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Introduction to Organic Agriculture - From Haber-Bosch to Howard: A Century of Agricultural Transformation

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ABSTRACT

Agriculture, the science and practice of cultivating plants and raising livestock, has been fundamental to human civilization, enabling the development of sedentary communities and food surpluses. Traditional farming methods, relying on natural practices like crop rotation and composting, gave way to synthetic fertilizers and pesticides in the early 1900s, raising concerns about soil health and food safety. The Haber-Bosch process, developed in the early 20th century, revolutionized fertilizer production by synthesizing ammonia from atmospheric nitrogen, significantly boosting agricultural yields. However, visionaries like Sir Albert Howard and Rudolf Steiner advocated for practices

mimicking nature's cycles, emphasizing soil health and laying the groundwork for organic agriculture. Conventional agriculture, characterized by mechanization and reliance on synthetic inputs, has greatly increased food production. However, this approach raises concerns about environmental impacts such as soil degradation, water pollution, and biodiversity loss. Studies indicate pesticide use, while boosting crop yields, contaminates food and the environment, posing health risks. In China, agricultural emissions increased by 410 Mt CO₂ eq between 2001 and 2018, primarily due to fertilization and irrigation in maize, fruit, and vegetable production. Animal husbandry, another key aspect of agriculture, involves breeding and raising domestic animals for food, fiber, and labor. In India, low livestock productivity necessitates a bottom-up breeding policy and improved market linkages. Aquaculture, the cultivation of aquatic organisms, is increasingly vital for global food supply. Asia dominates global aquaculture, producing over 91% of the world's farmed aquatic animals and plants (102.9 million tonnes in 2017). However, monoculture practices increase disease risk, and chemical use poses environmental risks. Forestry, the management of forests and woodlands, provides timber, fuelwood, wildlife habitat, and clean water. Non-timber forest products (NTFPs) are crucial for the livelihoods of 275 million poor rural Indians, but overexploitation and deforestation threaten these resources. Sustainable development strategies are needed to balance resource conservation with livelihood needs.

Keywords: Agriculture, Food Security, Organic Farming, Livestock, Aquaculture, Mechanization, Conventional Agriculture, Sustainability, Soil Health, Forestry

1. INTRODUCTION

Organic farming has a rich history, though the term itself is relatively recent. Although not called "organic" at the time, traditional farming methods for millennia relied on natural practices. This included crop rotation, compost, and fostering a healthy soil ecosystem. In the early 1900s saw a shift towards synthetic fertilizers and pesticides. However, concerns arose about their impact on soil health and food safety. Justus Von Liebig, a German chemist who is considered the "Father of the fertilizer industry" and was the first man who discovered Nitrogen (N) is an essential element. His work in the mid-1800s laid the foundation for the development of synthetic fertilizers, which are not part of organic farming.

In 1910, German chemist Fritz Haber made a significant breakthrough: the synthesis of ammonia (NH₃) by directly combining nitrogen (N) from the atmosphere with hydrogen (H₂). This process, now known as the Haber-Bosch process (after Haber and Carl Bosch who later industrialized it), was a game-changer for several reasons: as most plants can't directly utilize atmospheric nitrogen, a crucial nutrient for growth. Haber's method offered a way to convert readily available air into a usable form of nitrogen. Ammonia is a key component in the production of synthetic fertilizers. Prior to Haber-Bosch, farmers relied on natural sources like animal manure or imported minerals, limiting food production. This new method paved the way for large-scale fertilizer production, boosting agricultural yields.

While Haber's initial discovery laid the groundwork, the Haber-Bosch process wasn't commercially viable until the 1910s. Carl Bosch, an engineer, made significant contributions by developing high-pressure and high-temperature industrial systems that made ammonia production efficient and cost-effective. Visionaries like Sir Albert Howard (often called the "father of modern organic agriculture") and Rudolf Steiner emerged. They advocated for practices that mimicked nature's cycles and emphasized soil health. Key eras are explicated in the Table 1.

Table 1. History of Organic Farming.

Eras	Scientific Role	Work Contribution
1905-1924	Sir Albert Howard	Organic agriculture started more or less simultaneously in India and central Europe. Father of modern agriculture. He wrote that Indian traditional agriculture is better than European modern agriculture.
1909	Franklin Hiram King	Studied traditional fertilization, tillage and other farming practices, published his findings in a book: Permanent Agriculture.
1940	Masanobu Fukuoka	Microbiologist from Japan. He left his Govt. Job and devoted remaining 30 years of his life to “Fukuoka Farming”. He was a proponent of no-till, herbicide and pesticide-free cultivation methods from which he created a particular method of agriculture, commonly referred to as "natural farming" or "do-nothing farming".
1943	Lady Eve Balfour	The Living Soil by Lady Eve Balfour is considered a seminal classic in organic agriculture and the organic movement.
1947	Jerome Irving Rodale.	A key figure in organic farming's rise in the US. The founding year of the Rodale Institute. A core area of focus, emphasizing natural methods for home gardens. Mainly worked on “Organic Gardening” and Creation of “Association of Organic Farmers” in France.
1962	Rachel Carson's	"Silent Spring," published in 1962, was a landmark book that for the first time brought widespread public attention to the dangers of pesticides, particularly DDT (Dichlorodiphenyltrichloroethane).
1972	IFOAM	The International Federation of Organic Agriculture Movements (IFOAM), founded in 1972, plays a key role in promoting and advocating for organic agriculture on a global scale. IFOAM brings together over 750 member organizations from more than 116 countries.
1991	European Union	the European Union (EU) took a significant step towards promoting and regulating organic agriculture by establishing its first legal framework. This framework, embodied in Council Regulation (EEC) No. 2092/91, addressed several key aspects.

2. WHAT IS AGRICULTURE? BRIEF OVERVIEW OF CONVENTIONAL AGRICULTURE

Agriculture is the science and practice of cultivating plants and raising livestock for human use and consumption. It encompasses various activities, including crop production,

livestock rearing, aquaculture, and forestry. The term originates from the Latin words "ager," meaning field, and "cultura," meaning cultivation. This practice has been fundamental to human civilization, enabling the establishment of sedentary communities and the development of food surpluses that support urban living. It encompasses a wide range of activities, including:

1) Crop production:

Crop production is a vital component of agriculture, focusing on the cultivation of various plants for food, fiber, and other uses. This process involves several stages, from selecting the right crops to harvesting and marketing the produce. Studies comparing historical food nutrient data are unreliable due to methodological inconsistencies. Soil mineral depletion isn't supported by archived samples. Lower mineral concentrations in modern high-yield crops are due to a "dilution effect," not soil decline. For example, copper levels vary widely (1555-20600%) in produce, and apparent declines are small in absolute terms. Increased yields offset minor dilution effects (Marles, 2017).

