend to have lower emissions based on most studies. Despite requiring less energy, organic products generally occupy more land. When considering nitrogen leaching, nitrous oxide emissions, ammonia emissions, eutrophication, and acidification potential, organic produce tends to have higher impacts per unit compared to conventionally grown produce. However, other variations were deemed insignificant by the researchers. The study concluded that debates surrounding farming practices should acknowledge the nuances of employing both conventional and organic methods, rather than simply pitting one against the other. Specific solutions tailored to specific circumstances were also sought by the researchers. Proponents of organic farming argue that organic agriculture places emphasis on closed nutrient cycles, biodiversity, and effective soil management, which can potentially help mitigate and even reverse the effects of climate change. Furthermore, organic agriculture is believed to have the ability to reduce fossil fuel emissions. In temperate climates, the carbon sequestration efficiency of organic systems is significantly higher, primarily due to the utilization of grass clovers for feed and cover crops in organic rotations (Muller *et al.*, 2017; Smith *et al.*, 2019; Wilson, 2019). However, research indicates that organic farming systems necessitate a larger amount of land to generate an equivalent yield as traditional farms. Transitioning to organic agriculture in developed nations, where the majority of arable land is already utilized, could potentially lead to a rise in deforestation, consequently reducing overall carbon sequestration. In a hypothetical medium scenario, where half of the additional land is transitioned from grassland and a moderate level of soil carbon sequestration is assumed, this shift would cause a 21% increase in global greenhouse gas emissions when compared to the conventional farming system (Tilman *et al.*, 2001; Undersander *et al.*, 2002).

14.15.1 Nutrient leaching

A 2012 meta-analysis of 71 studies found that organic products had higher levels of nitrogen leaching, nitrous oxide emissions, ammonia emissions, eutrophication potential, and acidification potential. While the emissions per land area were lower for organic products, the emissions per amount of food produced were higher due to the lower crop yield of organic farms. The excess nutrients from organic farming can lead to algal blooms, eutrophication, and the creation of dead zones in lakes, rivers, and groundwater. Furthermore, nitrates, which are harmful to aquatic organisms, are a byproduct of organic farming practices (Avery and Avery, 2007; Bradley, 2014).

14.15.2 Land use

A 2012 meta-analysis conducted by Oxford University involving 71 studies revealed that organic farming typically necessitates 84% more land in comparison to traditional farming methods to yield an equivalent amount of harvest. This increased land requirement can be attributed primarily to

nutrient deficiencies, although other factors such as weed infestations, diseases, pests, lower animal yields, and the need for cultivating fertility-building crops also contribute to this phenomenon. However, recent advancements in organic farming practices have begun to tackle these challenges effectively, demonstrating promising results in terms of land conservation for wildlife sanctuaries and forestry preservation. According to calculations by the Hudson Institute, the land area required for organic beef production can be as much as three times greater. On the contrary, specific organic livestock management approaches have proven to rejuvenate arid, marginal, or otherwise unproductive lands for agricultural purposes and wildlife habitats. For instance, utilizing fields for both forage and cash crop production simultaneously can help minimize overall land usage. Certain practices associated with System of Rice Intensification (SRI) have resulted in record-breaking harvest yields on some rice farms without relying on external inputs, although success rates have varied among different agricultural settings (Piras, 2013).

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Chapter 15

Effect of Organic Farming on Plant Viruses and Insects

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Abstract

The global threat to food and nutritional security is exacerbated by the introduction of efficient vectors and phytoviruses to non-endemic areas, as well as the impact of climate change. Insect vectors are responsible for transmitting a wide array of viruses that can harm valuable vegetable crops. These viruses are diverse in nature and have varying modes of transmission. This complicates efforts to mitigate losses and maintain sustainability, especially in the context of organic farming, which is gaining popularity for valid reasons. Organic farms, typically smaller in size, are particularly vulnerable to the effects of the landscape. Achieving effective control over vectors that transmit plant viruses is challenging, especially with the rapid proliferation of super vectors like thrips and whiteflies. Despite this, progress can be made through the integration of multiple management strategies. While there is no one-size-fits-all solution, host resistance stands out as a promising approach. Cultivars with resistance, whether complete or partial, can be effectively combined with various management methods, such as cultural, biological, and chemical interventions. This analysis aims to underscore the severity of insect-transmitted viruses in organic vegetable production, provide an overview of available management strategies and their limitations, and highlight areas for future research to enhance sustainability.

Keywords: Pathogenic Plant Virus Control, vector, transmission, organic farming, pest management.

15.1. Introduction

Production of vegetables plays a crucial role in ensuring global food security and meeting nutritional needs. However, traditional methods of intensive vegetable cultivation heavily reliant on chemical inputs pose significant challenges to sustainability and can have unintended negative consequences. Over the past decade, there has been a notable increase in organic vegetable production as an alternative approach. By 2012, organic vegetable cultivation had expanded to cover 244,856 hectares, representing 0.4% of the total global vegetable area. Despite the increase in organic vegetable production, it remains a small fraction when compared to conventional farming practices. Challenges hindering the growth of organic vegetable cultivation include the prevalence of pests and diseases, as well as a lack of effective management strategies tailored to organic farming methods (Schreinemachers *et al.*, 2018; Willer *et al.*, 2024). In recent times, insect vectors and the viruses they carry have been introduced into numerous new geographic regions, with climate change playing a significant role in the establishment of these introductions. An example of this phenomenon is the proliferation of the sweet potato whitefly (*Bemisia tabaci* Gennadius) and various begomoviruses, both old and new, which have emerged as significant obstacles to production in newly established areas. Within the United States, the invasive *B. tabaci* B cryptic species (commonly known as MEAM1) has proven to be a highly effective carrier of multiple begomoviruses and cirniviruses, thereby displacing the less efficient native 'A' cryptic species, which typically transmits viruses originating from the New World (Brown *et al.*, 2023).

In Europe and the Mediterranean region, similar scenarios have emerged due to the introduction of new whitefly cryptic species and transmitted viruses. One such recent instance is the tomato leaf curl New Delhi virus making its way into Europe. Another notable example is the arrival of the thrips-transmitted tomato spotted wilt orthotospovirus (TSWV), which has had a significant impact on tomato and pepper production in the United States. The multitude of current and emerging challenges poses significant obstacles for vegetable production in traditional settings, and these challenges are further exacerbated in organic production environments. A recent study involving modeling and empirical research on various virus pathosystems has indicated that insect-

transmitted viruses in organic vegetable production may pose either similar or reduced risks compared to conventional vegetable production (LaTora *et al.*, 2022; Parrella *et al.*, 2018). This assertion, however, will require thorough validation through more rigorous experimentation. For example, the introduction of traditional insecticides with swift feeding cessation capabilities, such as diamides and others, has proven effective in halting the secondary spread of viruses. It is theorized that vegetable seedlings are most vulnerable at planting and soon after and protecting the crop diligently during this susceptible period could lead to reduced symptom severity and improved yields through mature plant resistance. Even though conventional production utilizes tools like diamides, there is still a risk of crop damage from rapid increases in vector populations. Unfortunately, there is a lack of stringent and cost-effective tools for organic production. Nonetheless, by implementing strategies like the use of row covers on seedlings during the critical stage, along with compounds that enhance plant defense (such as plant growth promoting rhizobacteria formulations, salicylic acid analogs for systemic acquired resistance activation, and harpin proteins), it may be possible to minimize risks. However, the use of row covers may also prove to be prohibitively expensive from a spatial standpoint (Jiménez *et al.*, 2020; Ullman *et al.*, 2002).

15.2. Crucial carriers of plant viruses in organic farming environments

Numerous agricultural profiles and plans for pest management in traditional vegetable cultivation highlight concerns surrounding insect vectors such as aphids, thrips, and whiteflies, as well as the viruses they actively transmit. However, these plans are often not specifically tailored for organic production and may not receive sufficient recognition from regulatory or funding entities. Aphids, belonging to the Aphididae family within the Hemiptera order, play a significant role in transmitting various crucial vegetable viruses. These insects feed on plant phloem, piercing cells with their stylets and siphoning nutrients with watery saliva. Additionally, aphids use gelling saliva to seal wounds caused by their feeding, maintaining cell pressure and vitality necessary for effective virus transmission. Similarly, whiteflies from the Aleyrodidae family of the Hemiptera order exhibit similar feeding mechanisms to aphids, utilizing a 'piercing and sucking' approach with their mouthparts. Thrips, identified in the Thripidae family of the Thysanoptera order, possess asymmetrical mouthparts and feed by scraping on epidermal cells and extracting cellular contents. Other insect vectors, including leaf and plant hoppers from the Cicadellidae and Delphacidae families of the Hemiptera order, as well as beetles from the Chrysomelidae family of the Coleoptera order, also contribute to the spread of viruses in vegetable crops. Furthermore, recent studies have revealed that bumblebees from the Apidae family of the Hymenoptera order can unknowingly transmit significant vegetable viruses, such as the tomato brown rugose fruit virus (ToBRFV) of the Tobamovirus genus, through pollination (Panno *et al.*, 2020; Polston and Anderson, 1997; Zhang *et al.*, 2022).

The active vectors mentioned above are commonly known in ecological terms as 'R strategists', utilizing environmental conditions in temperate and tropical areas, leading to rapid population growth. These insect populations can quickly overwhelm vegetable crops. In an open production system, around twelve thousand tomato seedlings are typically planted per hectare, but during peak vector populations, it is common to find numerous insects on a single leaf. Just one adult vector carrying a virus, such as a whitefly, can easily infect a healthy tomato plant. Despite the presence of effective insecticides that can stop feeding rapidly in conventional farming, controlling vectors and preventing virus spread remains challenging. Managing virus transmission becomes even more complex in organic farming environments (Caballero *et al.*, 2015; Pirone and Perry, 2002).

The dissemination of viruses through vectors involves intricate interactions and is influenced by two key factors. One factor involves the duration of persistence within the vectors, while the other pertains to whether the virus is capable of replication. Aphids are commonly associated with transmitting non-persistent viruses (stylet-borne), with acquisition and inoculation periods typically

lasting from a few seconds to minutes. Examples of non-persistently aphid-transmitted viruses include those found in the Potyvirus and Cucumovirus genera. Both colonizing and non-colonizing aphid species have the ability to transmit non-persistent viruses. In contrast, only colonizing aphids and whiteflies are able to transmit semi-persistent (foregut-borne) and persistent non-propagative (circulative) viruses. These viruses are confined to the phloem of their host plants. The acquisition and inoculation periods for semi-persistent viruses are longer than those for non-persistent viruses, ranging from a few minutes to hours (Gadhave *et al.*, 2020; Zehnder *et al.*, 2007). There is no delay involved in this method of transmission. Illustrations include viruses found in the Ipomovirus and Crinivirus genera. Persistently transmitted circulative non-propagative viruses take a winding route within insects (vectors) after being ingested into the midgut, entering the hemocoel, and moving into the salivary glands through various interactions facilitated by receptor-mediated endocytosis. The time required for acquisition and inoculation is longer compared to previously described methods, spanning from hours to days and including a period of dormancy lasting from hours to days as well. Genera such as Polerovirus and Begomovirus serve as examples. The final mode of transmission through feeding is persistent propagative transmission, which encompasses all the characteristics of transmission identified in the non-propagative mode and also involves virus reproduction within the vector. These viruses may or may not be specific to certain tissues and are spread by colonizing insects like leafhoppers, planthoppers, and thrips. In addition to feeding transmission routes, there is also non-feeding transmission routes recognized to exist. One example is vertical transovarial transmission, allowing viruses to survive in the environment even without susceptible hosts present. Examples of such transmission modes include hopper-transmitted rhabdoviruses and reoviruses (Chauhan *et al.*, 2021).

15.3. Management

The various methods of virus transmission play a crucial role in determining appropriate management strategies. In the realm of organic vegetable production, there is no singular solution that guarantees success. Nevertheless, host resistance (HR) is a highly effective approach when available. HR should be integrated with other tactics including biological, cultural, and chemical methods. Each of these strategies will be thoroughly explored (Piau and Schmitt-Keichinger, 2023).

15.4. Host resistance

Frequently, the same varieties utilized in traditional agriculture are also utilized in the cultivation of organic vegetables, albeit with the use of organically produced seeds. These varieties are often vulnerable to various vectors and the viruses they spread, posing a challenge in organic management due to limited available tools. Certain vegetable crops, like squash, may possess resistance through transgenic methods; however, transgenics are not compatible with organic practices. Ideally, in organic farming scenarios, conventionally bred varieties with resistance to the vectors and/or viruses would be beneficial. These varieties are developed by incorporating genes from wild species into the desired cultivar, although the process can be time-consuming and demanding, it has shown to be effective. Conventional breeding can produce cultivars with varying degrees of resistance and tolerance, with high resistance typically involving a single gene that prevents infection by the pathogen, such as with tomato spotted wilt virus in tomato and pepper production where resistance is provided by Sw5 and Tsw, respectively (Gautam *et al.*, 2023; Kabaş *et al.*, 2021). The use of this type of resistance can lead to a high level of selection pressure on the virus, potentially causing resistance to break down. Despite its drawbacks, single-gene resistance may be well-suited for organic vegetable cultivation. For instance, semi-dominant genes like Ty1-6, which confer resistance against TYLCV transmitted by whiteflies, have shown promise in reducing symptom severity without the hypersensitive response-based resistance. These cultivars tend to have higher yields even in the presence of the virus and are particularly suitable for organic farming. Resistance against vectors and viruses can also be achieved through multiple or recessive genes (Gautam *et al.*, 2023). The presence of these genes results in resistance to systemic

infection, leading to milder symptoms in plants which then produce higher yields compared to susceptible genotypes. An example of this resistance is seen in snap beans, *Phaseolus vulgaris* L., against the cucurbit leaf crumple virus (CuLCrV). This resistance, conferred by semi-dominant and multiple genes, is known to be long-lasting and less affected by selection pressure from viruses. A laboratory study involving TYLCV-resistant cultivars with semi-dominant genes exposed them to ten consecutive inoculations, with periodic sequencing of TYLCV genomes showing no signs of positive selection pressure or emergence of resistance-breaking strains (Marchant *et al.*, 2020).

15.5. Coinfection and the response of the host's immune system

Vectors have the ability to spread various viruses to the same crop in a particular plant system. In the southeastern region of the United States, the whitefly is known to transmit a variety of ipomoviruses, criniviruses, and begomoviruses. Whiteflies have been documented transmitting TYLCV and a crinivirus called tomato chlorosis virus (ToCV) to tomato plants. Likewise, in the context of squash, whiteflies have been found transmitting a begomovirus (CuLCrV) and two criniviruses (CCYV- cucurbit chlorotic yellows virus and CYSDV- cucurbit yellow stunting disorder virus). The sequential or consecutive acquisition of these viruses has been shown to impact vector preference and fitness in different ways (Gautam *et al.*, 2020). The findings so far suggest that mixed infections in both susceptible and resistant crop varieties tend to result in increased severity of symptoms (greater susceptibility) when compared to single infections. Mixed infections can trigger synergistic interactions among the viruses involved, sometimes leading to the breakdown of resistance. For instance, a study showed that when both TYLCV and ToCV infect tomato plants with a resistance-conferring gene (Ty-1), the resistance breakdown was more significant compared to single infections (Fortes *et al.*, 2023).

