INNOVATIVE FARMING TECHNIQUES : EMBRACING PRECISSION AGRICULTURE AND RENEWABLE ENERGY

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INNOVATIVE FARMING TECHNIQUES : EMBRACING PRECISSION AGRICULTUREAND RENEWABLEENERGY

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The seminar report is submitted for the partial fulfillment of the requirement for the degree of B.Sc (Hons.) at the Dept. of Soil, Water & Environment,University of Dhaka.

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Certificate of Authentication

This is to certify that the seminar paper titled “Innovative Farming Techniques: Embracing Precision Agriculture and Renewable Energy” has been prepared and submitted by Shuvo Howlader, Class Roll: AE-190, Session: 2018-19. He has prepared the paper actively and sincerely under my instruction and direct supervision.

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Acronym	Full Form

1.Introduction

The global population is predicted to reach 8 billion by 2025 and expected to exceed 9 billion by 2050. As a consequence, there will be a staggering need for 70% increase in food production worldwide, due by 2050.The rapidly-growing human population has increased food demands for human survival on the Earth. Meeting the food requirements with limited resources of the planet is a big challenge.Therefore, modernisation and technology intensive smart agricultural practices is an inevitable need for sustainable increase in food production with high efficiency in resource consumption.To address these issues and enhance agricultural productivity, innovative framing techniques, particularly precision farming and renewable energy integration, are gaining prominence. (Tzounis et al., 2017; FAO,2016)

One of the most promising concepts on this track is Precision Agriculture (PA). Because, the mandate of PA is to optimise and improve processes in the concerned agricultural segments (Zhang et al,. 2002).To ensure fast, reliable and authentic delivery of knowledge and resources for maximizing agricultural productivity, Precision Agriculture offers the farmers a technology intensive coordinated distributed system. This might include for instance (Tzounis et al., 2017; Kacira et al., 2005; Körner & Van Straten,2008) (a) circumstantial overview of the current condition of their cultivation area, (b) coordinate the automated machinery for agricultural process control (e.g.,irrigation,pest control, fertilization, growth monitoring and others) through optimal energy consumption, (c) build knowledge driven intelligent smart algorithms that can evaluate agricultural information gathered from many heterogeneous systems, to better assess the current situations and offer well educated predictions, suggest course of actions, provide early warnings on potential dangers, and improved automated control signals based on plant responses. However, a system of such capacity requires interconnecting heterogeneous components wireless with a high processing cloud service to run the algorithm. The transcript of requirements as detailed above can be achieved through effective adoption of IoT (Internet of Things) design principles and technological support. Because, IoT offers a networked interconnection of heterogeneous objects possessing ubiquitous intelligence (Xia et al,. 2012). This setup offers highly distributed communication network, increased computation power and intelligence with optimized resource consumption (Xia et al,. 2012).

Use of renewable energy in farming systems can mean several different things. For example, fossil fuels such as oil are non-renewable, so finding alternative ways of fertilising the land and controlling pests that do not depend on chemicals, will normally involve the use of renewable resources. Such methods reduce farmers' vulnerability to the rising price of oil (Murphy, 2008). Renewable energy also includes generation of power to do a number of farm tasks: pumping water for irrigation, for livestock or for domestic use; lighting farm buildings; powering processing operations and others. These forms of renewable energy include solar energy, wind and water power, oil from plants, wood from sustainable sources, other forms of biomass (plant material), and biogas (gas produced from fermentation of manure and crop residues) (Pimentel & Pimentel,1996).

2. Objectives

1)Evaluate the current state of traditional farming methods in Bangladesh and identify their challenges and limitations.

2)Investigate the principles and applications of precision farming techniques, such as sensor technology and data analytics, and assess their potential benefits for improving agricultural productivity and sustainability in Bangladesh.

3)Examine the feasibility and advantages of integrating renewable energy sources, particularly solar energy, into agricultural practices in Bangladesh, with a focus on reducing reliance on fossil fuels and enhancing energy security for farmers.

3. The Evolution of Innovation Process in the Agricultural Context

There are four main approaches to agricultural innovation. Technology Transfer (TT), a technology-oriented approach, characterized the period of agricultural modernization (the 50s-80s). TT reflects the idea of knowledge transfer taking place through processes of a "top-down" type from researchers to farmers. In this period, the researchers' main purpose was to enable rapid technological progress and increase agricultural productivity. This approach was strongly disconnected from the socio-political and institutional contexts where new technologies were operating (Klerkx et al., 2017; World Bank,2006). After this period, the researchers' studied in depth system-oriented approaches, such as

Farming Systems (FS), Agricultural Knowledge and Information System (AKIS), and Agricultural Innovation System (AIS) (schut et al., 2017).The lack of attention to specific contexts (socio-economic, cultural and agro-ecologic) was observed in the 80s within the FS approach. This approach attributed a new role to farmers, which shifted from simple users to adopters of knowledge and technologies. In the 90s, the transition from the top-down to bottom-up approach reflected in AKIS, where mechanisms of innovation were no longer considered a simple transfer of technology, but the exchange of knowledge and information between actors. The increasing importance attributed to the institutional and political components of the process of innovation also fostered a broader vision of the innovation system, in which the AKIS is a sub-set of a more complex framework, named AIS (Leeuwis,2004). Compared to AKIS, AIS highlights the institutional and political dimensions of the innovation processes.