Pesticide use, while boosting crop yields, contaminates food and the environment, posing health risks. Mitigation strategies include rational pesticide use, organic farming, and stronger regulations (Grewal, 2017). A study of 16 Chinese crop systems (2001-2018) found vegetables and tea had the highest carbon footprints.

Rice, maize, wheat, fruits, and vegetables contribute 87-90% of national agricultural emissions, primarily from fertilization and irrigation (73-77%). National emissions increased by 410 Mt CO₂ eq, mainly due to maize, fruit, and vegetable production. Reducing reactive nitrogen loss is the most effective mitigation strategy (Chen et al., 2021).

2) Animal husbandry:

Animal husbandry involves the breeding, raising, and care of domestic animals for various purposes, including food (meat, milk, eggs), fiber (wool, hair), and labor. It's a multifaceted practice that requires knowledge of animal nutrition, health, behavior, and genetics. Indian livestock productivity is low due to limited structured breeding, poor nutrition, and socio-economic issues.

A bottom-up breeding policy is needed, along with addressing indiscriminate mating (due to cattle slaughter bans), requiring resources for castration and rehabilitation centers. Genetic evaluation of indigenous cattle and small ruminants needs financial support. Market linkages and infrastructure strengthening are also crucial, involving private and community-based initiatives (Gowane et al., 2019).

Greco-Roman animal breeding spanned 3,000 years and diverse scales, from pet birds to industrial livestock like snails and horses. Beyond domestication, they actively manipulated breeding to maximize animal utility and production (Kitchell Jr, 2016). The importance of veterinary medicine and animal husbandry skills for livestock production and management. It uses dairy farms and dog kennels as examples, listing common veterinary and husbandry activities, highlighting the need for veterinarians to handle both routine and emergency situations (Verma et al., 2024).

Article analyzed Bryansk region's animal husbandry development, examining livestock populations, product manufacturing, and animal productivity. It reviews best practices, investment projects, and forecasts production, outlining strategic development directions for the industry (Vaskin et al., 2021).

3) Aquaculture:

Aquaculture, also known as fish farming or aquafarming, is the practice of cultivating aquatic organisms in controlled environments for commercial purposes. This includes a wide range of species such as fish, crustaceans (like shrimp and crabs), mollusks (like clams and oysters), and aquatic plants. As global demand for seafood continues to rise, aquaculture has become an increasingly important sector within the agricultural industry. Aquaculture is increasingly important for global food supply, but monoculture practices increase disease risk, especially viral infections. High-density farming near wild fisheries facilitates pathogen emergence. This chapter introduces the diverse aquaculture industry and its role in providing protein, setting the stage for virology discussions (Kibenge, 2016). It is a vital protein source, faces challenges from chemical use. Many chemicals, adopted from livestock agriculture, pose environmental risks, particularly to water quality. Pharmaceuticals and other pollutants, including metals and microplastics, impact aquatic life.

Understanding aquaculture practices is crucial for assessing toxicological risks and improving management in this growing industry (Kibenge, 2021). Aquaculture, a rapidly growing field, is crucial for food security, especially in developing nations like India, where it significantly contributes to GDP. While offering a solution to food demands, it presents challenges in maintaining profitability and environmental sustainability. Aquaculture, particularly shrimp farming, can negatively impact vital ecosystems like mangrove forests, important carbon sinks, through habitat destruction. Although some countries have protective legislation, enforcement remains difficult. Sustainable development practices are crucial to mitigate the environmental impacts of aquaculture (Bhavsar et al., 2016). Asia dominates global aquaculture, producing over 91% of the world's farmed aquatic animals and plants (102.9 million tonnes in 2017), exceeding capture fisheries by 18.32 million tonnes. Developing countries account for over 95% of production, growing at 6.13% annually. Fish (53.4 million tonnes) are the largest group, followed by aquatic plants (31.8 million tonnes). Freshwater fish, especially carps, dominate fish aquaculture. Crustacean production (8.4 million tonnes) is led by marine shrimp. Aquaculture represents a US\$250 billion industry with diverse species and production methods (Tacon, 2020).

4) Forestry:

Forestry encompasses the science and art of managing forests and woodlands for a variety of purposes. It involves the cultivation, conservation, and sustainable utilization of forest resources, including timber, fuelwood, wildlife habitat, recreation areas, and clean water. Forestry practices include activities like planting new trees (reforestation or afforestation), selectively harvesting mature trees, controlling pests and diseases, managing forest fires, and protecting watersheds. The goal of forestry is often to balance the economic, ecological, and social values of forests, ensuring their long-term health and productivity for present and future generations. Non-timber forest products (NTFPs) are crucial for the livelihoods of 275 million poor rural Indians. However, overexploitation and deforestation threaten these resources. This study examines NTFP reliance and proposes sustainable development strategies to balance resource conservation with livelihood needs (Pandey et al., 2016).

The undervalued importance of non-wood forest products (NWFP) and advocates for their integration into forest management. It emphasizes the need for a shift towards ecosystem-based approaches, acknowledging NWFP's economic and livelihood contributions. Improved

research, policy, and governance are crucial for sustainable NWFP management and a bio-based economy (Sheppard et al., 2020).

Existing models predict yields for some economically important non-timber forest products (NTFPs), including berries and mushrooms. Integrating NTFP harvesting can boost forest owner income, but requires management changes. Further model development is needed for various NTFPs and climate change impact assessment (Miina et al., 2020). A study examined that the Ethiopia's forest product development and its impact on sustainable forest management. Current fuelwood consumption is 133M m³, with 90% of cooking energy from wood. Wood demand for manufacturing will rise to 158M m³ by 2033. The study recommends a policy framework promoting sustainable forest practices, balancing production with ecological functions (Rawat & Tekleyohannes, 2021). Globally, 60% of forests are used for wood and non-wood products. Wood fuel accounts for half of roundwood production, while industrial roundwood makes up the other half. The 2008 financial crisis significantly impacted wood product production and trade, especially construction-related products. China's growing demand has fueled trade expansion, making it a major importer and exporter. Population growth, urbanization, and economic development influence wood product demand (Brack, 2018).