15.6. Biological control

In light of the challenges associated with current management strategies in organic production systems, it is imperative to establish a comprehensive systems-based sustainable management approach on a regional scale. Biological control offers a sustainable solution for controlling major insect pests (Ali *et al.*, 2017; Hassanein *et al.*, 2018; Iqbal and Ashraf, 2019), although its effectiveness in managing insect-transmitted viruses has been subject to limited scrutiny and yielded varied outcomes. The dynamic interactions among components of the pathosystem - including the host plant, vector, virus, and natural enemies - can influence the efficacy of natural enemies in suppressing insect-transmitted viruses. Biological control can be categorized as either augmentative or conservative. Given the brief life cycle of vegetable crops, safeguarding them during their most vulnerable stage immediately after planting is crucial. In this context, augmentative or inundative releases may be preferred over conservative approaches. The abundance and mobility of vectors are key factors in determining the feasibility of biological control as a management strategy. While coccinellid beetles and parasitoids can impact colonizing vectors like aphids, they may have limited efficacy against transient populations of winged adults responsible for virus transmission. Mixed results have been observed even with established vector populations, as evidenced by the increased spread of bean yellow mosaic virus (BYMV) in the presence of *Coccinella californica* (Mannerheim) (Roitberg and Myers, 1978).

In a comparable manner, the incidence of BYMV infection rose by a factor of nine when *Aphidius ervi* (Haliday) was present, even though there was a notable decrease in the population of pea aphids, *Acyrthosiphon pisum* (Harris). The existence of natural predators can lead to a higher rate of aphid displacement from their host plants and aid in their migration to nearby vegetation. During this migration, aphids can transfer viruses to vulnerable hosts, thereby increasing the spread of the virus (Hodge *et al.*, 2011). The effectiveness of utilizing biological control methods may be influenced by the mode of virus transmission. Non-persistent viruses are capable of being

transmitted through brief acquisition and inoculation processes lasting only a few seconds. For instance, the virus mentioned in the preceding paragraph, BYMV, falls under the category of non-persistent viruses. On the other hand, semi-persistent and persistent viruses require longer acquisition and inoculation periods (ranging from minutes to hours), with persistent viruses also exhibiting a latent period. Research concerning the transmission of barley yellow dwarf virus (BYDV) in a persistent manner revealed that the early introduction of natural predators in the season resulted in a decrease in the colonization of disease-carrying vectors and the secondary spread of the virus (Landis and Van der Werf, 1997).

The efficacy of utilizing biological control agents in the management of vectors and the viruses they transmit may be influenced by the dynamic interactions among the host, virus, and vector. Hosts that are infected with persistently transmitted viruses have been observed to attract and impede the vector for an extended duration, thereby positively impacting the reproductive fitness of the vector. In contrast, plants infected with non-persistent viruses are known to attract the vector without impeding them for an extended period (Mauck *et al.*, 2010). Vectors have a tendency to quickly inhabit hosts infected with persistent viruses compared to hosts infected with non-persistent viruses. When it comes to persistent viruses like TYLCV, whiteflies are more likely to be attracted to and remain on virus-infected plants longer than non-infected plants. Additionally, the immature whiteflies do not move from the infected plants, providing a window of time that could be utilized for releasing predators and parasitoids to prevent further spread of the virus. While biocontrol agents may not be able to control the initial spread caused by incoming viruliferous whitefly adults, they could potentially help in mitigating secondary spread. In contrast, insecticides that work quickly may not be effective in preventing the transmission of persistent viruses by incoming viruliferous vectors. Furthermore, biocontrol agents do not have negative environmental impacts and can contribute to sustainability efforts (Legarrea *et al.*, 2015).

Control agents can help manage the spread of pests, but it may not fully eliminate secondary transmission. Despite the effectiveness of fast-acting insecticides, they may not be able to completely stop the transmission of persistent viruses by viruliferous vectors. In contrast, biological control agents show promise in controlling pests without causing negative environmental consequences and promoting sustainability. In addition to consuming prey directly, omnivorous predators like mirids have the ability to trigger systemic defense responses against pathogens post-herbivory. Feeding on plants by hemipteran predators could activate defense mechanisms involving the salicylic acid pathway, alongside the jasmonic acid pathway, potentially impacting the transmission of persistently transmitted viruses. Further research is needed to determine whether the plant defenses induced by omnivores like mirids generate localized or systemic signaling. A recent study examined the expression patterns of genes related to the salicylic acid pathway, Pathogenesis-related protein 1a (PR1a) and Salicylic acid carboxyl methyltransferase (SAMT), following the release of the mirid *Dicyphus hesperus* (Knight). PR1a showed increased expression only at the mirid release site, while SAMT exhibited enhanced expression at both the local release site and a distant site, suggesting that defense signaling induced by biological control agents could have a systemic impact on virus-host interactions (Legarrea *et al.*, 2015).

Entomopathogenic fungi, such as *Beauveria bassiana* (Bals.-Criv.) Vuill, have the potential to be utilized for the suppression of populations of virus vectors. However, further research is needed to fully understand their effectiveness in reducing virus transmission. Although natural outbreaks of entomopathogenic fungi targeting soft-bodied hemipterans are common, efforts to create commercially viable formulations have not yielded successful results. For instance, instances of *Cordyceps javanica* outbreaks in vegetable production are frequent in the Southeastern United States. Nevertheless, using *C. javanica* to manage whitefly-transmitted viruses, particularly in the presence of large whitefly populations, remains unproven. Controlled experiments in laboratory settings have shown promise for both *C. javanica* and *B. bassiana* in suppressing virus acquisition, inoculation, and limiting secondary virus transmission. While there is potential for the use of entomopathogenic fungi in organic farming to control virus vectors, challenges related to

commercial production, availability, and quality control continue to hinder widespread adoption (Sun *et al.*, 2021).

15.7. Organic insecticides

Organic insecticides, also known as bioinsecticides, are insecticides that derive from natural sources, including plants such as pyrethrins or azadirachtin, microbes like Spinosad or *Bacillus thuringiensis*, and minerals such as boric acid, cryolite, or diatomaceous earth. Essential oils extracted from plants also fit into this category, commonly known for their repellent properties rather than their toxicity (Iqbal and Ashraf, 2019; Kanwal *et al.*, 2016). The term "biorational insecticides" is sometimes used interchangeably with organic insecticides due to their minimal impact on the environment and non-target species, as well as their ability to reduce risks of insecticide resistance development and low environmental persistence. In this review, we adopt a comprehensive definition of organic insecticide as any insecticide approved for use in organic agriculture in the US, indicated by the OMRI label (Dimase *et al.*, 2024). Some bioinsecticides have a long history in agriculture, with sulfur being used by the Mesopotamians against mites 4,000 years ago and the Chinese using mercury and arsenic compounds 3,200 years ago. Pyrethrum, derived from dried Chrysanthemum flowers, has been in use for over 2,000 years, containing pyrethrins that disrupt nerve cell function by binding to sodium channels. Pyrethrins are distinct from pyrethroids, synthetic analogs not permitted in organic farming due to their rapid degradation and the need for frequent applications (Lybrand *et al.*, 2020). Pyrethrum continues to be produced in large quantities through cultivation of *Chrysanthemum cinerariifolium* in Africa and Australia, known for its antifeedant properties against sap feeders like thrips, aphids, and whiteflies. Spinosad, a newer insecticide discovered in 1982 and commercialized in 1992, originates from the soil actinomycete *Saccharopolyspora spinosa*, and targets thrips by affecting nicotinic acetylcholine and GABA receptors. Azadirachtin, present in neem oil extracted from *Azadirachta indica* seeds, hinders ecdysteroid and juvenile hormone effects while repelling insects that transmit viruses through feeding. This organic insecticide has shown high efficacy against whiteflies, causing mortality rates above 90% in immatures (Kumar *et al.*, 2005).

Fatty acids, which are compounds comprised of a lengthy hydrocarbon chain and a carboxylic acid group at one end, are derived from plants. Their known potential as insecticides has been established for quite some time. There are several commercially available insecticides based on fatty acids, with one of the most popular options being M-Pede®: a combination of potassium salts of oleic and linoleic acids. This particular insecticide is highly effective against whiteflies. The potassium salts of fatty acids disrupt the lipid-protein matrix of the insect's cellular membrane, causing insect cells to leak and ultimately die from dehydration (Kumar *et al.*, 2005). In order to enhance the effectiveness of bioinsecticides, formulations with multiple modes of action have been developed. One popular combination is pyrethrins with diatomaceous earth (DE), thanks to DE's strong adsorption capabilities. Diatomaceous earth consists of fossilized remains of unicellular eukaryotic phytoplankton known as diatoms, which were prevalent on Earth predominantly during the Miocene and Eocene periods in both freshwater and marine environments. As a result, natural DE deposits can be found everywhere and are easily accessible. The external shell of diatoms is high in silicon dioxide and functions as an insecticide. It acts abrasively on insects, leading to their desiccation upon contact (Zeni *et al.*, 2021).

Overuse of synthetic insecticides from the same classes has resulted in the development of insecticide resistance and failures in pest control in real-world agricultural settings (Ali *et al.*, 2017; Iqbal and Ashraf, 2022). One example is the resistance seen in Western flower thrips populations worldwide due to the excessive use of Spinosad. Therefore, adhering to practices such as rotating different modes of action and preventing pests from being exposed to sub-lethal doses of the compound is crucial in organic vegetable production. Insecticides that act through physical contact rather than chemical properties, like DE, are less likely to develop resistance and can be applied more frequently. One challenge of biopesticides is their short half-life and limited duration of protection, which can pose difficulty in managing viruliferous insects responsible for spreading

viruses in the field. The mentioned biopesticides can be used alone or in combination with other management strategies (Kliot *et al.*, 2016).

15.8. Multicrop systems

Monoculture has been the prevailing agricultural method in the past century. This farming practice involves planting and harvesting a single crop, which allows for streamlined operations and cost savings through bulk purchases and the use of specialized equipment. However, monoculture also poses risks as it makes crops more susceptible to pests and diseases. Increasing biodiversity by incorporating multiple crops can help mitigate these risks. In a multicrop system, two different crops are grown together in the same field. Unlike trap crops or companion crops, the crops in an intercropping system are chosen for their economic value and are harvested for profit. Multicrop systems have the potential to reduce pest pressure in several ways, such as making the host plant less appealing to pests, directly interfering with pest behavior, and promoting the presence of natural enemies that control herbivores, including disease-carrying vectors (Letourneau *et al.*, 2011).

15.9. Definitions of various cropping systems

Trap crop: an additional crop planted alongside the main crop to lure pests away from the main crop, typically without any commercial value.

Intercropping: the simultaneous cultivation of two crops in the same field, both with commercial value.

Cover crop: a crop planted and harvested prior to the main crop, possibly with commercial value.

Companion crop: similar to intercropping, but the companion crop lacks commercial value and is only planted to benefit the primary cash crop.

Insectary plants: plants deliberately cultivated to attract beneficial insects to fields and provide floral resources like pollen and nectar, suitable for intercropping, companion cropping, or cover cropping.

Live mulch: a cover crop planted beneath the main crop to act as natural mulch.

The 'disruptive crop' hypothesis proposes that the presence of a non-host plant could interfere with the foraging behavior of herbivores by chemical interactions with the volatiles of non-host plants. Intercropping can directly affect herbivores by repelling them or by increasing the distance between plants of the same species, leading to more encounters with non-target plants and premature dispersal. Visual cues of pests may also be disrupted when primary host plants are concealed by other foliage. An example of a successful intercropping method is highlighted in a study where several crops that were less preferred by whiteflies were examined. Among these, Malabar spinach (*Basella alba* L.) significantly reduced the number of adult whiteflies landing on the main crop, cucumber (*Cucumis sativus* L.). Gas Chromatography-Mass Spectrometry (GC-MS) analysis revealed that the spinach variety emitted high levels of limonene, a terpene known for its repellent properties (Dimase *et al.*, 2024).

Multicropping systems have the ability to attract natural enemies of specific pests. One effective strategy involves the use of insectary plants, also known as banker plants. These companion plants enhance the resources available to beneficial insects by offering pollen and nectar. Pollen is rich in essential amino acids, lipids, vitamins, and minerals, while nectar provides carbohydrates that are essential for the nutrition of beneficial insects. Some insects, such as hover flies belonging to the Diptera family Syrphidae, primarily feed on flowers during their adult stage but serve as predators of aphids in their larval phase. Additionally, other insects, typically viewed as predators, can also benefit from an enriched diet that includes floral resources. For example, the adult longevity of the minute pirate bug *Orius* sp. increased when floral options were incorporated into their thrips diet. In

specific cases, aphids have been effectively managed through the utilization of insectary plants. For instance, organic lettuce cultivation in California often involves planting 5 to 9% of the field area with sweet alyssum, which is highly attractive to syrphids - the principal predator of the lettuce aphid *Nasonovia ribisnigri*. Some lettuce growers incorporate sweet alyssum into a mixture of insectary plants, which may also consist of coriander, phacelia, or buckwheat, to enhance flower diversity and prolong the blooming season. However, one limitation of multicrop systems is that their efficacy is confined to specific spatial areas and diminishes as one move further away from the flowering patches. This is particularly evident in the case of insectary plants, where beneficial insects tend to primarily forage near the vicinity of companion flowers (Strzyzewski and Martini, 2024).

15.10. The effectiveness of plant essential oils as eco-friendly biopesticides in agriculture

Traditionally, these oils have been extracted using various techniques in local settings, resulting in lower quantities and quality of bioactive essential oil compounds (EOCs). In order to advance towards commercial production, local knowledge and practices need to be upgraded. Farmers in regions affected by epidemics are gradually embracing natural products, recognizing their benefits. The global market presents a competitive landscape for producers, who must adapt to environmental and health trends. Concerns regarding environmental pollution and health risks associated with the excessive use of chemical pesticides have prompted research and discussion in recent years. Despite the high efficiency, specificity, and rapid action of chemical pesticides in pest management, their drawbacks are becoming increasingly evident. This has led to a growing interest in exploring the potential of plant EOs as safe and sustainable alternatives to chemical pesticides (Iqbal *et al.*, 2019). In order to fully realize the potential of plant EOs as green biopesticides, research and development efforts must be focused on innovative technologies that align with three key concepts: social acceptability, economic feasibility, and environmental sustainability (Figure 15.1) (Zhang *et al.*, 2018). This approach will facilitate the wider adoption and utilization of plant EOs in pest management strategies, leading to a more sustainable and environmentally-friendly agricultural sector (Sulewski *et al.*, 2018).

The utilization of plant essential oils (EOs) and their active constituents in managing insect pests, while also exhibiting antiviral or virucidal properties, presents an intriguing opportunity (Figure 15.2). Extensive research has been conducted on the medicinal properties of these compounds against pathogenic viruses affecting both humans and animals. This valuable information can be systematically documented and leveraged to enhance agricultural practices for controlling plant pathogenic viruses and insect vectors (Sarowska *et al.*, 2021). The essential oils (EOs) derived from plants and their compounds have proven to be effective in enhancing physical, chemical, and biological stabilities along with their antiviral properties. Various research studies have highlighted the potential of plant EOs in combating viral activity. For example, it was observed that the EOs from star anise (*Illicium verum* Hook.f., Illiciaceae) and fennel (*Foeniculum vulgare* Mill., Apiacae) exhibited inhibitory effects on Potato virus X (PVX: Potexvirus, Flexiviridae), Tobacco ringspot virus (TRSV: Nepovirus, Secoviridae), and Tobacco mosaic virus (TMV: Tobamovirus, Virgaviridae). Additionally, studies have shown that tea tree oil (*Melaleuca alternifolia*) reduced local TMV lesions on tobacco plants (Nicotiana glutinosa), while the EO of clove (*S. aromaticum*) inhibited Potato leaf roll virus (PLRV: Polerovirus, Luteoviridae) effectively. Moreover, research revealed that the EOs from artemisia, ginger, and lemongrass inhibited TMV transmission, while lavender oil was found to control Tomato spotted wilt virus (TSWV: Tospovirus, Bunyaviridae).

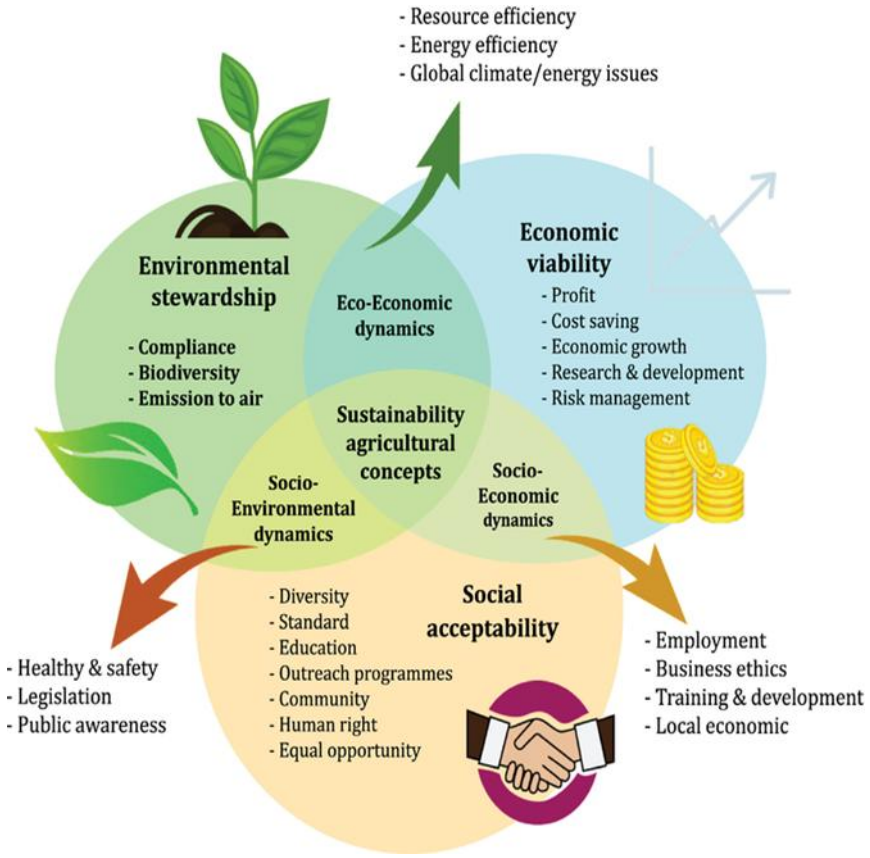

Fig. 15.1. The sustainability agricultural management concepts (Sulewski *et al.*, 2018).

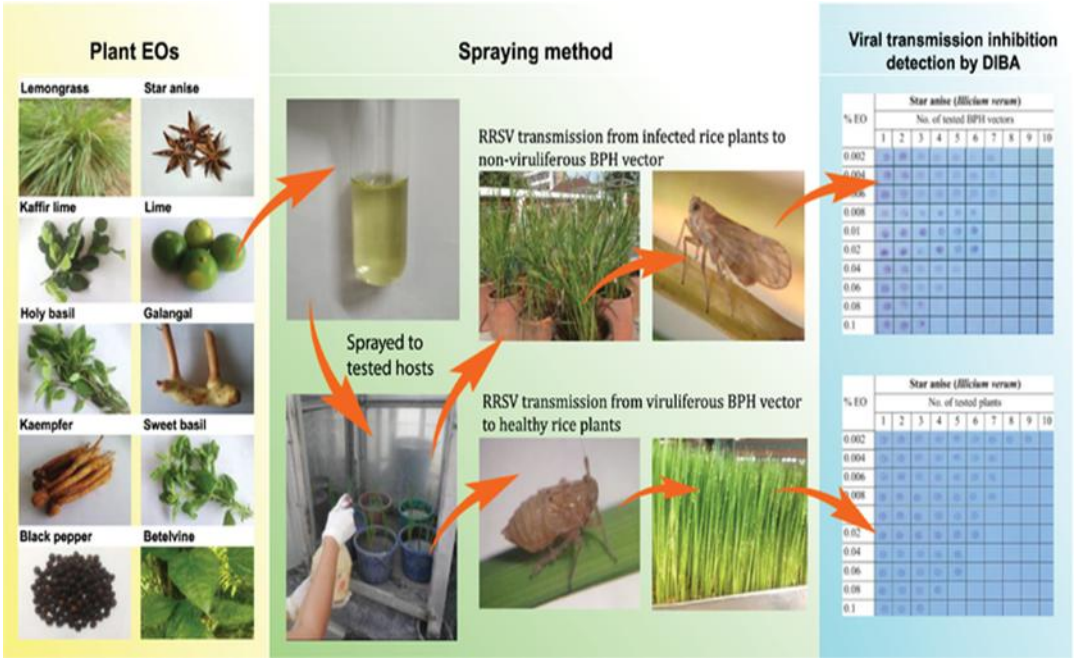

Fig. 15.2. The potential of plant EO for transmission inhibitory effects on RRSV by the BPH vector and detection method by DIBA (Na Phatthalung and Tangkananond, 2021).

Other plant EOs, such as those extracted from billygoat-weed, bottle brush, ajwain, holy basil, and pepper elder, have also demonstrated potential inhibitory effects on various viruses. Furthermore, plant EOs of thyme and peppermint have been shown to inhibit Tobacco necrosis virus (TNV: Necrovirus, Tombusviridae) and Cucumber mosaic virus (CMV: Cucumovirus, Bromoviridae) respectively. In a recent study, Na Phatthalung and Tangkananond utilized dot-immunobinding assay (DIBA) to evaluate the transmission inhibitory effects of plant EOs on Rice ragged stunt virus (RRSV: Oryzavirus, Reoviridae) by the brown planthopper (BPH: Nilaparvata lugens Stål). The results of these studies indicated that various plant EOs were effective in inhibiting virus transmission, with a range of 0.002% to 0.1% efficiency from infected rice plants to non-viruliferous BPHs. Plant EOs from black pepper, lemongrass, star anise, kaffir lime, and kaempfer exhibited high inhibition levels, while lime, galangal, holy basil, sweet basil, and betelvine showed moderate inhibition. Further assessment of star anise and lemongrass EOs revealed toxic and physiological effects on the BPH vector, leading to malformed structures and complete destruction within 3-5 days after treatment (Figure 15.3). Overall, these findings suggest that plant EOs have the potential to be developed as commercial antiviral agents for plant protection and sustainable agricultural management (Bishop, 1995; Dikova *et al.*, 2017; Helal, 2019; Iftikhar *et al.*, 2013; Lu *et al.*, 2013; Na Phatthalung and Tangkananond, 2021; Rao *et al.*, 1986).

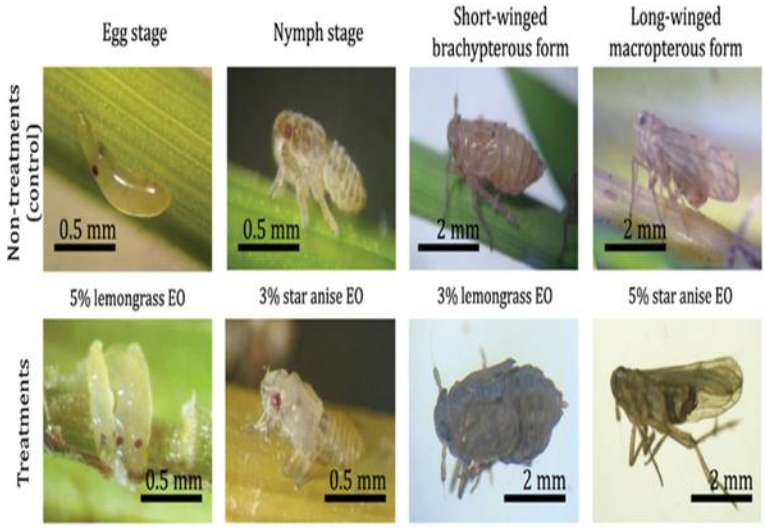

Fig. 15.3. The morphological effects of plant EOs on the BPH (Na Phatthalung and Tangkananond, 2021).

It is feasible to formulate hypotheses regarding antiviral mechanisms through a comprehensive analysis of the existing literature concerning the viral infection process in in vitro cell-culture-based systems and in vivo viral host models, as well as through molecular docking simulations. The fundamental concept of antiviral mechanisms associated with plant essential oils can be categorized into two main types: direct and indirect actions (Figure 15.4). Multiple direct antiviral actions have been identified, involving the obstruction of substances and enzymes, which impact both enveloped and nonenveloped (naked) viral particles at different stages of the viral infection process. Various plant essential oils and their active components exhibit considerable potential in terms of inactivating viruses, decreasing transmissibility, enhancing stability, and reducing infectivity, particularly in relation to enveloped viruses (Aoki-Utsubo *et al.*, 2018; Cagno *et al.*, 2015; Ma and Yao, 2020; Panikar *et al.*, 2021).

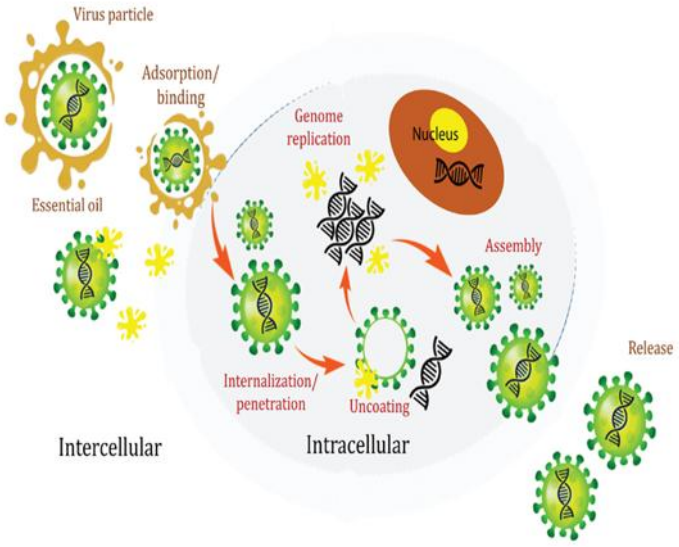

Fig. 15.4. The mechanism of antiviral actions as possible targets for plant EO (Ma and Yao, 2020).

Several mechanisms of indirect antiviral actions impact host characteristics, modes of viral transmission, and efficacy of infection. Typically, plant essential oils exhibit significant hydrophobic properties, such as surface tension, contact angle, droplet size, and various viscosities, which influence the structural properties of the external surface area of viral hosts. The application of plant essential oils on insect vectors or plants may alter their physiology and disrupt the metabolism of infected cells. This coating of the external surface areas of viral particles and hosts inhibits infectivity and transmissibility. The developmental and survival stages of insect vectors play a crucial role in viral transmission, with nymph stages being particularly important. Adult stages contribute to population growth, migration, and viral dissemination. However, certain plant essential oils demonstrate greater effectiveness against soft-bodied insects compared to hard-bodied insects. These oils impact host plant manipulation by inducing systemic resistance and possessing insecticidal properties. Utilizing active plant essential oils can mitigate the damaging effects of insect vectors on crops and diminish their ability to transmit plant viruses. The composition of plant essential oils is conducive to adhering to the general surface structure of the stylet or body cuticle of insect vectors and effectively inhibiting viral transmission. As such, plant essential oils hinder virus transmission within the intricate relationships between the virus, vector, and plant (Abou Baker *et al.*, 2021; Phatthalung and Tangkananond, 2021; Saiz-Rubio and Rovira-Más, 2020; Shafie *et al.*, 2017; Siejak *et al.*, 2021; Singh *et al.*, 2014).

15.11. Current status progress of plant essential oils (EO's) and active compounds for sustainability in agriculture

The utilization of applied plant essential oils by farmers has not yielded tangible outcomes due to the primary focus on subsistence farming and the absence of structured business practices aligned with agricultural policies. As a result, the integration of plant essential oils into the production processes, starting from plantation levels to ensure the quality of raw materials, becomes crucial. Furthermore, disseminating relevant information through active networks is essential to foster acceptance and confidence among stakeholders by merging agricultural expertise, scientific knowledge, and cutting-edge technologies. Collaborative networks involving researchers, entrepreneurs, and farmers are necessary to facilitate the establishment of robust support mechanisms for agricultural innovation. Implementing a smart operational cycle utilizing agricultural

database systems and network management structures can greatly enhance efficiency and effectiveness, as depicted in Figures 15,5 and 15.6 (Himesh *et al.*, 2018; Janssen *et al.*, 2017; Saiz-Rubio and Rovira-Más, 2020). The use of plant-based essential oils for crop protection and management during initial farm operations is a promising approach. The success of pathogen detection processes hinges on the execution of a sophisticated framework encompassing data collection, analysis, and dissemination through intelligent platforms.

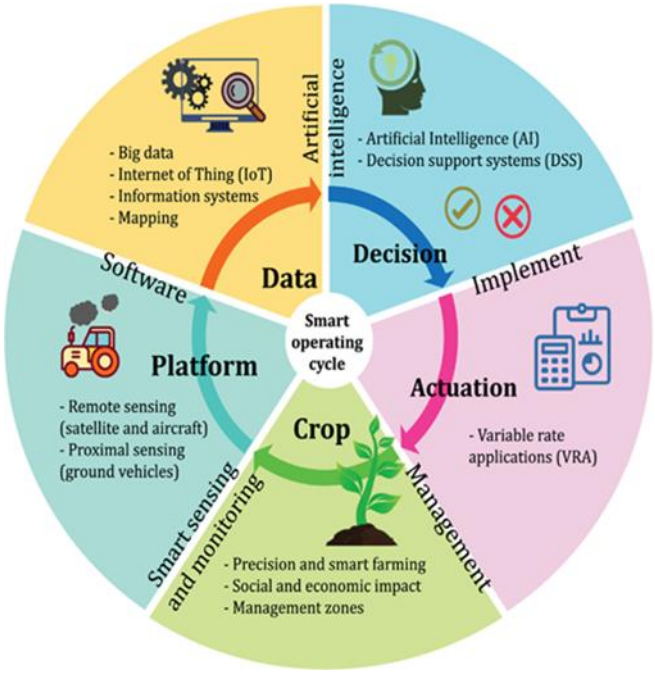

Fig. 15.5. The smart operating cycle based on agricultural database systems and network management organization (Saiz-Rubio and Rovira-Más, 2020).