Agriculture has been a key driver in the development of human civilization, enabling the transition from hunter-gatherer societies to sedentary communities. It has evolved over time, with the advent of modern agronomy, plant breeding, and agricultural technologies leading to significant increases in crop yields. However, conventional industrial agriculture has also contributed to environmental degradation through practices such as monoculture farming, excessive use of agrochemicals, and deforestation. Concerns have been raised about the sustainability and ecological impact of modern agricultural methods.

3. CONVENTIONAL AGRICULTURE

Conventional agriculture is a system of farming that relies heavily on synthetic inputs, such as chemical fertilizers, pesticides, and herbicides, to maximize crop yields and efficiency. It often involves large-scale monoculture, where a single crop is grown repeatedly over a vast area, and extensive mechanization using heavy machinery for planting, harvesting, and other tasks. The primary goals of conventional agriculture are to increase food production, reduce costs, and meet the demands of a growing population. While it has contributed to significant increases in food availability, it also raises concerns about environmental impacts like soil degradation, water pollution, biodiversity loss, and potential health risks associated with chemical residues.

The long-term sustainability of conventional agriculture is a subject of ongoing debate, with increasing emphasis on the need to balance productivity with environmental and social considerations. Conventional agriculture, often referred to as modern or industrial farming, is characterized by several key features:

1) Mechanization:

It relies heavily on advanced machinery and technology to enhance productivity. This mechanization allows for large-scale farming operations that can produce significant quantities of food efficiently.

Technological innovation is crucial for boosting agricultural efficiency and global supply (Huang & Wang, 2024). This study reviews impact assessments of advanced agricultural machinery, highlighting how it drives competitiveness, growth, and sustainability. Modern machinery enables large-scale, cost-efficient production, saving resources and transforming value chains. Enabling conditions are vital for widespread technology adoption to maximize benefits (Reddy, 2022).

Ghana's push for agricultural mechanization, while increasing adoption rates, has unintended consequences. GIS analysis and farmer interviews reveal a "mechanization paradox": farm sizes expand, but cropping patterns shift from traditional staples (millet, sorghum) to market-oriented crops (maize, rice, groundnuts).

This impacts food security, social organization, and climate adaptation, necessitating policy adjustments (Kansanga et al., 2019). A Bill & Melinda Gates Foundation meeting emphasized the importance of farm power and mechanization for achieving Sustainable Development Goals 1 and 2. It advocated for stimulating smallholder farm mechanization demand, considering sustainability (financial, social, environmental).

Public sector roles should focus on policy, skills, and demand stimulation. The study suggests custom hire and group ownership models for sub-Saharan Africa, along with establishing an African Center for Sustainable Agricultural Mechanization (Sims & Kienzle, 2016).



Figure 1. Mechanization processes at Nishat Agri. Farm (Pvt.) Ltd, Pindi Bhattian, Hafizabad, Pakistan.

2) Chemical Inputs:

Conventional farming typically employs synthetic fertilizers, pesticides, and herbicides to maximize crop yields and control pests. These chemicals are integral to maintaining high productivity levels but have raised concerns regarding their environmental impact. A review analyzed the economic merits of different agricultural systems: conventional, organic, biotechnology (GM), and Integrated Pest Management (IPM). Organically farmed products often have lower production costs and higher prices, but yields can be lower. IPM enhances both conventional and organic systems. GM crops offer lower costs and higher yields, benefiting smaller farms. Farmers should adopt a flexible, customized approach rather than strictly adhering to one system (Durham & Mizik, 2021). Pesticides, used since the 1940s, are crucial for crop protection and food supply but harm the environment and biodiversity. Overuse poses a significant threat to various species. Integrated Pest Management (IPM), combining multiple control measures, offers a sustainable alternative. Biotechnology and nanotechnology advancements may lead to less harmful herbicides and resistant crops (Khan et al., 2023). A "mineral-ecological cropping system" (MECS) is proposed as a compromise between conventional and organic farming, aiming for high yields without synthetic pesticides. MECS anticipates moderate yields, potential profitability challenges, increased soil fertility and biodiversity, wider crop rotations, and balanced nitrogen use. Farmer compensation is recommended during MECS adoption. Further research on farmer adaptation is needed (Pergner & Lippert, 2023). An article reviews on organic agriculture's highlights the potential role in global food production, challenging its claimed environmental superiority over well-managed conventional agriculture. It argues that sustainably-run conventional farming, due to higher yields, is a more sustainable approach to feeding a growing population and minimizing agriculture's overall environmental impact (Tal, 2018).



Figure 2(a). Using GASPARDO MASCHIO UNIGREEN BOOM SPRAYER at Nishat Agri. Farm (Pvt.) Ltd, Pindi Bhattian, Hafizabad, Pakistan, for insect and pest control in the fields of alfalfa under central pivot system.



Figure 2(b). Using GASPARDO MASCHIO UNIGREEN BOOM SPRAYER at Nishat Agri. Farm (Pvt.) Ltd, Pindi Bhattian, Hafizabad, Pakistan, for insect and pest control in the fields of alfalfa under central pivot system.

3) Monoculture Practices:

Farmers often cultivate single crops over large areas, which can lead to increased efficiency but also poses risks such as soil degradation and reduced biodiversity. This practice contrasts with traditional methods that promote crop rotation and diversity. A study investigated the impact of excessive chemical use in agriculture. A survey revealed high chemical reliance (98.2%), monocropping (84.8%), and declining traditional practices (87.6%). Farmers are skeptical of manure's effectiveness. The research emphasizes the urgent need for sustainable agricultural practices, farmer education, and policy changes to balance productivity with environmental protection (Katherasala et al., 2024).

Indonesian sugarcane monoculture, practiced for over 30 years, negatively impacts the agroecosystem, decreasing soil quality, hydrological function, and biodiversity, while increasing greenhouse gas emissions. This leads to reduced yields, increased pest/disease pressure, and higher costs. The study proposes sustainable practices like crop rotation, intercropping, and precision agriculture, but acknowledges implementation challenges like knowledge and capital limitations (Putra et al., 2020). Traditional farming, rooted in agroecology, champions agrobiodiversity through diverse crops and local animal breeds, enhancing ecosystem resilience and food security. These practices, including crop rotation and intercropping, improve soil health and conserve genetic resources. Despite challenges from industrial agriculture and climate change, traditional methods offer sustainable solutions for food security and ecosystem preservation through community participation and knowledge sharing (Otieno, 2024).