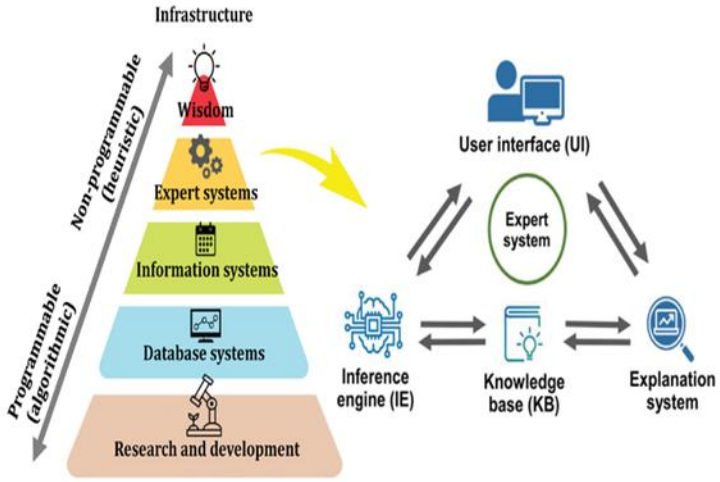

Fig. 15.6. The pyramid of smart agricultural operating hierarchy (Himesh *et al.*, 2018; Janssen *et al.*, 2017).

The integration of Farm Management Information Systems (FMIS) involves a variety of technologies and standardized software packages such as information technology (IT), information systems (IS), and enterprise resource planning (ERP) to facilitate data collection, processing, storage, and

distribution (Salami and Ahmadi, 2010). This comprehensive approach unites all FMIS functionalities, information, and diverse business operations into a single cohesive system designed to streamline registration, interactivity, and external system communication (Verdouw *et al.*, 2015). Silvie and team presented a knowledge-based system (KBS) called Knomana, as well as a software prototype, that focuses on botanical species used for crop protection against pests. This software prototype classifies botanical species and their corresponding parts used for protecting specific organisms, while also providing information on the most effective plant species for maintaining plant health and offering alternative strategies and applications for pest management. Consequently, this software prototype facilitates the generation of new knowledge related to pest management strategies and policies, such as the IPM push-pull strategy (Silvie *et al.*, 2021). These advanced systems have the potential to predict and detect crop diseases in their early stages through the integration of meteorological systems with sophisticated algorithms. Additionally, robot systems can collaborate in offering comprehensive services by incorporating various detection methods such as next-generation sequencing techniques, loop-mediated isothermal amplification, and lab-on-chip technology based on electrical impedance spectroscopy (Kanzi *et al.*, 2020; Mongkolchart and Ketcham, 2020).

15.12. Bio control product trends and innovative technological developments for antiviral and insect-pest management

The utilization of plant essential oils for their antiviral and insect-pest management properties within sustainable agricultural practices has not been widely embraced as compared to synthetic chemicals. The interactions between hosts and viruses have led to the development of resistance to bioactive compounds. The use of natural products offers various benefits such as ensuring agricultural product safety, reducing levels of plant viruses and insect pests, enhancing product quality and value, and facilitating market access. However, the realization of these advantages is dependent on physical factors such as agro-climatic zones, seasons, and crops, as well as biological factors like biotransformation and the population dynamics of microorganisms. Product development should cater to a wide range of applications and be suitable for large-scale agricultural operations. The Agriculture 4.0 policy plays a crucial role in advancing the preparation and processing of plant materials for the efficient production of natural substances, crop protection, and effective pest management. Several bioactive compounds found in plant essential oils have been recognized as generally safe by regulatory bodies such as the United States Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) for their applications in medicine and agriculture. For instance, compounds like thymol and carvacrol, extracted from winter savory, have been shown to directly deactivate certain plant viruses. Studies have also demonstrated the antiviral activity of eugenol from lemon-scented gum against Tomato yellow leaf curl virus and its ability to trigger the salicylic acid biosynthetic pathway. Meanwhile, eucalyptol, D-limonene, L-limonene, and eugenol in clove buds have displayed inhibitory effects against certain plant virus infections. Monoterpenes like thymol, carvacrol, and p-cymene from various plant sources have also been found to inhibit Herpes simplex virus type 1. However, the efficacy of plant essential oils in antiviral and insecticidal applications can be influenced by the diversity of viral types and the composition of the oils (Boukhatem and Setzer, 2020; Sun *et al.*, 2016).

The limitations associated with traditional techniques for the detection and analysis of bioactive compounds includes issues such as sampling methods, adsorbent selection, and time-consuming processes. Furthermore, these methods often require additional equipment like adsorbent traps, laboratory-based molecular assays, and gas chromatography-mass spectrometry (GC-MS). On the other hand, non-invasive approaches and innovative technologies, such as E-nose, gas chromatography-flame ionization detector (GC-FID), proton-transfer-reaction mass spectrometry (PTR-MS), proton-transfer-reaction-time of flight-mass spectrometry (PTR-TOF-MS), electrolyte-

insulator-semiconductor (EIS) sensor, and image analysis systems, offer promise for the specific analysis of compounds. Morphological and physiological changes in plants can be utilized with advanced technologies for indirect detection of plant diseases in the field. Techniques like visible/RGB imaging-based methods using digital camera technologies can enable plant phenotyping and monitoring throughout the growth period. Hyperspectral (HS) imaging systems have demonstrated success in early detection of Tomato spotted wilt virus (TSWV) with a high accuracy rate, while the economic impacts of plant viruses such as Tobacco mosaic virus (TMV), Grapevine vein-clearing virus (GVCV), Tulip breaking virus (TBV), and Potato virus Y (PVY) can be similarly assessed. Similarly, alternative viral detection methods, like chlorophyll fluorescence (ChlF) imaging, have the potential to identify viruses like Cucumber mosaic virus (CMV), TMV, Pepper mild mottle virus (PMMoV), Sweet potato feathery mottle virus (SPFMV), Sweet potato chlorotic stunt virus (SPCSV), and Turnip crinkle virus (TCV) before visible symptoms appear (Nguyen *et al.*, 2021; Sharifi-Rad *et al.*, 2017; Silva-Flores *et al.*, 2019; Tholl *et al.*, 2021; Wang *et al.*, 2019).

In addition, other advanced technologies and high-throughput techniques have significantly improved agricultural analysis and can be combined and utilized alongside artificial intelligence (AI) innovations like thermography, Raman spectroscopy, phytohormone biosensing, and active remote sensing methods such as RADAR and LiDAR. Plant essential oils and their active components will be administered following initial detection and analysis through user-friendly smart technologies, where the data collection process is automated and generates real-time reports. Consequently, the incorporation of various cutting-edge technologies is enhancing crop protection, particularly through smartphone applications that blend imaging, telecommunications, and computing technologies, including VOC sensor systems (Figure 15.7). Several AI applications for smartphones, like Leaf Doctor, Pestoz, and PlantSnap, can be obtained for free download, allowing for imaging and phenotyping applications in plant disease and pest identification. Li et al. demonstrated the successful detection of volatile emissions from tomato plants during early infection stages of Phytophthora infestans using a smartphone-based VOC fingerprinting platform equipped with nanosensors and traditional chromogenic dyes, achieving a detection accuracy exceeding 95%. Similarly, automated mobile applications have accurately identified various plant viruses, such as Banana bunchy top virus and Cassava brown streak virus (Cubero *et al.*, 2020; Li *et al.*, 2019; Mrisho *et al.*, 2020; Pineda *et al.*, 2020).

Fig. 15.7. Read-out platforms of smartphone applications and parallel advancements by different methods for plant disease diagnosis and detection.

15.13. Significance of thymol and carvacrol

Essential oils (EOs) have gained widespread acceptance as an alternative method for managing various diseases, owing to their numerous advantageous properties. Their efficacy has been recognized for centuries, particularly for their digestive stimulant, antiviral, antioxidant, and antifungal qualities, as depicted in Figure 15.8. Furthermore, EOs have been found to possess the capability to impede, preclude, or even reverse the development of cancerous cells. These characteristics render them valuable for disease management, with their application in the poultry industry being quite prevalent. In addition to disease prevention, EOs has been shown to enhance the overall productivity of birds (Alharbi, 2024; Coles *et al.*, 2023). Herbs like thyme and oregano produce thymol and carvacrol, respectively, which have numerous health benefits for poultry and could be potential substitutes for traditional antibiotics. Working together, these compounds display enhanced antibacterial properties against important poultry pathogens, including drug-resistant bacteria like *Salmonella* and *E. coli*, thereby reducing antibiotic resistance. In addition to their well-known antibacterial effects, thymol and carvacrol also exhibit antiviral properties, which are crucial for maintaining poultry health. Viral infections in poultry farming carry a substantial financial risk, and utilizing natural products such as thymol and carvacrol could be an effective strategy for disease prevention (Coles *et al.*, 2023; Zhao *et al.*, 2023).

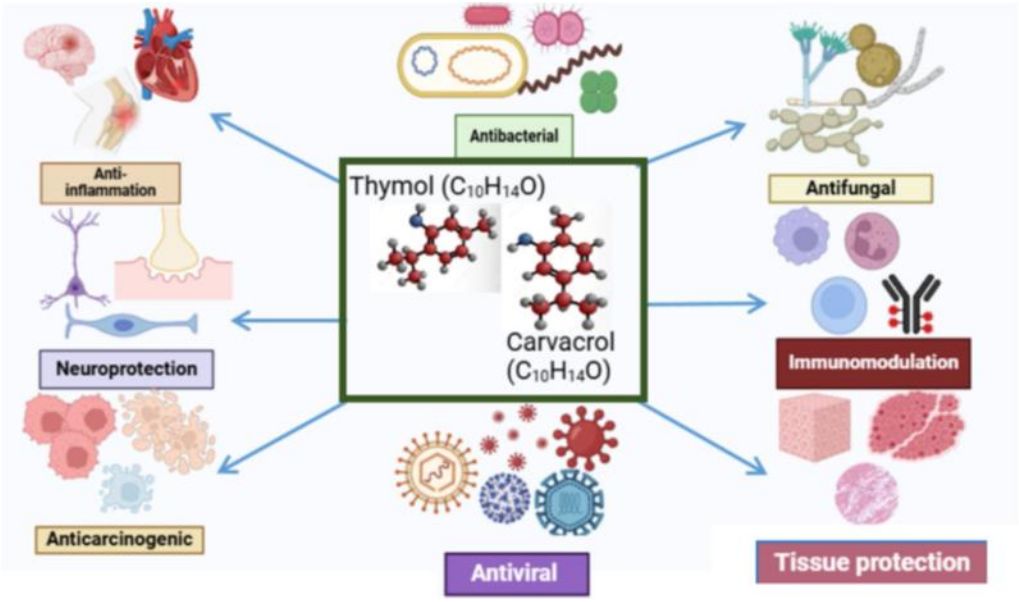

Fig. 15.8. Various effects of thymol and carvacrol on poultry health.

15.14. Non-circulative, stylet-borne transmission

CaMV, a pararetrovirus belonging to the family Caulimoviridae, possesses virions with isometric T¼7 capsids measuring approximately 52nm in diameter, primarily consisting of the P4 (gag or capsid) protein. The transmission of CaMV by aphids involves a complex tritrophic interaction, where the virus can be acquired through probing and puncturing of infected leaf tissues, as well as sustained ingestion from phloem tissues during feeding (Figure 12). In contrast to potyviruses, the

transmission of CaMV by aphids necessitates interactions among three CaMV-encoded proteins, including P2, which also interacts with the aphid stylet. Additionally, P3, anchored within the virion capsid shell, plays a crucial role in the transmission process along with P2, which serves as a non-virion helper component protein binding to the aphid stylet. Furthermore, the binding of P2 to the aphid stylet involves its N0-terminus, while its C0-terminus binds to the N0-terminal region of P3 (Ammar *et al.*, 2009; Blanc *et al.*, 2014; Miyazaki *et al.*, 2013).

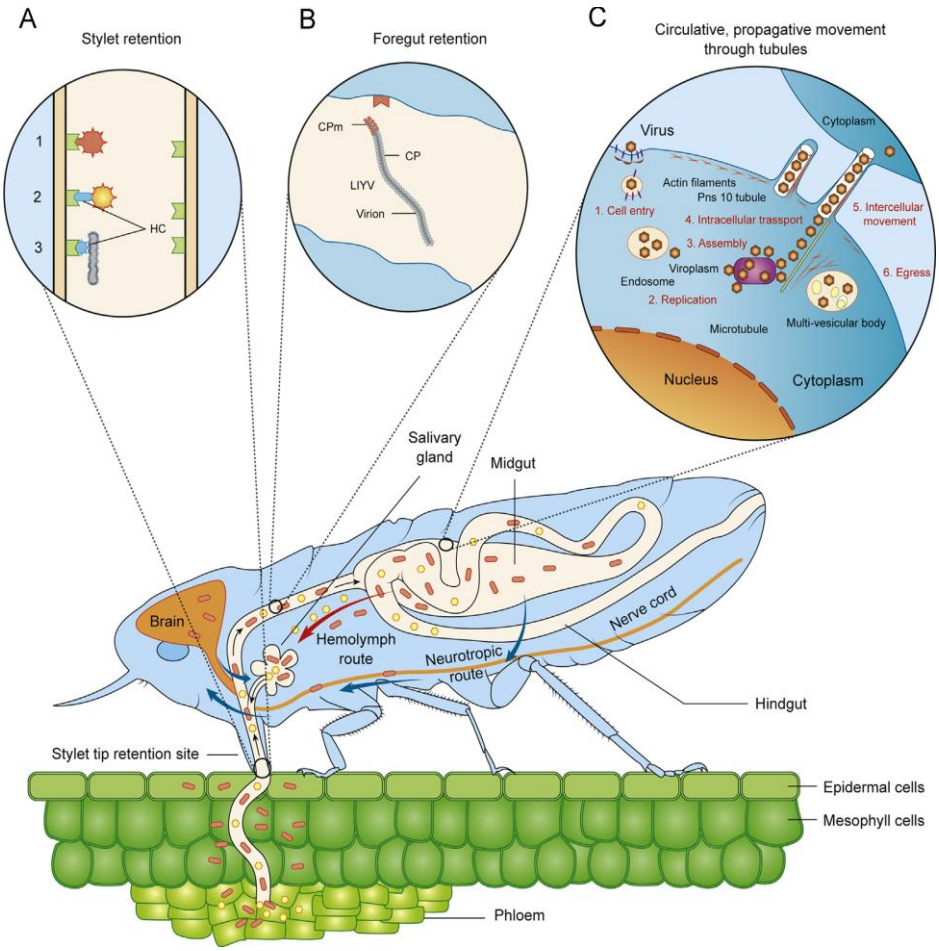

Fig. 15.9. Viruslocalization sites in insect vectors. Noncirculative viruses are retained in the insect stylet (A) or fore gut (B). Non propagative circulative (yellow circles) viruses are generally phloem limited and penetrate the insect body via the midgut or hind gut. Circulative viruses use a hemolymph route to reach the salivary glands (Ammar *et al.*, 2009; Blanc *et al.*, 2014; Miyazaki *et al.*, 2013).

15.15. Conclusions

Organic vegetable cultivation is currently at a critical juncture, facing challenges from climate change and human activities that introduce new vectors and viruses into previously unaffected ecosystems. The demand for organic produce is steadily increasing, but this growth requires more farming land due to lower productivity compared to conventional methods. Weaknesses in existing policies have resulted in the destruction of ecosystems, such as deforestation for the establishment of new organic farms, with serious long-term consequences for ecosystem sustainability.

In order to mitigate these negative impacts, organic farms must prioritize the preservation and enhancement of natural ecosystems and their functions. Sustainable practices in organic vegetable production should focus on both spatial and temporal aspects to ensure long-term viability.

The emergence of plant pathogenic viruses and insect vectors resistant to traditional control methods has posed significant challenges to farmers. To address these issues, innovative technologies aimed at developing environmentally friendly antiviral and insect-pest management products have been introduced to maintain high-quality agricultural production on a large scale. Agriculture 4.0 represents a modern approach that seeks to enhance the efficacy of natural products through advanced extraction techniques and quality testing, ultimately gaining acceptance among farmers.

However, the success of modern agricultural systems relies on the support and collaboration of not only governmental entities but also the wider public sector, promoting policies that prioritize sustainable practices for the mutual benefit of the environment and society.

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Chapter 16

Effects of Organic Plants on Cryptosporidium and Immunity

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Abstract

Cryptosporidiosis, caused by Cryptosporidium sp., is a disease that is spreading globally. In recent times, research has been focused on finding a treatment for this disease that is both effective and free of side effects, especially for young individuals and those with compromised immune systems. The objective of the present chapter was to assess the therapeutic potential of coconut oil extracts as a natural remedy for Cryptosporidium infection in immunocompromised mice. The disposal of organic plant waste and by-products from the food and pharmaceutical industries typically comes with a high financial burden. Human ileocaecal adenocarcinoma (HCT-8) cell cultures were exposed to *C. parvum* oocysts and the progress of parasite development was monitored using an indirect fluorescent antibody technique (IFAT) and microscopic examination for clusters of secondary infection (CSI). The minimum inhibitory concentrations (MICs) were determined, along with any potential harmful effects on the host cells. An ethanolic extract derived from olive (*Olea europaea*) pomace, obtained after oil pressing and phenol recovery processes, consistently inhibited *C. parvum* development. While tyrosol, hydroxytyrosol, trans-coniferyl alcohol, and oleuropein were identified as key compounds in the olive pomace extract, their individual contributions to the observed activity were found to be minimal. The developed test system served as a rapid and effective method for identifying anti-cryptosporidial properties within biological waste materials, allowing for comparison with reference compounds of choice.

Keywords: *Cryptosporidium*, Cell culture, Phytogenic, oil extracts, mice, *Zingiber,* Nitazoxanide, Cytokines.

16.1. Introduction

Cryptosporidium parvum is a widely distributed protozoan parasite that has implications for both human and animal health. The illness caused by this parasite, known as cryptosporidiosis, is characterized by short-lived diarrhea and complications such as poor absorption of nutrients and dehydration. In immunocompromised individuals and young animals, the disease can be especially severe. Cryptosporidia are inherently resistant to many medications designed to combat protozoan parasites. Although a study screening a large number of drugs showed some effectiveness in 40 out of 101 tested, only a few were able to completely inhibit parasite growth at low concentrations in laboratory settings. As a result, the range of available treatments for patients affected by cryptosporidiosis remains very limited. Currently, azithromycin, paromomycin, and nitazoxanide are among the most commonly used medications, often in combination with highly active anti-retroviral therapy (HAART). Similarly, only a select few drugs have been identified as effective against cryptosporidiosis in animals (Shahiduzzaman and Daugschies, 2012; Smith and Corcoran, 2004; Woods *et al.*, 1996).

Plants have long been utilized for their rich reservoir of bioactive compounds, which have been historically employed for the prevention and treatment of a diverse array of human and animal ailments, including parasitic diseases. For instance, genistein, an isoflavone derived from soybean, silibinin, a flavonolignan mixture found in milk thistle, and curcumin, a curcuminoid derived from ferulic acid in turmeric, have shown promising anti-cryptosporidial properties in laboratory settings. Mangiferin, a xanthone compound typically associated with mangoes, has also exhibited efficacy in live subjects. Notably, recent research has revealed that pomegranate peel powder can effectively combat experimental *Cryptosporidium parvum* infections in mice, while pomegranate extract has shown potential in lessening Cryptosporidium-related illnesses in calves (Adams *et al.*, 2011; Ndjonka *et al.*, 2013; Teichmann *et al.*, 2012). The initial framework provided a basis for examining

the potential impacts of various waste materials and by-products on *C. parvum*. The reduction of waste production and the recycling of waste materials are now considered crucial in contemporary and future societies. Utilizing by-products from food production as feed for livestock has been established as a method to minimize waste accumulation and promote the cost-effective production of animal products (Shamsi *et al.*, 2011). The SAFEWASTES project, funded by the EU, delved into the nutritional value of various plant waste and by-products, while also seeking to uncover potential health advantages for livestock. Contributions were received from a range of industry collaborators including juice manufacturers, oil refineries, and pharmaceutical firms involved in processing medicinal herbs. A rapid and straightforward method for evaluating the efficacy of plant-derived samples against *C. parvum* in cell cultures has recently been devised. In this study, 42 samples from 18 different plant wastes and by-products were examined using solvents of varying polarity (water, aqueous ethanol, or heptane) through the aforementioned assay. Efforts were made to pinpoint the active ingredient by means of High Pressure Liquid Chromatography (HPLC) analysis and through testing of pure compounds and specific extracts from anti-cryptosporidial specimens (Bone Relat *et al.*, 2022; Shahiduzzaman *et al.*, 2009). Except for the ethanolic extract derived from olive pomace (referred to as OEE), the remaining six initially identified extracts did not display any activity across all replication trials. The inhibitory concentrations of OEE were determined without applying a logarithmic transformation to the data, with IC50 values of 361 (279–438) μg mL^{-1} and IC90 values of 467 (398–615) μg mL^{-1} (95% confidence intervals shown in parentheses). Monensin sodium salt was used as a positive control, demonstrating minimal inhibitory concentrations ranging from 8.3 to 33.4 ng mL^{-1}.

16.2. Chromatography

HPLC chromatograms and peak spectra depicting (a) an ethanolic extract derived from olive fruit pomace of *Olea europaea* L. (OEE; 260 nm) and the pure reference compounds confirmed as constituents of the extract, including (b) hydroxytyrosol (280 nm), (c) tyrosol (280 nm), and (d) trans-coniferyl alcohol (260 nm), are presented. The representations include retention times (in minutes; rotated view), relative absorption intensity (AU), UV spectra, and absorption maxima at specific wavelengths in nm.

Pure reference compounds such as tyrosol and trans-coniferyl alcohol, an extract abundant in oleuropein (8.2%), and an extract rich in hydroxytyrosol (10%) did not demonstrate complete parasite inhibition at non-toxic concentrations to the host cells. The inconsistency in the anti-cryptosporidial activity observed in the six initially active samples could potentially be attributed to inadequate storage stability of the samples or their active compounds. Variation in results was evident in this assay, as indicated by the MIC-range of monensin (8.3–33.4 nM). Furthermore, the effectiveness of monensin slightly surpassed that observed in prior experiments (Teichmann *et al.*, 2012). Variability in oocyst freshness and batch-to-batch differences could potentially account for the varying levels of parasite inhibition observed. However, consistent complete inhibition of *C. parvum* at 133.5 nM or lower has served as a dependable positive control in both current and previous studies. An analysis of the dose-response curve for OEE depicted in Figure 1 revealed a sharp increase in inhibition efficacy between concentrations that were non-inhibitory and those that were inhibitory. This was further demonstrated by the close proximity of the IC50 and IC90 values, which were measured at 361 and 467 μg mL^{-1}, respectively. At the maximum tested concentration of 1000 μg mL^{-1}, there was a noticeable decrease in host cell viability, indicating minor cytotoxic effects. Consequently, the therapeutic window of the extract seems to be relatively narrow.

Based on a literature review regarding the chemical composition of olive fruits, it has been established that key components include water, oil, carbohydrates (such as cellulose and pectin), protein, organic acids, pigments, and inorganic substances. Phenolic compounds and polyphenols have also been identified, along with unsaturated fatty acids, tocopherols, and phospholipids, all of which are believed to contribute to the various health benefits associated with olives and olive oil. Phenols play a critical role in determining the unique taste and oxidative stability of olive-based

products. Oleuropein, tyrosol, and hydroxytyrosol are among the most prevalent phenolic substances found in olive fruits, with their concentrations varying based on the ripeness of the fruit. Some phenolic compounds are not completely eliminated during the oil extraction process, likely due to their hydrophilic properties. Noteworthy phenolic compounds in olive press cake include hydroxytyrosol, oleuropein, tyrosol, caffeic acid, p-coumaric acid, vanillic acid, verbascoside, elenolic acid, catechol, and rutin (Ghanbari *et al.*, 2012). Several potential chemical compounds present in olive press cake extract were acquired in the form of synthetic or purified chemicals. Analysis using high performance liquid chromatography (HPLC) revealed the presence of tyrosol, hydroxytyrosol, and coniferyl alcohol in the olive extract, although oleuropein was not detectable. This finding is not unexpected, as mature olives are typically used for oil production, leading to the degradation of oleuropein into demethyloleuropein, elenolic acid dialdehyde, and hydroxytyrosol during the fruit maturation process. Additionally, trans-coniferyl alcohol was identified as a potential chemical compound, which has not been previously documented in this context. The presence of coniferyl alcohol is not surprising, as its derivatives, lignans, have been reported in olive oil. The olive press cake used in this study had undergone a phenol recovery process (methanol-ethanol extraction) before extraction for Cryptosporidium testing. The detection of simple phenols like tyrosol, hydroxytyrosol, and coniferyl alcohol indicates that the oil pressing and phenol recovery steps were not entirely successful in removing phenols from the olive pomace (Amiot *et al.*, 1989; Brenes *et al.*, 2000).

Tyrosol, trans-coniferyl alcohol, and extracts abundant in oleuropein or hydroxytyrosol were evaluated for their ability to inhibit cryptosporidium in our tests, using concentrations similar to or higher than the effective concentration of OEE. However, none of them demonstrated the capacity to impede infection and parasite growth at the concentrations tested, suggesting that they may not be solely responsible for the effectiveness of OEE. Pentacyclic triterpenes such as oleanolic acid and maslinic acid have been found in the skin of olive fruits. Maslinic acid, in particular, has been identified as a compound with anti-parasitic properties, inhibiting *Eimeria tenella* in a study involving infected chickens. Furthermore, it exhibited anti-malarial activity both in vitro and in vivo, indicating a potentially broad range of actions. Maslinic acid has also been linked to antiviral, anti-cancer, anti-inflammatory, and antioxidant effects, suggesting its pivotal role in the observed benefits of OEE and warranting further investigation in future research efforts (De Pablos *et al.*, 2010; Moneriz *et al.*, 2011). In 2012, the global annual production of virgin olive oil surpassed 3 million tons, leading to the generation of approximately 1 million tons of olive press cake. This is because roughly one-third of the mass of fresh olives remains as press cake. Additionally, over 30 million cubic meters of olive mill wastewater is produced annually in the Mediterranean region, which is responsible for 95% of the world's olive production. While there are potential benefits to spreading olive mill wastewater on agricultural land and utilizing composted olive press cake to improve soil quality, there is also concern about the environmental impact due to the presence of phytotoxic compounds in some phenolic compounds. This prevents direct use of these byproducts as fertilizers or compost. Finding alternative methods of utilizing olive mill waste could alleviate this environmental issue (Aktas *et al.*, 2001; Barbera *et al.*, 2013; Chowdhury *et al.*, 2013; Nakai, 2018).

Using olive oil production by-products (such as wastewater and pomace) as feed for animals is a common and advantageous practice, primarily due to the substantial protein content found in the pomace. Historically, the use of olive pulp in the diets of ruminant animals has been prevalent. Research has also been conducted to assess the impact of incorporating these by-products into the diets of monogastric animals like layer chickens. Previous studies have shown positive effects on the production parameters of pigs raised for fattening. However, recent findings, along with other scientific investigations, suggest that these by-products have the potential to serve as a valuable resource for disease prevention in animals (Friedman *et al.*, 2013; Molina-Alcaide and Yáñez-Ruiz, 2008). The search for the anti-cryptosporidial compound(s) in OEE has thus far yielded no success, necessitating further investigation to uncover its true identity. If the inhibitory activity is mediated by different chemicals than those responsible for cytotoxic effects on host cells, a targeted purification process could help isolate a specific active fraction or pure compound. Additionally, the

active ingredient may arise from chemical transformations occurring during the production of olive oil or the recovery of phenols. Processes such as oxidation and acid hydrolysis can take place during the storage of olive oil, potentially leading to the formation of the active substance. It is possible that the inhibition of *C. parvum* is not attributable to a single chemical compound, but rather to a synergistic blend of multiple substances. Plant metabolites have developed specific activities based on their environmental context, as demonstrated by the pro- and anti-oxidant properties of flavonoids. Compounds that are easily oxidized, including many antioxidants, have a tendency to produce radicals that could disrupt critical parasite enzymes, suggesting a potential mechanism of action against *C. parvum* for a substance rich in antioxidants like OEE (Brenes *et al.*, 2001; Chobot *et al.*, 2013).

Cryptosporidium sp. is a group of parasitic protozoa with zoonotic potential that can infect a diverse range of vertebrate hosts. While most infections result in asymptomatic or diarrheal symptoms in individuals with a robust immune response, immunocompromised patients may experience severe and prolonged episodes of diarrhea, as well as complications affecting the pancreas, biliary system, and respiratory tract, which could potentially lead to fatal outcomes. While the drug nitazoxanide has been effective in treating Cryptosporidium-induced diarrhea, its efficacy is limited in individuals with compromised immune systems or malnutrition, and it is not approved for use in infants under one year old. The urgent demand for new and more potent therapies for cryptosporidiosis is underscored by this pressing need. Coconut oil is a natural substance consisting of 92% saturated fatty acids, with its main component being Lauric acid, known for its advantageous antimicrobial, antioxidant, and anti-inflammatory properties. Early investigations into coconut oil's antimicrobial effects date back to the 1970s, with pioneering research conducted by John Kabara, revealing its wide-ranging capabilities against bacteria, viruses, and fungi (Börekçi *et al.*, 2005; Dayrit, 2014; DebMandal and Mandal, 2011; Widiyarti *et al.*, 2010).