Modern agriculture's practices, like tillage and agrochemical use, impact soil microbes and sustainability. Beneficial microorganisms offer a sustainable alternative, enhancing nutrient

uptake and biocontrol, potentially replacing harmful chemicals. Despite organic awareness, overuse of chemical fertilizers and pesticides persists. This review examines microbial shifts due to current practices and explores microbial potential for sustainable agriculture (Gupta et al., 2022).

4) High Yield Focus:

The primary goal of conventional agriculture is to achieve maximum output. This focus on yield has led to significant increases in food production globally over the past few decades, with estimates suggesting that 70% to 90% of recent food production increases are attributable to conventional methods rather than expanding cultivated land. A meta-analysis of 193 studies (2896 comparisons) assessed yield stability in organic, conservation (no-till), and conventional agriculture. Organic agriculture showed 15% lower temporal yield stability per unit yield than conventional, despite its environmental benefits. No-till agriculture's stability (3% lower) was not significantly different. The study suggests that green manure and enhanced fertilization may improve organic yield stability (Knapp & van der Heijden, 2018). Growing populations and diminishing resources strain agricultural production, leading to overuse of chemicals and environmental degradation. Sustainable agriculture is crucial, requiring innovative soil and crop management strategies (SCMS) like integrated nutrient management, conservation agriculture, and sustainable water management. Reducing chemical use and improving input efficiency are key to minimizing environmental impact and ensuring future food security. Global cooperation is essential for achieving sustainable agricultural practices (Shah & Wu, 2019).

Meeting global food demand sustainably is crucial. While conventional farming, using high-yielding varieties and chemical inputs, increases yields, it can degrade land and pollute the environment. Organic farming, using organic nutrients, is proposed as a sustainable alternative, but faces several myths. This review clarifies these misconceptions, including the limitations of organic materials in supplying all nutrients, improving all soil types, and guaranteeing cheaper, high-quality products. Yields from organic farming are often 20-50% lower than conventional. The review suggests a 75:25 ratio of inorganic to organic nutrients and proposes "Evergreen Agriculture" as a promising approach for increased on-farm biomass production, carbon sequestration, and improved soil fertility, citing its success with millions of African farmers (Timsina, 2018). Climate change threatens crop production and food security. However, traditional farmers possess valuable knowledge and practices, particularly regarding biodiversity, that enhance resilience to climatic variability (Mijatović et al., 2013). Integrating these agroecological strategies, like biodiversification, soil management, and water harvesting, into modern agroecosystems can improve both resilience and economic benefits while contributing to climate change mitigation (Vikas & Ranjan, 2024).

5) Economic Accessibility:

Conventional agriculture has contributed to the availability of inexpensive food in many regions, shaping consumer expectations around food pricing and availability. Consumers increasingly shape the food system. Understanding how policies influence consumer choices and their impact on health, environment, and food security is crucial. A paper addressed challenges related to diet, trust, technology acceptance, environmental impact, food quality, and safety, along with research barriers and the economist's role (Lusk & McCluskey, 2018). Global food and nutrition security depends on safe, affordable, and nutritious food for all.

Meeting the needs of a growing population requires increased food production, reduced food loss, and sustainable improvements in preservation, nutrient content, safety, and shelf life through food processing. A balanced approach to food's energy and nutrient content, along with environmental sustainability, is crucial, demanding innovation across the entire food supply chain (Augustin et al., 2016).

Modern food systems are unsustainable due to negative health, environmental, and social impacts. Reform requires connecting diverse efforts—government, business, and grassroots initiatives—through food democracy for lasting change (De Schutter, 2017). Consumers want food that is local, sustainable, and ethically produced. Agriculture must also provide fuel, meet environmental goals, and ensure equitable income distribution. A paper examines the food chain's evolution, the impact of these demands, and agricultural policies needed to increase food production by 70% by 2050 (Saitone & Sexton, 2017). Feeding a growing population requires navigating debates about staple food production versus dietary diversification. A review focused on wheat and maize value chains in Africa and Asia, highlighting ecological threats to production, the need to overcome adoption barriers for promising innovations, and the impact of these factors on all four food security dimensions. Research should prioritize stability and utilization alongside productivity and sustainability (Grote et al., 2021).

While conventional agriculture has played a crucial role in feeding the growing global population, it faces criticism for its environmental consequences, including pollution, loss of biodiversity, and contributions to climate change. The reliance on chemical inputs has sparked debates about sustainability and the need for alternative agricultural practices that prioritize ecological balance.

4. INTRODUCTION OF ORGANIC AGRICULTURE AS AN ALTERNATIVE APPROACH

Organic agriculture presents an alternative approach to conventional farming, emphasizing ecological balance and sustainability. It prioritizes practices that enhance soil health, minimize environmental impact, and promote biodiversity. Organic agriculture avoids synthetic inputs like chemical fertilizers, pesticides, and genetically modified organisms, instead relying on natural methods such as crop rotation, composting, and biological pest control. While organic yields may sometimes be lower than conventional yields, proponents argue that its benefits include improved soil health, reduced pollution, enhanced biodiversity, and potentially healthier food with fewer chemical residues. Organic agriculture represents a growing sector within the broader agricultural landscape, driven by consumer demand for more sustainable and environmentally conscious food production methods.

While often perceived as more sustainable, organic farming has lower yields and isn't necessarily less polluting per unit of output. Widespread adoption could lead to habitat loss and higher food prices. Organic farming isn't a silver bullet, but combining organic and conventional methods may offer a path to sustainable productivity increases (Meemken & Qaim, 2018). The EU organic regulations, IFOAM norms, and agroecology principles and practices. While sharing similar goals and a systems approach, they differ in scope. EU organic focuses on biological processes and input restrictions. IFOAM is broader, encompassing holistic sustainability. Agroecology includes ecological and socio-economic principles. Practices overlap, but differ in input origin and quantity, particularly in animal production.

Both offer potential for sustainable food systems, especially with a transformative approach (Migliorini & Wezel, 2017).

Modern agriculture impacts the environment, but organic farming minimizes these effects by preserving natural cycles and potentially improving food quality. It excludes chemical inputs. Combining organic practices with new technologies is crucial for overcoming limitations, enhancing sustainability, and improving farmers' livelihoods (Gamage et al., 2023). Sustainable agriculture debates center on improving conventional efficiency versus transforming systems with agroecological principles. Transformative systems like organic offer sustainability benefits but may have lower yields. Conventional systems are productive but have negative externalities.