In the field of parasitology, research has shown that Lauric acid has demonstrated safety, ease of use, and excellent tolerability when used in conjunction with metronidazole for the treatment of giardiasis. Additionally, Lauric acid has exhibited potential as a prophylactic measure, particularly in cases of traveler's diarrhea. Moreover, Lauric acid may possess immune-stimulant properties, making it a promising option for immune-compromised individuals. Historical observations revealed that Cryptosporidium led to the death of epithelial cells in the intestine, resulting in structural changes in villous formations and the presence of apoptotic epithelial cells. A significant correlation was noted between epithelial apoptosis and the pathogenesis of cryptosporidiosis (Maisa A *et al.*, 2013; Sasahara *et al.*, 2003). Delineating apoptosis, Caspase-3 serves as a vital cysteine protease responsible for prompting cellular morphological modifications. Positioned as a convergence point between two key apoptotic pathways, this enzyme efficiently cleaves numerous cellular substrates during the apoptotic process. Consequently, evaluating the activity of Caspase-3 stands as a crucial and trustworthy method for determining apoptosis. Various studies have underscored its significance as an independent prognostic factor in digestive system tumors, particularly in colorectal carcinomas. Regarded as an excellent indicator for gauging apoptosis in cancer cases, CDX2 is a transcription factor showcasing a homeobox domain. Recognized for its pivotal role in governing the proliferation and differentiation of intestinal cells, CDX2's expression serves as a hallmark of intestinal differentiation. Its nuclear expression in intestinal epithelial cells from the duodenum to the rectum confers noteworthy utility in pinpointing the source of metastatic tumors (Ahmed *et al.*, 2022; van den Akker *et al.*, 2002; Zheng *et al.*, 2003).

The concept of "returning to nature" is a relatively new idea within the realm of general health. Utilizing medications derived from plants has been practiced since the early days of human civilization. In recent years, there has been a growing interest in the use of herbal medicines, particularly due to the increasing resistance of human pathogens to conventional treatments.

Coconut oil is natural oil that is primarily composed of triglyceride compounds containing high levels of saturated medium-chain fatty acids. One of the key fatty acids found in coconut oil is Lauric acid (C12:0), which makes up approximately 50% of the total fatty acids present. This fatty acid has

been shown to have various beneficial effects, including antimicrobial, anti-inflammatory, immunostimulant, and antioxidant properties (Maisa A *et al.*, 2013; Mohammed, 2012). This chapter reveals a significant discrepancy in the count of Cryptosporidium oocysts among various treatment groups, including nitazoxanide, positive control, coconut ethanol, coconut hexane, and coconut water. The group with the lowest oocyst count was coconut water, indicating a potential impact on fecal oocyst levels. Moreover, the experimentally-treated mice groups with coconut water extract maintained a normal appearance and showed varying degrees of histopathological improvements compared to the positive control group. These results suggest promising outcomes for the treatment of cryptosporidiosis. This observation is consistent with Helmy's findings of complete healing of intestinal mucosa following the combined treatment of metronidazole and Lauric acid in the management of giardiasis, as demonstrated through histopathological and electron microscopic examinations (Fahmy *et al.*, 2014; Rayan *et al.*, 2005). It is important to highlight that coconut oil has the ability to modulate cellular immunity and may serve as a viable alternative to antibiotics, given its wide-ranging antibacterial and antiviral properties (Subroto and Indiarto, 2020; Widianingrum *et al.*, 2019). Numerous studies have delved into the presence of Caspase-3 in ileal epithelial cells of infected mice and its pivotal role in inducing apoptosis of epithelial and stromal cells during Cryptosporidiosis. Activation of Caspase-3 is believed to drive the cell towards irreversible apoptotic cell death (Porter and Jänicke, 1999).

In the current investigation, immunohistochemistry results of Caspase-3 demonstrated that prior to the administration of coconut oil, sections of the intestine from the positive control group displayed scattered cytoplasmic positive cells in the intestinal crypt for Caspase-3. This phenomenon can be attributed to the heightened apoptotic activity caused by the oncogenic impact of cryptosporidiosis. These findings are consistent with earlier research indicating that *C. parvum* increases Caspase-dependent apoptosis both in vitro and in vivo. After the treatment with coconut oil in this study, only a few positive cells stained with Caspase-3 were observed. This suggests a reduction in the apoptotic index following coconut oil treatment, showcasing promising outcomes in the treatment of cryptosporidiosis (Coutinho *et al.*, 2008; Ojcius *et al.*, 1999). There was no significant correlation between the dual treatment of infected mice with phenyl vinyl sulfone and nitazoxanide and the expression of Caspase-3. This discrepancy could be attributed to the use of rabbit polyclonal anti-Caspase-3 in their study as opposed to the monoclonal antibody utilized in our research, which offers greater specificity, precision, and reveals characteristic apoptotic nuclear alterations (Samaka *et al.*, 2021). CDX2 plays a vital role in intestinal development and differentiation, serving as a marker typically expressed in colonic mucosa and reduced in instances of tumorigenesis (Simmini *et al.*, 2014). Its absence has been identified in advanced tumor grades and is associated with unfavorable prognosis and metastasis (Singh, 2019).

Human cryptosporidiosis is a disease that is attributable to an infection caused by apicomplexan protozoa from the genus Cryptosporidium. In-depth molecular research has illustrated that this condition is the result of infection by no less than 15 distinct species within the genus. Commonly encountered species include *Cryptosporidium hominis* (*C. hominis*), which exclusively infects humans, and *Cryptosporidium parvum* (*C. parvum*), known to infect both bovines and humans. Notably, *C. parvum* has shown significant resistance to current pharmaceutical interventions. Despite numerous efforts by the pharmaceutical industry to develop effective treatments for cryptosporidiosis, this ailment remains a prominent public health concern (Bouzid *et al.*, 2013; Del Coco *et al.*, 2009). Infection caused by Cryptosporidium is linked to a sudden onset of clinical symptoms such as diarrhea in both humans and various domestic and wild animals. This type of infection tends to be particularly harmful in newborns and the elderly. In individuals with a healthy immune system, the illness typically manifests as severe watery diarrhea, abdominal discomfort, nausea, vomiting, and a mild fever that usually resolves within a period of 2 to 12 days. Conversely, in immune-compromised or malnourished patients, the infection can persist for a longer period, leading to issues such as malabsorption and significant dehydration that may necessitate treatment with fluid replacement therapy (Klein *et al.*, 2008; Xiao, 2010). The Food and Drug Administration of the United States has granted approval for nitazoxanide (NTZ), a versatile anti-parasitic medication

proven to be effective against a variety of parasites in humans, including cestodes, trematodes, nematodes, and protozoa (Rossignol and Maisonneuve, 1984).

16.3. The Efficacy of natural ginger on *Cryptosporidium parvum*

The efficacy of ginger against *Cryptosporidium parvum* infection in young cattle has been well documented. In addition, alternative anti-parasitic treatments have garnered substantial attention in light of the growing issue of drug resistance. Consequently, the currently available medications are deemed to be ineffective in combatting cryptosporidiosis. The emergence of drug-resistant strains of this parasite underscores the necessity of exploring alternative medical approaches. Ginger, scientifically known as *Zingiber officinale*, is globally recognized for its culinary uses as a spice and flavoring agent. Its antioxidant properties have been shown to bolster the immune system, enabling the body to naturally combat infections. Furthermore, ginger exhibits various other beneficial effects that may aid in eliminating parasites, such as its ability to stimulate digestive secretions, as well as absorb and neutralize toxins. Research has been conducted on the antibacterial, antiviral, antifungal, and antiparasitic properties of ginger and its bioactive compounds (Abdel-Hafeez *et al.*, 2015; Abouelsoued *et al.*, 2020; Mostafa *et al.*, 2011; Schnyder *et al.*, 2009).

Ginger has demonstrated therapeutic benefits across various medical conditions by influencing the immune response. Specifically, it has been shown to reduce the secretion of proinflammatory cytokines such as IFNγ, TNF α, IL6, IL12, and IL17, while simultaneously boosting the levels of anti-inflammatory cytokines like IL4, IL5, and IL10. Additionally, the compound 6-gingerol has exhibited efficacy in the treatment of DSS-induced ulcerative colitis in mice and in combating chemically-induced cutaneous inflammation (Sheng *et al.*, 2020; Tawfek *et al.*, 2017; Tzipori, 2002; Xu *et al.*, 2019). Numerous botanical substances and pharmaceutical agents have been evaluated for their efficacy against *C. parvum* infection, primarily by modulating the immune response to inhibit TH1 cytokines, which are pro-inflammatory, and promoting the production of anti-inflammatory cytokines such as IL4, IL5, and IL10. This immunological response observed aligns with the immune reaction noted in this particular study. In terms of histopathological analysis, the group that was infected but left untreated (referred to as G2) displayed characteristics such as sub-epithelial cell edema, hemorrhaging, atrophy, and shedding of the superficial portion of the intestinal villi in the ileum, along with infiltration of inflammatory cells. These observed pathological alterations are likely a result of the parasite's proliferation, the release of harmful toxins, and an elevation in proinflammatory levels. Cytokines induce an uneven depletion of epithelial cells, leading to the shortening and fusion of the villi. Toxins produced by *C. parvum* have a direct detrimental effect on epithelial cells (Tzipori, 2002). Both the group treated with infected/ginger (G3) and the group treated with infected/NTZ (G4) displayed noticeable enhancement in the symmetry, length, and cellular structure of the villi, as well as a decrease in bleeding (Harp *et al.*, 1996). This improvement could be attributed to the presence of various compounds in ginger, such as gingerols, shogaols, and phenolic compounds, which may interfere with receptor sites on the intestinal surface, potentially reducing *C. parvum* colonization or inhibiting parasite growth and multiplication through immunomodulation. Similar results were observed in a previous study (Al-Masoudi, 2011).

16.4. Conclusions

Olive leaf extract (OEE) has demonstrated effective anti-cryptosporidial activity in laboratory settings. Further investigation is warranted to identify the specific active components of OEE, enhance comprehension of its mechanism of action, and broaden its therapeutic potential by isolating and characterizing these active compounds. Cryptosporidiosis, as confirmed through various parasitological, histopathological, and immunohistochemical assessments, has displayed potential as an effective anti-parasitic treatment against Cryptosporidium. Nevertheless, additional research is necessary to deepen our understanding of the diverse coconut extracts available in

order to optimize treatment efficacy. The efficacy of aqueous ginger suspensions in combating *C. parvum* has been underscored across all key metrics assessed in this study. Mice infected with cryptosporidiosis and treated with ginger exhibited consistent weight gain and improved intestinal histopathology throughout the experimental period. Moreover, ginger-treated mice ceased shedding fecal oocysts by the 21st day of treatment. These findings suggest that ginger holds promise as a natural remedy for cryptosporidiosis.

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Chapter 17

Green Energy, Plant Physiology and the Secrets of Organic Agriculture

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Green Energy, Plant Physiology and the Secrets of Organic Agriculture

Abstract

Green Energy in agriculture refers to sustainable energy practices, while plant physiology is the study of plant functions and processes, and organic agriculture is a system that uses natural methods and resources to cultivate crops, excluding synthetic chemicals and GMOs. These concepts are interconnected as understanding plant physiology helps in developing more effective organic farming strategies, and green energy supports sustainable agricultural practices, ultimately enhancing health and ecological balance. Sustainable agriculture strives to ensure future food and energy supply while safeguarding natural resources. The interpretation of sustainability varies by context and country, yielding distinct indicators. Researchers have studied sustainable agriculture for the past 25 years and have developed several indicators. Renewable energy holds a vital role in sustainable agriculture, aiding energy needs and mitigating environmental harm tied to agriculture. It curbs fossil fuel dependency and harnesses agricultural waste for energy. However, a consistent update of renewable energy indicators for agricultural sustainability is needed. Employing SALSA (Search, Appraisal, Synthesis, and Analysis) and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodologies within the PRISMA protocol, this study extracts 84 indicators from 420 papers via SCOPUS. These indicators span social, environmental, economic, institutional, and technical dimensions. The study refines these indicators based on significance and influence, offering an enriched perspective. Furthermore, the analysis categorizes papers by publication year, continent, and topic, providing insights for stakeholders, policymakers, and researchers. By ensuring periodic indicator updates, this research promotes sustainable agriculture, informs priority areas, and guides strategic decisions. This contributes to global resilience and food security aspirations in a changing world. The future of renewable energy and sustainable agriculture will involve cutting-edge technologies, refined policy frameworks, and inclusive cross-sector collaboration to address pressing global challenges and create a greener, more resilient world.

Keywords: Green Energy, plant physiology, organic agriculture, environmental sustainability.

17.1. Introduction

Our lives are not possible without agriculture, which is the foundation of both our food supply and our ability to survive. It includes the raising of livestock; the cultivation of crops; and the production of food, fiber, and other agricultural goods. We would not have access to a wide variety of healthy foods that are vital to our wellbeing without agriculture. It offers the building blocks for a nutritious and balanced diet, supporting our physical development, growth, and general well-being (Rafael, 2023).

Additionally, agriculture contributes to our economies and ways of life in addition to just producing food. Particularly in rural areas where farming and related professions are common, it is a significant source of employment. Along the entire value chain, from farmers and laborers to processors, distributors, and retailers, agriculture generates employment opportunities. Additionally, it promotes economic expansion through trade and exports, boosting national prosperity and promoting food security on a global scale (Payumo *et al.*, 2018).

Additionally, agriculture is vital to the sustainability of our planet and the development of our environment. Sustainable agricultural methods encourage soil health, biodiversity, and water conservation. Farmers can lessen the use of harmful pesticides and fertilizers, stop soil erosion, and preserve natural resources by implementing sustainable techniques like organic farming,

agroforestry, and precision agriculture. Through techniques like biofuel production and the use of agricultural waste for energy generation, agriculture also has the potential to contribute to the production of renewable energy, assisting in the transition to a greener and more sustainable future (Iqbal, 2023a; Sofo *et al.*, 2022).

Sustainable agriculture emphasizes the use of integrated pest management (IPM) techniques to control weeds, diseases, and pests. Crop rotation, biological control strategies, habitat diversification, and the selective use of pesticides only when necessary are a few of the techniques used in this process. IPM seeks to manage pests effectively while using fewer synthetic chemicals. To reduce greenhouse gas emissions and reliance on non-renewable resources, sustainable agriculture encourages energy-efficient practices and the use of renewable energy sources. It encourages the adoption of energy-efficient technologies, renewable energy systems (such as solar or wind power), and the utilization of agricultural byproducts for bioenergy production (Islam and Hasanuzzaman, 2020).