The SDGs offer a framework to reconcile these divisions by focusing on sustainability contributions and policies that promote a transition, drawing inspiration from both transformative and incremental approaches (Eyhorn et al., 2019). Organic agriculture excels in some sustainability areas but faces lower yields. Increasing these yields is crucial, but past efforts have had negative side effects. This review analyzes various yield-increasing measures in Northern Europe, examining their impact on biodiversity, emissions, soil, animal welfare, and profitability. It identifies low-risk strategies (e.g., improved pest control) and high-risk ones (e.g., increased nitrogen input), emphasizing the need for careful management and potentially reconsidering core organic principles, including nutrient sources and animal production (Röös et al., 2018).

Marsh et al., (2020) demonstrated that organic agriculture is an alternative approach to conventional farming that emphasizes the use of natural processes and minimizes the use of synthetic inputs like fertilizers and pesticides. Some key principles of organic agriculture include:

- i)** Crop rotation to maintain soil fertility and prevent pests.
- ii)** Use of organic manure and compost instead of synthetic fertilizers.
- iii)** Biological pest control methods instead of chemical pesticides.
- iv)** Avoiding genetically modified organisms (GMOs) and growth hormones.

Cherlinka et al., (2020) elaborated that organic farming has several advantages over conventional methods:

- a)** Produces food free from harmful chemicals and with higher nutritional value.
- b)** Avoids costs for expensive synthetic inputs.
- c)** Protects the environment by reducing pollution and enhancing biodiversity.
- d)** Improves soil quality through organic matter addition and reduced tillage.

However, (Crinnion et al., 2010) organic agriculture also faces some challenges:

- Reduced yields, especially during the initial transition period.
- Higher labor requirements for manual weed control and crop monitoring.
- Shorter shelf-life of organic produce due to lack of preservatives.
- Higher prices of organic products compared to conventional ones.

Despite these drawbacks, organic farming has gained popularity in recent years due to growing consumer demand for healthy, environmentally-friendly food. It has been shown to double or triple the productivity of traditional low-input systems in some cases. Organic agriculture is not limited to certified organic farms, but includes all productive systems that use

natural processes to enhance sustainability. Traditional farming systems in developing countries often meet organic standards without certification. Thus, organic agriculture provides an alternative approach to conventional farming that emphasizes natural processes, environmental protection, and production of healthy food. While it faces some challenges, it has significant potential to address the social, economic and environmental issues associated with industrial agriculture (Canwat et al., 2022).

5. IMPORTANCE OF UNDERSTANDING ORGANIC PRINCIPLES AND PHILOSOPHIES

The principles and philosophies of organic agriculture are crucial for understanding the significance and benefits of this approach. Following key reasons are given below:

1) Holistic Perspective

The organic principles emphasize a holistic view that sees the farm as an interconnected ecosystem. This contrasts with the reductionist approach of conventional agriculture that focuses on maximizing yields through external inputs. The organic philosophy recognizes the complex relationships between soil, plants, animals and humans (Anonymous et al., 2023). A study examines Dutch organic food consumption, tracing its roots to historical movements like Lebens- reform. Interviews reveal modern consumers value nature, purity, and ethical living. While organic buyers are a segment, these values are widespread. Promoting these values may increase organic consumption, supporting sustainable food transitions (Schösler et al., 2013). Soil organic matter (SOM) understanding evolved through three periods: humus-focused agriculture (pre-1840), mineral fertilization dominance (1840s-1940s), and modern recognition of SOM's complexity (post-1940s). Scientific advances, environmental concerns, and climate change research drove this shift. SOM's importance is now widely acknowledged for soil fertility and carbon sequestration (Manlay et al., 2007). Organic agriculture, rooted in early 20th-century philosophies like Steiner's, emphasizes natural processes for human health. Founders like Howard and Rusch stressed soil health and nature's superiority. Modern organic practices, guided by IFOAM, still prioritize avoiding synthetic inputs, reflecting the founders' core principles (Kirchmann et al., 2008).

2) Environmental Sustainability

According to NASAA Organic 2023, while demonstrating the Organic principles and benefits, explained that organic farming practices prioritize the conservation and enhancement of biodiversity across farm landscapes. By preserving natural habitats, avoiding synthetic chemicals, and using techniques like crop rotation, organic farmers help maintain ecological balance and ecosystem services. Organic farming, despite rapid growth and recognition, is narrowly defined by regulations as "chemical-free," neglecting its holistic origins. Consumer focus on health drives this, but it overlooks soil health and environmental sustainability. Global regulations largely agree on input restrictions, highlighting a need for broader ecological principles (Seufert et al., 2017). Study analyzed Italian consumers, finding organic consumers more aligned with sustainability. Shared traits like healthy diets and self-transcendence values suggest joint promotion of local and organic foods can effectively encourage sustainable food

consumption (Scalvedi & Saba, 2018). Russia's environmental education within its Federal State Educational Standard. It explores how the standard integrates sustainable development concepts, aiming to cultivate an environmental worldview in students. It highlights the importance of continuity, scientific knowledge, and ethical considerations in fostering sustainable development awareness (Shutaleva et al., 2020).

3) Social Responsibility

The organic principles emphasize fairness in terms of the common environment and life opportunities. This includes ensuring fair treatment and working conditions for farm workers and animals. The transparency and participatory nature of organic systems also promotes social responsibility. A study reveals that consumer trust is crucial for green product markets, particularly organic food in Thailand. Lack of trust in certification and labeling hinders purchases. System mistrust negatively impacts perceived benefits and buying behavior, highlighting the need for trust management (Nuttavuthisit & Thøgersen, 2017). It is examined that the Syrian FFV farmers' attitudes towards organic farming. Surveying 266 farmers, it found strong positive intentions to adopt organic practices within five years. Many already used organic-compatible methods. Utilizing the Theory of Planned Behavior, the research highlights potential for organic FFV exports to the EU (Issa & Hamm, 2017).

It is examined in research that the introduced "brand social responsibility" (BSR), distinct from corporate social responsibility (CSR). Studies show consumers perceive social responsibility differently across brands, even within the same company. BSR better predicts consumer responses to products, while CSR predicts corporate outcomes, highlighting their unique roles (Grohmann & Bodur, 2015). Research distinguished between business ethics and corporate social responsibility (CSR), showing both impact brand attitudes. A 351-respondent study revealed customers prioritize ethical behavior over CSR in brand perception, despite CSR's continued importance (Ferrell et al., 2019). A study in India explored that how ethical leadership affects CSR in Indian healthcare social enterprises. Analyzing 350 managers, it found ethical leadership directly and indirectly boosts CSR. Clan and adhocracy cultures mediate this influence, demonstrating that ethical leaders foster these cultures, driving CSR. This highlights the importance of leadership style for social responsibility (Pasricha et al., 2018).