Sustainable agriculture considers the well-being of farmers, farm workers, and local communities. It supports fair labor practices, equitable trade relationships, and the development of local food systems. By implementing sustainable agriculture, it fosters community engagement, knowledge sharing, and capacity building to ensure the social and economic viability of farming communities. Sustainable agriculture is crucial for environmental preservation, food security, economic resilience, climate change adaptation, and social equity. By adopting sustainable practices, we can create a more resilient and sustainable food system that meets the needs of present and future generations while safeguarding the planet's resources (Davis *et al.*, 2016).

To meet the energy needs of agricultural operations, sustainable energy in this context refers to the use of clean renewable energy sources. It entails shifting away from fossil fuels and toward more sustainable substitutes. Sustainable energy in agriculture involves harnessing renewable energy sources such as solar power, wind energy, biomass, and hydropower. Solar energy can be utilized through photovoltaic systems to generate electricity for powering farm operations, water pumps, and irrigation systems. Particularly in places with good wind conditions, wind turbines can generate electricity on farms. Agricultural waste, animal waste, or crops specifically bred to be used as fuel for the production of heat and power can all be sources of biomass energy. To produce clean electricity, hydropower can be harnessed from streams or small-scale water systems (Lee and San Lee, 2023).

In order to maximize energy use and reduce waste, sustainable energy in agriculture also emphasizes energy efficiency measures. Adopting energy-efficient machinery, equipment, and irrigation systems is part of this. Energy-efficient technologies, such as LED lighting, insulation, and smart controls, can be incorporated into the design and retrofit of farm buildings and infrastructure. Energy audits can aid in locating inefficient energy uses and direct farmers toward energy-saving practices (Liu *et al.*, 2018).

Through procedures like anaerobic digestion or biomass gasification, agricultural waste and byproducts, such as crop residues, animal manure, and waste from the food processing industry, can be converted into bioenergy. Biogas is a renewable energy source that can be used to generate electricity and heat, and is created by anaerobic digestion. In the process of biomass gasification, organic materials are transformed into a combustible gas that can either be burned directly or further processed to produce biofuels. Farmers can manage waste efficiently, cut back on greenhouse gas emissions, and support the circular economy by using bioenergy made from agricultural waste. By adopting sustainable energy practices in agriculture, farmers can reduce greenhouse gas emissions, decrease reliance on non-renewable energy sources, and contribute to climate change mitigation. Sustainable energy solutions in agriculture not only benefit the environment, but also offer cost savings, energy independence, and increased resilience to volatile energy markets. They promote a more sustainable and resilient agricultural sector while supporting the transition to a low-carbon and energy-efficient future (Wang *et al.*, 2023; Yu *et al.*, 2023).

Relying on renewable energy sources in agriculture provides greater energy independence. Farmers can generate their energy, reducing dependence on external energy suppliers and mitigating the risks associated with fluctuating energy prices. Renewable energy systems are often modular and scalable, allowing farmers to expand energy production as needed. This enhances the resilience of agricultural operations, ensuring a stable energy supply even in remote or off-grid areas. The relationship between agriculture, renewable energy, and sustainable agriculture is intricate and interdependent, contributing significantly to a more resilient and environmentally friendly food production system. First, agriculture is a substantial energy consumer, comprising around 30% of the global energy consumption. The heavy reliance on fossil fuels for tasks such as mechanized farming, irrigation, and transportation not only raises concerns about greenhouse gas emissions, but also exposes the sector to energy price volatility. The integration of renewable energy sources, like solar panels, wind turbines, and bioenergy into agriculture, offers a sustainable solution. These renewable technologies can power irrigation systems, provide electricity to farms, and even harness energy from agricultural residues, reducing emissions and lowering energy costs for farmers while aligning with global climate mitigation goals (Kumar *et al.*, 2023; Majeed *et al.*, 2023).

Secondly, the relationship between energy and sustainable agriculture extends beyond the adoption of renewable sources. Sustainable agriculture practices aim to minimize environmental impact and enhance long-term productivity, and energy plays a pivotal role in achieving these goals. Energy-efficient technologies, such as precision agriculture and improved irrigation systems, can optimize resource use, reduce waste, and lower emissions. Moreover, renewable energy systems can offer decentralized and reliable power sources to rural agricultural communities, increasing their resilience to external disruptions while creating economic opportunities. In this context, the synergy between energy and sustainable agriculture is integral to building a more environmentally conscious, economically viable and resilient food production system for the future (Zlaoui *et al.*, 2023).

The lack of research on sustainable energy in agriculture has been a significant challenge that hinders the widespread adoption and implementation of sustainable energy solutions. Research and development require substantial financial resources, but funding for sustainable energy research in agriculture has often been limited. Many research grants and programs tend to prioritize other sectors or areas of study, leaving agriculture with fewer resources for dedicated sustainable energy research. Limited funding restricts the ability of researchers to conduct comprehensive studies, gather robust data, and develop innovative solutions specific to the agricultural context. Sustainable energy in agriculture is a complex and multidisciplinary field. It requires expertise in agriculture, energy systems, engineering, environmental science, and socio-economic factors. Addressing the diverse challenges and opportunities related to sustainable energy in agriculture necessitates comprehensive research efforts. However, the integration of these diverse disciplines and the collaboration between researchers from different backgrounds can be challenging. The lack of coordination and interdisciplinary research efforts contributes to knowledge gaps and hinders the development of holistic solutions (Rasul, 2016; Timilsina *et al.*, 2012).

Building research infrastructure for sustainable energy in agriculture, such as specialized laboratories, testing facilities, and field research sites, requires significant investments. Many research institutions and agricultural organizations may not have the necessary resources to establish dedicated infrastructure for sustainable energy research. The absence of adequate infrastructure limits the ability to conduct large-scale experiments, field trials, and long-term monitoring, hindering the generation of robust data and evidence-based solutions. Indeed, reviewing research in the sustainable agriculture sector is of paramount importance, not only for the reasons mentioned earlier, but also because it allows for the periodic reassessment and updating of key indicators. Agriculture is highly dynamic, subject to constant shifts in environmental conditions, technology, and market forces. Therefore, the indicators used to measure sustainability and success must adapt accordingly to remain accurate and effective. Regular reviews ensure that the chosen indicators stay aligned with the evolving agricultural landscape, allowing for more precise

assessments and informed decision making to address the ever-changing challenges and opportunities in sustainable agriculture (Brinkley and Leach, 2019).

17.2. Organic farming and climate change

The organic farming movement has so far been a success, mostly. Measured in land area, number of farms, or product sales, organic agriculture has experienced stunning growth over the past few decades. Prior to the 1980s, the number of organic farms was "negligible" according to Lockeretz in *Organic Farming: An International History*. Today, organic farms occupy 1% or slightly more of global agricultural land area and considerably more than this in many developed countries. Organic product sales have reached USD 55 billion in the United States and USD 100 billion worldwide. This surge has been driven in large part by a societal desire to curb environmental damages caused by agriculture and to consume "wholesome, high-quality foods" (Lockeretz, 2007; Meemken and Qaim, 2018; Reganold and Wachter, 2016; Sridhar *et al.*, 2023; Willer *et al.*, 2024).

The organic farming community has been steadfast in keeping its core values, but it has also been open to collaborating with the science community to understand and solve problems. Additionally, while scientific research has provided justification for many claims about organic farming and food in terms of reduced fossil-energy consumption, improved soil and water quality, reduced exposure to pesticides, and protection of biodiversity, questions remain about organic farming's net effect on greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), and its impact on climate change relative to conventional agriculture. Maintaining a "healthy soil" through the use of cover crops, crop rotation, and organic soil amendments is fundamental to organic farming. This "feed the soil, not the plants" approach represents a long-term commitment to improving and maintaining soil quality and is expected to increase soil organic matter (SOM), thus sequestering more carbon per unit area compared to conventional farmland, at least over a period of decades until a new SOM equilibrium is reached. Indeed, research supports this understanding of soil carbon dynamics and has demonstrated organic farming's greater efficiency in its use of non-renewable energy as well (Gomiero *et al.*, 2011; Meemken and Qaim, 2018; Reganold and Wachter, 2016).

This means that in addition to storing more carbon in soil, organic farms are also directly and indirectly emitting less carbon from combusted fossil fuels by using less natural gas, diesel, and gasoline and using no synthetic fertilizers or pesticides in their management of soil fertility and pests. All of this would strongly suggest that a transition to organic farming would lead to a reduction in net GHG emissions. However, there are compelling studies indicating that this is not the case, and most of this emerging evidence hinges on organic farming's lower average yields. A meta-analysis revealed that organic crop systems generated lower N_2O emissions from soil per unit area but not per unit yield. In fact, they calculated that organic yields would need to increase by 9% just to match emissions per unit output from conventional systems. Similarly, the available data they reported for rice suggested higher CH_4 emissions for organic compared to conventional management on a yield basis (Skinner *et al.*, 2014).

Several years later, Skinner et al. reported the findings of a field study at the DOK (Bio-Dynamic, Bio-Organic, Konventionell) long-term cropping systems comparison trial in Therwil, Switzerland, over a 571-day period during which they compared GHG emissions from soils in five different crop production systems. They focused on emissions of N_2O and CH_4 because, according the authors, more than half of the total amounts of these GHG emissions come from agriculture. They reported a 40% reduction in N_2O emissions in organic compared to non-organic systems on a per-hectare basis. Yield-scaled comparisons to correct for the lower yields in the organic systems showed no significant difference in N_2O emissions for silage corn between the systems. They concluded that yield-scaled N_2O emissions did not differ between organic and non-organic treatments at the DOK site (Skinner *et al.*, 2019).

17.3. Life cycle assessments

Quantifying soil GHG dynamics is obviously a necessary part of assessing environmental performance, but other methods and approaches are also needed to understand whole-farm systems and identify problem areas and potential solutions. Life cycle assessment (LCA) provides a means of accounting for all of the environmental impacts of resource extraction and use, as well as the pollution generated along part or all of a product's existence from the acquisition of raw materials through the product's use and disposal (cradle to grave). The number of LCA-based analyses published on farming and food systems has increased dramatically since about 2005. These studies, which sometimes do have conflicting results, offer some interesting insights and raise some difficult questions (van Der Werf *et al.*, 2020).

A previous investigation analyzed 12 pairs of organic and conventional crop systems in California using LCA with publicly available data, mostly derived from publications of the University of California. The general trend reported in the literature prior to this study, according to the author, had been for lower GHG emissions in organic systems per unit land, but more mixed results for emissions per unit output due to lower yields from organic production. Indeed, in Venkat's study, organic production had lower GHG emissions in five comparisons, while conventional production had lower emissions in the other seven. On average, GHG emissions from organic production per unit product were 10.6% higher than conventional production. This analysis indicated that during the shift from conventional to organic management, when higher rates of carbon sequestration are expected, this transition period often performed better than either conventional or organic production. Once soil SOM has reached a new steady state, after 15–30 years, the advantage disappears (Venkat, 2012).

Two new studies (Aguilera *et al.*, 2015a; Aguilera *et al.*, 2015b) provide an interesting contrast to previous investigation (Venkat, 2012), as they analyzed cropping systems in relatively similar climates. In their first paper, the authors compared GHG emissions of 38 pairs of conventional and organic herbaceous crops in Spain using LCA. The crops included vegetables (open-air and greenhouse), cereals, and legumes (pulses). They reported a general pattern of lower GHG emissions per unit output under organic compared to conventional production with the exception of rice, which generated higher emissions under organic management due to greater methane production. Fossil fuels accounted for the greatest fraction of emissions for both conventional and organic systems under open-air management. Under greenhouse vegetable production, infrastructure accounted for the largest fraction of emissions. The authors summarized their findings by stating that production-based emissions from organic crops averaged 30% lower than conventional crops, with the exception of rice (Aguilera *et al.*, 2015a; Aguilera *et al.*, 2015b). GHG emissions from organic systems averaged 39% lower than their conventional counterparts per unit product. This was attributed mostly to greater carbon sequestration in the organic systems, which used cover crops and recycled pruning residues. By contrast, Venkat reported slightly lower GHG emission for organic wine grapes in California but considerably greater emissions for organic almonds and walnuts compared to their conventional counterparts. Such vastly different findings suggest that site-specific conditions and practices may have highly influential effects on the final outcomes. Assumptions built into the modeling may be another important factor in explaining differences (Venkat, 2012).

Lynch et al. and Gomiero et al. and a meta-analysis by Tuomisto et al. summarize much of the literature on the environmental performance of organic farming prior to 2010, including LCA studies (Gomiero *et al.*, 2011; Lynch *et al.*, 2011; Tuomisto *et al.*, 2012). Based on an extensive review of about 130 published studies using a variety of methods to quantify energy use and global warming potential (GWP) in crop and livestock production systems, Lynch et al. concluded that organic systems performed better than conventional systems in energy efficiency per unit area and per unit product in most cases. Their findings on GWP, were more variable, with organic systems generally performing better per unit area but less often per unit output due to lower yields. Where organic

systems performed better, this was mainly attributed to not using synthetic N fertilizers or livestock feed concentrates. In situations in which the yield gap between organic and conventional was large, the GWP favored conventional production (Lynch *et al.*, 2011). Gomiero et al. provided an equally expansive review of the literature on the environmental impacts of organic compared to conventional agriculture. They reported a general trend of better performance for organic systems per unit area with regard to GHG emissions but variable results and no consistent advantage when compared per unit product (Gomiero *et al.*, 2011).

Tuomisto et al. performed a meta-analysis using European studies to address the question: "Does organic farming reduce environmental impacts?" Despite differences in some product groups, there was no overall trend of lower or greater GHG emissions from organic compared to conventional production systems. They reported studies showing lower GHG emissions from organic olive, beef, and "some crops" but higher emissions for organic milk due to larger amounts of CH_4 and N_2O and lower milk production per animal. Thus, on a product basis, the findings in the literature have been mixed, which would seem to make most generalizations only tentative (Tuomisto *et al.*, 2012).

17.4. Expanding the scope and scale

In contrast to earlier studies that focused solely or mostly on production, more recent LCA studies have broadened their scope and expanded the assessment of products beyond the farm gate. Tasca et al. measured and compared the environmental impact of two endive supply chains in Italy using LCA. One system used organic production and local distribution, while the other used an integrated production system and large-scale distribution to retail outlets. A comparison of the two systems limited just to the farm production stage indicated very little difference in climate-change impact when viewed per unit area or per unit output. But the farming stage accounted for only 12–15% of the total climate-change impact along the conventional supply chain. Other steps in both supply chains, such as washing, packaging, cold storage, and transportation, accounted for the rest. Taken as a whole, the organic system with local distribution performed better with respect to climate change, but this had little to do with the use of organic production methods (Tasca *et al.*, 2017).

Treu et al. compared GHG emissions generated by typical conventional and organic diets in Germany and found them to be about equal despite the average conventional diet having about 45% more meat in it than the organic diet. In fact, meat dominated the carbon footprints of both diets, but lower yields from organic production and, therefore, the need for more land use resulted in larger carbon footprints per unit of organic food, particularly for pork and poultry. Transportation emissions were also somewhat higher for the organic diet in order to bring in products from further distances. The authors suggested that shifting toward less animal-based foods in diets would be a more effective means of reducing GHG emissions than expanding organic production (Treu *et al.*, 2017).

An analysis by Smith et al. used LCA to examine the consequences on GHG emissions if England and Wales were to convert 100% of food production to organic management. In order to maintain the same level of production, they reported that increased land use in other countries would be needed to compensate for the 40% lower yields expected from organic production. This would result in greater GHG emissions to produce the same amount of food organically. According to the authors, increases in carbon sequestration in agricultural soils would offset only a fraction of the increased emissions from converting land overseas to food production (Smith *et al.*, 2019).

The authors acknowledged that organic systems had lower yields on average, and therefore, a greater amount of land would be required to maintain the same availability of energy and protein for human consumption. They also factored in the influences of potential behavioral or technical changes that reduce food waste, meat consumption, and livestock production on arable cropland. They generated a range of possible scenarios, including one in which "a combination of 60% organic production, 50% less food-competing feed and 50% reduced food wastage would need

little additional land" (Muller *et al.*, 2017). They also reported that a reduction in GHG emissions could be achieved even with a 100% conversion to organic production, but only with a concurrent reduction in livestock production, meat consumption, and food wastage. The authors acknowledge that in this scenario maintaining sufficient N availability would be a challenge.

17.5. Responding to the climate crisis

The studies by Muller et al., Tasca et al., and Treu et al. demonstrate the value of analyzing the problem of GHG emissions from agriculture at different stages along food supply chains and at different scales of food systems (Muller *et al.*, 2017; Tasca *et al.*, 2017; Treu *et al.*, 2017). Based on the current evidence, a transition to organic farming at a national or global scale without other substantial changes in the food system is unlikely to reduce GHG emissions and will likely only worsen the problem. Although global climate change is the most critically important environmental challenge facing humanity presently (Iqbal, 2021; Iqbal and Ashraf, 2023), the other environmental issues addressed by organic farming are also important. Compromising other ecosystems services in an effort to address GHG emissions would be short-sighted and irresponsible. That is why the all-or-nothing proposition for organic agriculture is potentially misleading and distracting.

Instead, context- and site-specific evaluations would allow for better understanding of where organic production is more appropriate and effective in addressing GHG emissions and where it is not (Iqbal, 2023b). For example, Aguilera et al. reported that organic fruit and nut orchards produced less GHG per unit product compared to conventional orchards (Aguilera *et al.*, 2015b), while Venkat reported the opposite. Understanding how vastly different findings are generated using LCA methodology would give some useful context and details for interpreting the appropriateness of extrapolating results to different situations (Venkat, 2012).

Further, changing agriculture to address climate change will require societal-level shifts in understandings, values, and behaviors (Heller and Keoleian, 2015; Niles *et al.*, 2018). Market demand and government policies drive what farmers produce. Consumers who value organic products are willing and able to pay a premium for them. That premium is transferred through the supply chain to producers who require at least part of that additional gross income to cover the higher production costs, often resulting from the need for more labor and management. Organic farmers are in effect being compensated for internalizing the externalities typically resulting from agriculture, such as pollution and environmental degradation. Organic farmers may also need to recoup losses incurred during the transition period (usually three years), during which they produce organically but receive conventional market prices for their output.

What remains of the premium is an additional incentive to continue producing organically, both for farmers who are attracted to organic production solely for the financial opportunities as well as those who are deeply committed to the principles and ideologies of organic farming regardless of the added income. If market incentives from consumers or government policies drive farmers in the future to address GHG emissions on their farms, a truly impressive range of creative solutions could begin to emerge, blending traditional organic practices with new innovations such as automated field monitoring with data analysis to support timely management decisions that improve resource-use efficiency and yields to specialized field equipment that facilitates tillage reductions while suppressing weed competition without herbicides. But in order for organic farmers to creatively innovate and make meaningful contributions toward addressing climate change, their businesses must be financially viable and stable.

Organic farming today has changed considerably since the 1970s when it was referred to as "scientific nonsense" by a panel of scientists at an annual meeting of the American Association for the Advancement of Science (Meemken and Qaim, 2018). It is impossible to know precisely how organic farming will change over the next half-century, but incentivizing efforts to address GHG emissions is not only prudent but essential for meeting the food production and environmental challenges faced by humanity. Recent calls to find ways to increase organic yields should be

examined carefully to ensure they are economically viable and environmentally sound. Even where less expensive off-farm organic amendments are available, applying high N levels to maximize yields will likely also result in N and phosphorus leakage from farms, a practice that contradicts organic farming's emphasis on nutrient cycling and avoidance of causing water pollution and eutrophication elsewhere. However, continued consideration should also be given to blending the best of conventional and organic practices in a way that fairly remunerates farmers for products as well as protects ecological services, either through market mechanisms with third-party certifications and price premiums or government subsidies.

The organic farming movement has been a leader in developing and farm-trialing new production methods that often are adopted by the wider agricultural community, such as cover cropping, biocontrol of insect pests, and mechanical weed control. That progressive approach to improvement should extend to examining emerging technologies that can reduce GHG emissions through combinations of increasing yields, reducing fossil-fuel energy inputs, and/or other means. If the evidence is compelling that particular new technologies or inputs can support the goals and principles of organic farming's approach to production and stewardship, then they should be given fair and rational consideration for allowance. Critics of organic agriculture have called out the apparent unwillingness of the movement to revise approved practices. Certainly, some suggested changes, such as limited use of synthetic fertilizers (Connor, 2008), would compromise the integrity of the label, threaten consumer confidence, and possibly result in detrimental environmental impacts. There are others, however, such as accepting new crop breeding techniques (Nawaz *et al.*, 2020; Ronald and Adamchak, 2018; Ryffel, 2017; Vincelli, 2016), which might allow organic farmers to substantively address the current yield gap without the use of additional inputs. Making changes like this would undoubtedly be contentious and risk setting back the industry if consumer confidence is lost. Still, if environmentally sound food production is indeed a foundational value of organic farming, then new innovations for addressing the global climate crisis must be found and put to use.

17.6. Plant physiology with organic electronics

The organic electronic ion pump (OEIP) provides flow-free and accurate delivery of small signaling compounds at high spatiotemporal resolution. To date, the application of OEIPs has been limited to delivery of nonaromatic molecules to mammalian systems, particularly for neuroscience applications. However, many long-standing questions in plant biology remain unanswered due to a lack of technology that precisely delivers plant hormones, based on cyclic alkanes or aromatic structures, to regulate plant physiology. Here, we report the employment of OEIPs for the delivery of the plant hormone auxin to induce differential concentration gradients and modulate plant physiology. We fabricated OEIP devices based on a synthesized dendritic polyelectrolyte that enables electrophoretic transport of aromatic substances. Delivery of auxin to transgenic *Arabidopsis thaliana* seedlings in vivo was monitored in real time via dynamic fluorescent auxin-response reporters and induced physiological responses in roots.

The coordination of plants' physiological activity is regulated by a complex array of chemical signals within and between their cells, tissues, and organs. Although plants do not possess a central nervous system, fluxes and gradients of chemical hormone compounds play a central role in the overall management of growth, response to environment, and homeostasis. Among the hormones that are generally conserved across the plant kingdom, auxin (indole-3-acetic acid, or IAA) was the first discovered, is perhaps the best characterized, and is certainly one of the most crucial (Jaillais and Chory, 2010; Santner and Estelle, 2009; Zažímalová *et al.*, 2014).

Auxin plays an important role in a multitude of physiological processes and is involved in many aspects of plant development from the single-cell level (endocytosis and morphogenesis) to macroscopic phenomena (embryogenesis and organ formation). It is understood that the presence of tightly controlled auxin gradients within cells and tissues is essential for regulating physiology throughout the life of the plant. Precise regulation of cell-to-cell auxin gradients and their role in

plant development can be found in a variety of tissues, such as the base of the developing embryo, the inner apical hook of young seedlings, at the tips of the developing cotyledons, at the primary root tip, and at the primordia of organs such as lateral roots, leaves, and flowers. The cellular scale of auxin activity is clearly demonstrated by the isolated effects of its application on single cells or small cell groups in certain tissues. For example, auxin application affects the emergence of root hairs from specific epidermal cells and modulates K^+ channel currents within individual stomatal guard cells (Benková *et al.*, 2003; Blatt and Thiel, 1994; Fischer *et al.*, 2006; Friml *et al.*, 2003; Friml *et al.*, 2002; Robert *et al.*, 2013; Sabatini *et al.*, 1999; Vanneste and Friml, 2009).

As such, deciphering auxin's molecular and cellular modes of action is of fundamental importance for the elucidation of plant biology. Researchers have traditionally conducted studies of hormone effects in plants via exogenous application. A wide range of chemical compounds is routinely used for probing plant hormone biology. The applied compounds passively diffuse and/or are actively imported by the plant into the target tissues, where their effects can be observed. Commonly used methods include spraying or soaking of the plant, as well as applying gels, paraffin, or polymer beads that have been soaked in known concentrations of compound or have been allowed to absorb compounds from the plants themselves. For more localized studies, application of hormone-containing microdroplets via microscope-guided micromanipulators has been demonstrated. Others have used micro- or nanofluidic systems capable of fluidic transport and delivery of a variety of chemical species (Busch *et al.*, 2012; Cheng *et al.*, 2006; Doyle *et al.*, 2015; Geisler *et al.*, 2003; Grossmann *et al.*, 2011; Hicks and Raikhel, 2012; Ikeda *et al.*, 2009; Meier *et al.*, 2010; Sauer *et al.*, 2013).

Finally, some have turned to nanoscale functional systems for directed introduction of materials and molecules within plant cells and tissues. As with similar techniques for in vitro and in vivo animal studies, these methods all suffer from poor dynamic control, for example in the case of bead or nanoparticle-based delivery, or from cumbersome liquid transport that disrupts native concentration gradients or introduces undesirable stresses on cells and tissues. The shortcomings of currently available localized delivery methods, combined with the cellular-scale effects of auxin in particular, point toward an unmet technological need. The development of a method allowing controlled, localized delivery of hormones and other compounds at the tissue and cellular scale would thus represent a significant advance for the plant research community (González-Melendi *et al.*, 2008).

In recent years, a range of organic electronic tools has been developed that enable precise dynamic delivery of small ionic molecules. The organic electronic ionic pump (OEIP) is one of these technologies and was developed primarily as an application for mammalian systems to enable diffusive synapse-like delivery of neurosignaling compounds (alkali ions and neurotransmitters) with high spatiotemporal resolution. Recently, OEIP devices have been demonstrated for a variety of in vitro as well as in vivo applications, including therapy in awake animals. OEIPs are electrophoretic delivery devices that leverage the unique ionic and electronic properties of conducting polymers and polyelectrolytes to convert electronic signals into ionic fluxes. The OEIP's polymer delivery channel (i.e., electrophoresis channel) is composed of a polycationic (or polyanionic) material with a high density of fixed charge groups that allows for the selective transport of anions (or cations) (Isaksson *et al.*, 2007; Jonsson *et al.*, 2015; Simon *et al.*, 2016; Simon *et al.*, 2009; Tybrandt *et al.*, 2009).

The electrophoretic transport used by OEIP devices is flow-free—only the intended molecules are delivered to the target region, not additional liquid or oppositely charged counter ions that may be present in the source solution. The selective electrophoretic transport of the desired molecular species through an OEIP device results in high concentration gradients localized at the OEIP outlet, on the scale of ~100 μm to 1 mm. Additionally, electronic addressing to the OEIP enables the molecular delivery to be rapidly switched on and off, and, importantly, the electrical driving current can be directly correlated with the ionic delivery rate. These device characteristics allow for the precise control of chemical concentration gradients with high spatial and temporal resolution (Tybrandt *et al.*, 2009).

However, the materials used for all previous OEIP-based technologies pose a significant limitation. Controlled transport through OEIPs and similar "iontronic" devices has been demonstrated only for atomic ions or the smallest of linear molecules. However, many biological processes—and bioelectronic application scenarios—require transport of larger compounds. The number of available polyelectrolyte materials suitable for OEIP device technologies is limited. One class of materials—indeed, the ones used in all previous OEIPs—is cross-linked semirandom networks of linear polyelectrolytes, such as poly (styrenesulfonate) or poly(vinylbenzylchloride) (qPVBC). However, such linear polymers have not yet demonstrated the capability to transport larger and more rigid molecular compounds, and there exist inherent challenges for further optimization (Jonsson *et al.*, 2015; Simon *et al.*, 2009; Tybrandt *et al.*, 2012).

First, it is difficult to synthesize linear polyelectrolytes from prefunctionalized monomers bearing both cross-linkable and ionic groups because any cross-linkable groups also tend to inadvertently polymerize during polymerization. Second, linear polyelectrolytes are challenging to postfunctionalize to a high degree owing to their immiscibility to most postsynthetic methods. Thus, it is difficult to control key structural characteristics of linear polymer networks relevant to ion transport properties, namely the size and distribution of fixed charges and void fraction, the effective porosity of the bulk, and the degree of swelling of the polymer network during hydration (Gao and Yan, 2004; Geise *et al.*, 2014; Kariduraganavar *et al.*, 2006).

To address the need for OEIP technologies capable of transporting larger ionic compounds, we investigated hyperbranched polymers as the foundation for a previously unidentified class of polyelectrolyte materials. Hyperbranched polymers have generally spherical or globular structures and possess a high number of terminal functional groups that define their customizable physiochemical properties. Here, we present a dendritic polyelectrolyte material system using highly branched polyglycerols as the base unit, phosphonium chloride as the ionic charge component, and allylic groups for cross-linking. These "dendrolyte" materials enable the density of ionic and cross-linking groups to be tuned during synthesis instead of during post functionalization (Astruc *et al.*, 2010; Schüll and Frey, 2013; Sunder *et al.*, 1999).

In this way, fundamental limitations of previous OEIPs can be addressed: swelling and rigidity of the polymer network can be controlled by cross-linking, and transport of "larger" or rigid aromatic substances can be facilitated by tuning the void fraction distribution and effective porosity of the bulk. Importantly, dendrolytes enable processing from a "one-pot" three-component miscible mixture of functionalized dendritic polyglycerols, cross-linker, and photoinitiator. One-pot mixtures enable a homogeneous distribution of bulk charge and cross-linking in the membrane and further offer a high degree of compatibility with a variety of patterning processes such as printing or lithographic techniques (Kariduraganavar *et al.*, 2006).

17.7. Conclusions

The identified indicators spanning economic, environmental, institutional, social, and technical dimensions provide valuable insights into the sustainability and impact of renewable energy and agricultural practices. It is impossible to overstate the significance of this field because it holds the key to a future for our planet that is more resilient and sustainable. When compared to fossil fuels, renewable energy sources are more environmentally friendly, producing fewer greenhouse gas emissions and lessening the negative effects of climate change. Integrating renewable energy with sustainable agriculture practices can enhance food security, minimize environmental impacts, and foster rural development. Moreover, the research and innovations in this field contribute to achieving global sustainability goals, including the United Nations' Sustainable Development Goals (SDGs), by promoting responsible consumption, ensuring access to clean energy, and preserving biodiversity.

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