4) Health Benefits

A-farms exemplify on the linkedin in 2024, that organic foods are produced without the use of synthetic pesticides, fertilizers, antibiotics or growth hormones. Studies show they contain lower levels of toxic residues and higher levels of beneficial antioxidants compared to conventionally grown foods. This translates to health benefits for consumers. A 2016 Danish focus group study explored organic food consumer health perceptions. Participants emphasized "health as purity" when choosing organic. While general healthy eating discussions focused on nutrition, three health understandings emerged: purity, pleasure, and holistic. This clarifies consumer motivations, impacting organic producers and research (Ditlevsen et al., 2019). In 1750 Chinese consumers revealed the unique organic food perceptions: luxury, upscale, and marketing hype. Subjective norms influence purchase attitude, not directly intention. Identity expression plays a minor role. Trust and income are key predictors, with income dominating actual purchases. These findings aid organic food marketers targeting China (Bai et al., 2019).

5) Precautionary Approach

IFOAM emphasizes on the 4 principles of organic agriculture. It takes a precautionary approach to new technologies and methods. It rejects unpredictable ones like genetic engineering in favor of proven traditional and indigenous knowledge. This reflects the principle of care for current and future generations. In short, understanding the organic principles and philosophies provides a framework for evaluating the sustainability, health impacts and social implications of food production systems. It offers an alternative to the narrow focus on yields and profits that has characterized industrial agriculture. The precautionary principle, rooted in German "Vorsorge," emphasizes acting to prevent ecological harm despite incomplete knowledge. Endorsed by the US in the 1992 Rio Declaration, it advocates for proactive environmental protection. It recognizes the interconnectedness of nature, urging cautious decisions to safeguard ecosystems (Gilbert, 2020).

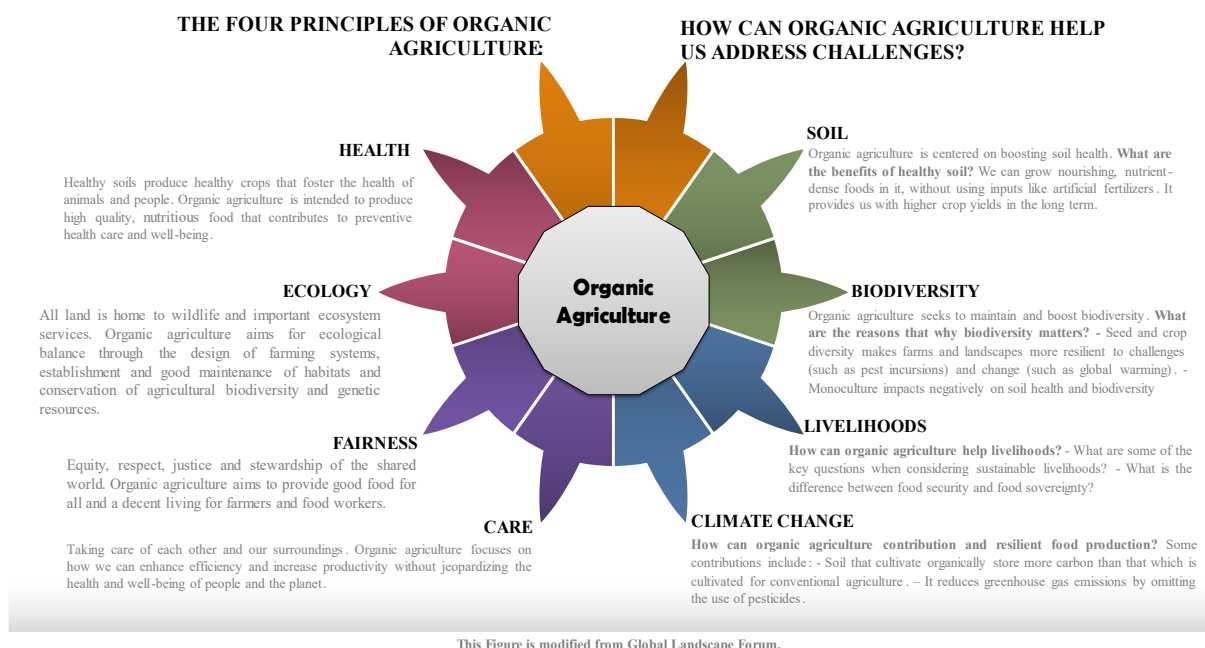


Figure 3. Core Principles of Organic Agriculture and how it helps to address the Challenges of Changing Climate.

6. CORE PRINCIPLES OF ORGANIC AGRICULTURE

Emphasis on soil health and fertility management (e.g., composting, cover cropping)

The core principles of organic agriculture emphasize environmental sustainability and ecological balance:

Environmental Sustainability

OANZ Organic Aotearoa New Zealand in 2020 reported that organic farming practices prioritize the conservation and enhancement of biodiversity across farm landscapes.

This includes preserving natural habitats, avoiding synthetic chemicals, and using techniques like crop rotation to maintain ecological balance. Organic Farm Knowledge is maintained by the Research Institute of Organic Agriculture FiBL Switzerland and generated a report in 2023, which inferred that a key tenet is maintaining and improving soil health through practices like composting, cover cropping, and minimizing tillage. This helps build soil organic matter and fertility without relying on synthetic fertilizers. Organic agriculture works in harmony with natural cycles and processes, aiming to emulate ecological systems rather than trying to control them through external inputs.

Health and Wellbeing

In September 2023, Stray Dog Institute reported and summarized again the Langner et al., 1986 work about organic farming and stated that organic agriculture rejects the use of synthetic pesticides, fertilizers, antibiotics, and other chemicals that can have adverse impacts on human, animal, and environmental health. It emphasizes the interconnectedness of human, animal, plant, and soil health, recognizing that the health of these systems is interdependent.

Fairness and Social Responsibility

Secchi et al., (2021) also brief that organic principles promote fairness in terms of equitable treatment of producers, workers, consumers, and the environment. This includes ensuring fair livelihoods and working conditions. Organic agriculture is also based on a precautionary approach, prioritizing long-term sustainability over short-term productivity gains. So, the core principles of organic agriculture center around environmental protection, natural resource conservation, and the interconnected health of all living systems. This holistic perspective contrasts with the reductionist approach of conventional industrial agriculture (Eyhorn et al., 2019).

Importance of biodiversity and ecosystem protection (e.g., integrated pest management, habitat creation)

In 2022, Dr. Hammermeister, director at Organic Agriculture Centre of Canada, Dalhousie University, reported that biodiversity is essential for maintaining healthy, resilient ecosystems that support agricultural production. Organic farming practices prioritize the conservation and enhancement of biodiversity across farm landscapes. Rodale Institute is growing the organic movement through research, farmer training, and consumer education.

Thus, publicized that organic farms rely on biodiversity to provide natural pest control services. By preserving habitats for beneficial insects, birds, and other predators, organic farmers encourage natural predation of crop pests. This reduces the need for pesticides and creates a more stable, resilient system.

Diverse soil microbial communities are essential for nutrient cycling, organic matter decomposition, and plant growth. Organic farming practices like cover cropping, composting, and reduced tillage support a wide variety of soil organisms. This builds healthy, fertile soils that are less dependent on external inputs. Bees, butterflies, and other pollinators are crucial for the reproduction of many crops. Organic farms provide diverse floral resources and nesting habitats to support pollinator populations. Maintaining biodiversity helps ensure adequate pollination for high yields. Dr. Hammermeister also professed that natural areas on organic farms provide valuable ecosystem services like flood control, water filtration, and carbon

sequestration. Biodiversity underpins the functioning of these systems. Preserving biodiversity helps maintain the ecological balance that sustains organic production. As said earlier that Afarm's in 2024, stated that diverse farms are more resilient to environmental stresses like drought, pests, and diseases. If one component of the system is impacted, other elements can compensate.

Biodiversity provides insurance against unpredictable events and long-term changes. In sum-up, biodiversity is a key component of organic farming systems. By preserving habitats, using integrated pest management, and maintaining soil health, organic farmers support a wide variety of species. This biodiversity provides essential services that sustain yields while minimizing environmental impacts. Investing in biodiversity is an investment in the long-term resilience and productivity of organic agriculture.

Water conservation and pollution reduction practices (e.g., irrigation techniques, buffer strips)

Irrigation Techniques

Drip irrigation delivers water directly to the plant roots, minimizing evaporation losses. It can reduce water use by 30-70% compared to conventional irrigation methods. Thilagam et al., (2021), reported that Alternate wetting and drying in rice fields allows the soil to dry out between irrigations, reducing water use by 15-30% without yield losses. Mulching with organic materials like straw or leaves helps retain soil moisture, reducing irrigation needs. A study was conducted to assess the irrigation and vegetative filter strip (VFS) effectiveness in reducing runoff pollution in arid agriculture. Improved irrigation reduced runoff and sediment, while VFS, 3-9m, significantly cut sediment delivery but not runoff. Optimized irrigation is crucial, with VFS as a complementary measure for targeted areas (Campo-Bescós et al., 2015). Riparian buffers offer diverse benefits like pollution control and biodiversity, but management is complex. They can saturate and release pollutants, requiring wider pollution control. Grass buffers excel at sediment capture, while wooded buffers aid climate mitigation. Zoned buffers balance these. Effective strategies require catchment-scale planning and targeted implementation (Cole et al., 2020). Modern soil and water conservation uses sustainable practices like conservation tillage, cover cropping, agroforestry, rainwater harvesting, and green infrastructure. These methods combat erosion, nutrient depletion, and pollution, crucial for sustainable agriculture and resource protection (Kurdekar et al., 2023).

Soil Management

A study was conducted to compare the organic, conservation, and conventional agriculture in Europe. Organic and conservation systems showed higher ecosystem multifunctionality, improving biodiversity, soil, and climate. Conventional agriculture yielded more but reduced multifunctionality. Organic farming also had better economic performance. Results highlight the productivity-environment dilemma in agriculture (Wittwer et al., 2021). African Organic Agriculture Manual Booklet Series 2011, also emphasize that cover cropping and green manures protect soil from erosion and improve water infiltration. An Indian Farmland Rainwater Harvesting System also proclaimed that reduced tillage and no-till practices leave crop residues on the surface, reducing evaporation and runoff. Composting and manure application enhance soil organic matter, which improves water holding capacity. Vegetated buffer strips along waterways filter out sediments, nutrients and pesticides, preventing water

pollution. Constructed wetlands can remove up to 90% of nutrients and 80% of pathogens from wastewater.

Global warming and soil degradation intensify drought. Restoring soil organic matter (SOM) improves water retention, especially plant-available water capacity. Conservation agriculture, cover cropping, and integrated farming enhance SOM. Site-specific adjustments are needed. Further research should quantify the SOM-PAWC relationship and its impact on drought resilience (Lal, 2020).



Figure 4. Major Constituents of Organic Matter.

Nutrient Management

Precision farming techniques match nutrient application with crop needs, reducing excess fertilizers that can pollute water. Legume cover crops fix atmospheric nitrogen, reducing the need for synthetic fertilizers (Thilagam et al., 2021). Integrated Nutrient Management (INM) combines organic manure, chemical fertilizers, and microorganisms to boost crop yield and soil health. It reduces chemical fertilizer use, improves soil properties, and minimizes environmental pollution. INM offers cost-effective, eco-friendly solutions for sustainable agriculture, addressing food security and poverty (Selim, 2020). Organic vegetable growers use biological inputs like manures, compost, and cover crops to manage soil fertility. These inputs enhance nutrient availability and soil health. Compost requires large volumes due to low nutrient content. Cover crops improve soil structure and nutrient levels. Timing nitrogen release to match crop needs is a key challenge (Brust, 2019).

A review addressed the myths surrounding organic and conventional farming. Organic yields are often 20-50% lower. It proposes a 75:25 inorganic-organic nutrient ratio to meet global food demands. Evergreen Agriculture, combining trees and crops, is highlighted as a sustainable solution, proven effective in Africa, with potential for expansion (Timsina, 2018).

Sustainable agriculture is challenged by balancing food demand with soil health. Organic nutrient management, while criticized for yield limitations, is crucial for soil health and environmental protection. Integrated approaches enhance its efficiency, proving essential for optimal crop production and soil improvement (Dotaniya et al., 2020).

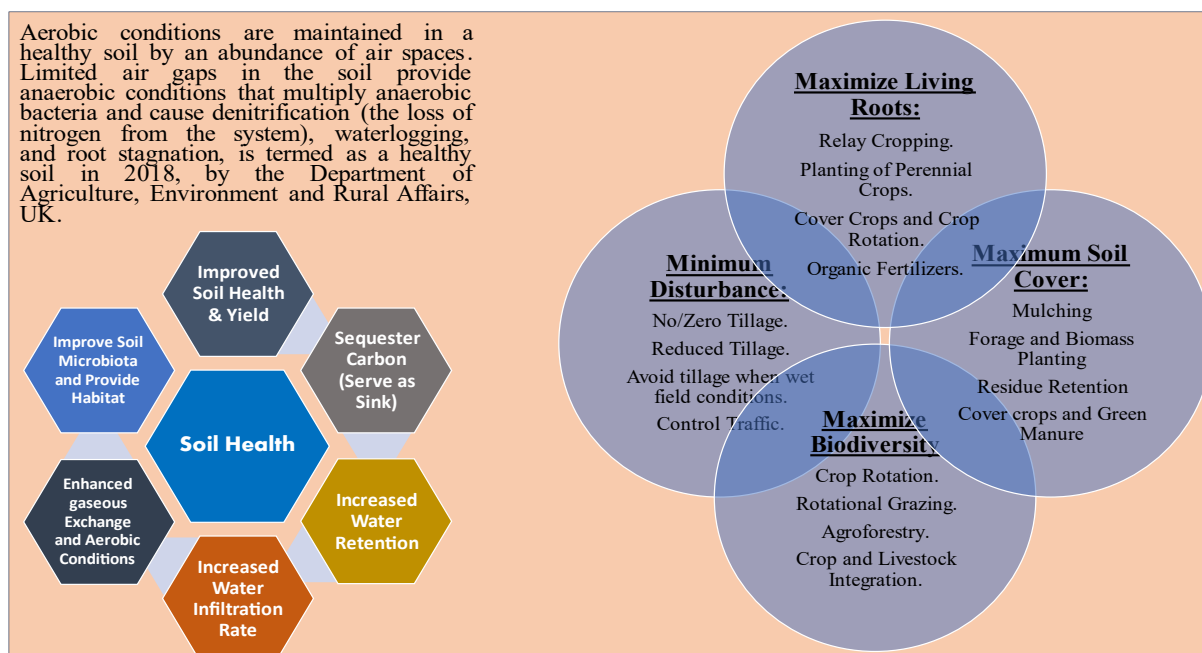


Figure 5. Major components on which Organic Farming based.

Pest Management

African Organic Agriculture Manual Booklet Series 2011, published on “how do I protect the soil nutrients and water from loss?” demonstrated that biological control using beneficial insects and microorganisms suppresses pests without synthetic pesticides. Crop rotation and diversity disrupt pest life cycles and minimize disease pressure. By implementing these water conservation and pollution reduction practices, organic farmers can enhance the sustainability and resilience of their production systems. This helps safeguard limited water resources while minimizing the environmental footprint of agriculture.

Biological pest control is crucial for sustainable agriculture, but adoption is slow. Overcoming barriers like awareness and cost requires collaboration between organic and IPM practitioners. Strategies include education, accurate cost-benefit analysis, and supportive policies to promote biological alternatives (Baker et al., 2020). It is analyzed that the organic farming's pest control performance compared to conventional systems. Organic farming boosts biological pest control potential but shows varied pest infestation levels. Pathogen infestation is lower, animal pests similar, and weeds higher in organic systems. Organic farming can reduce synthetic pesticide use for animal pests and pathogens without increasing infestations (Muneret et al., 2018).

Synthetic pesticide overuse harms health and the environment, driving demand for botanical alternatives. Botanical pesticides, derived from plants, offer eco-friendly pest control.

Their diverse phytochemicals provide varied action modes. Formulation and commercialization challenges hinder widespread adoption. This review explores their chemistry, benefits, and roles in sustainable agriculture (Lengai et al., 2020).

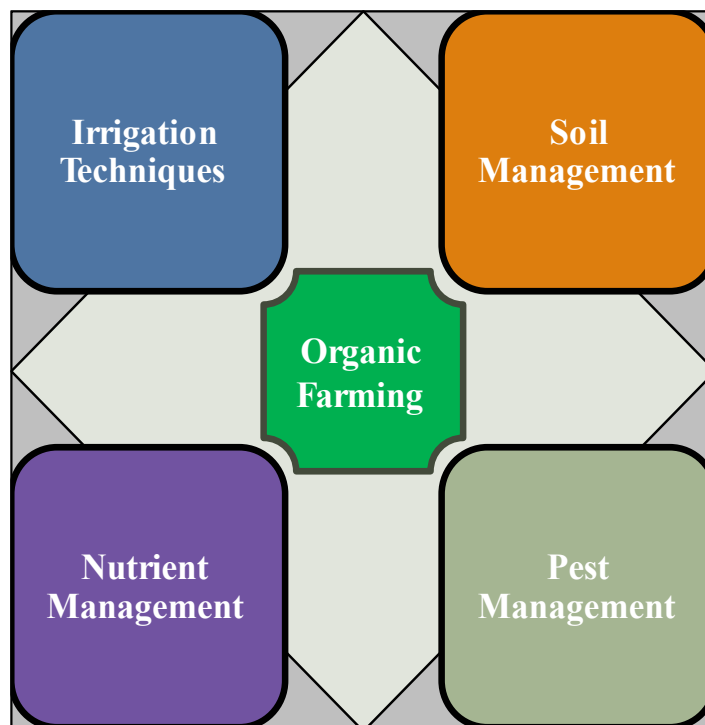


Figure 6. How does Organic Agriculture improve Soil Health.

7. CONCLUSION

Agriculture, from its traditional roots to the modern era, stands as a cornerstone of human civilization. While conventional agriculture has significantly boosted food production through mechanization and synthetic inputs, it has also raised concerns about environmental sustainability and potential health risks. The historical overview highlights the importance of practices that mimic natural cycles, advocating for soil health and reduced reliance on synthetic fertilizers and pesticides. Looking forward, the future of agriculture hinges on embracing sustainable and innovative practices. The integration of advanced technologies, such as precision farming and vertical agriculture, holds promise for optimizing resource use and minimizing environmental impact. Furthermore, promoting biodiversity, adopting climate-smart agricultural techniques, and supporting policies that prioritize environmental conservation will be crucial for long-term food security and ecosystem health. Research and development in areas such as drought-resistant crops, pest-resistant varieties, and sustainable aquaculture practices are essential to address the challenges posed by climate change and population growth. Encouraging community-based initiatives, strengthening market linkages, and fostering collaboration between stakeholders are key to achieving a resilient and equitable agricultural system that meets the needs of present and future generations. The focus should shift towards holistic approaches that value both productivity and ecological integrity.

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