The goals of this system were to optimize the exchange of knowledge and interactions between actors and institutions that modeled the innovation process inside and outside the agricultural sector. From this new conceptualization,different paths of analysis were developed. Vellema describes it statically as "innovation support infrastructure". A more dynamic analysis is the systems where a co-evolution and networking process connected to the development of emerging technology (novelty) in a dominant production system (Hekkert et al., 2007) proposed a third interpretation, no longer focused on the structure of innovation systems,but on the dynamics of innovation processes (labelled as "functions of innovation systems") at the micro level.Starting from this view, a clear understanding of innovation mechanisms and the heterogeneous role of actors is required. From the description of the AIS approach, it emerged that new proposals such as learning platforms and networks could be the key to creating a scenario conducive to innovation, stimulating interactions and bringing further innovations to the agricultural sector.

4. Overview of Innovative Farming Techniques

Agriculture has evolved significantly over the centuries, transitioning from traditional methods to innovative, technology-driven practices. This evolution has been driven by the need to enhance productivity, ensure sustainability, and meet the growing food demands of an increasing global population. This article provides an overview of the key differences between traditional and modern farming practices, highlighting the advancements in agricultural technology.

4.1 Traditional Farming Practices

Traditional farming practices, also known as conventional farming, rely heavily on manual labor and natural processes.(Flannery et al.,1967).These methods include:

Manual Labor: Most tasks, such as planting, weeding, and harvesting, are performed by hand or using simple tools.

Natural Inputs: Farmers use organic fertilizers like manure and compost, and rely on natural pest control methods.

Crop Rotation and Polyculture: Crops are rotated to maintain soil fertility, and multiple crops are often grown together to reduce pest outbreaks.

Water Management: Irrigation is often limited to traditional methods such as furrow and flood irrigation, which can be inefficient and wasteful.

4.2 Innovative Farming Practices

Innovative farming practices incorporate advanced technology and scientific methods to improve efficiency and productivity. Key components include:

Mechanization: The use of machinery such as tractors, combine harvesters, and seed drills reduces labor and increases efficiency.

Chemical Inputs: Synthetic fertilizers, pesticides, and herbicides are used to enhance crop growth and control pests and diseases.

Precision Agriculture: Technologies like GPS, GIS, and IoT sensors enable precise application of inputs, monitoring of crop health, and efficient resource management.

Genetically Modified Organisms (GMOs): The use of GMOs allows for crops with improved traits such as pest resistance, drought tolerance, and higher yields.

Irrigation Technology: Modern systems like drip and sprinkler irrigation ensure efficient water use and minimize waste.

5. Precision Agriculture Approaches and Applications

Precision agriculture involves data-driven management decisions to enhance resource efficiency, reduce costs, and minimize environmental impact. Key components include data collection systems, decision support tools, and equipment adjustments. Before smart technologies, ICT was integrated into agricultural practices using remote sensing, GPS, drones, and robotics. John Deere, for instance, introduced GPS for tractors to improve yield and reduce input waste (Hegde, 2021).

5.1 Data Collection and Acquisition

Data collection methods, and decision support tools are important for the identification and diagnosis of various aspect in agriculture, particularly within the realm of precision farming. Various sensors, monitors, and remote-sensing technologies, including drones and satellites, are employed to gather detailed information on climate, soil conditions, crop health, and livestock welfare (Alfred et al., 2021; Monteiro et al., 2021). These tools aid in making informed decisions regarding fertilization, crop care, and resource allocation. Remote sensing assists in identifying spatial patterns related to soil characteristics and pest infestations . Moreover, unmanned aerial vehicles equipped with GNSS technology are utilized for mapping, crop spraying, and livestock monitoring. Geospatial data and real-time sensing enable the creation of yield maps and soil maps, which play a crucial role in site-specific management decisions .These maps help characterize field production and identify factors influencing productivity, such as soil properties and climate trends (Lund et al.,2016). Ultimately, the integration of sensor data and remote sensing technologies enhances precision agriculture practices, optimizing productivity while minimizing resource wastage.

Humans have used digital tools and automated machines to enhance diagnosis and decision-making in agriculture, with Industry 4.0 further automating these processes and limiting human involvement to monitoring **(Figure 1).** This aims to optimize farming and manage variability to increase production. However, addressing food demand should also focus on reducing wastage of agricultural inputs and outputs (Cravero and Sepúlveda,2021).

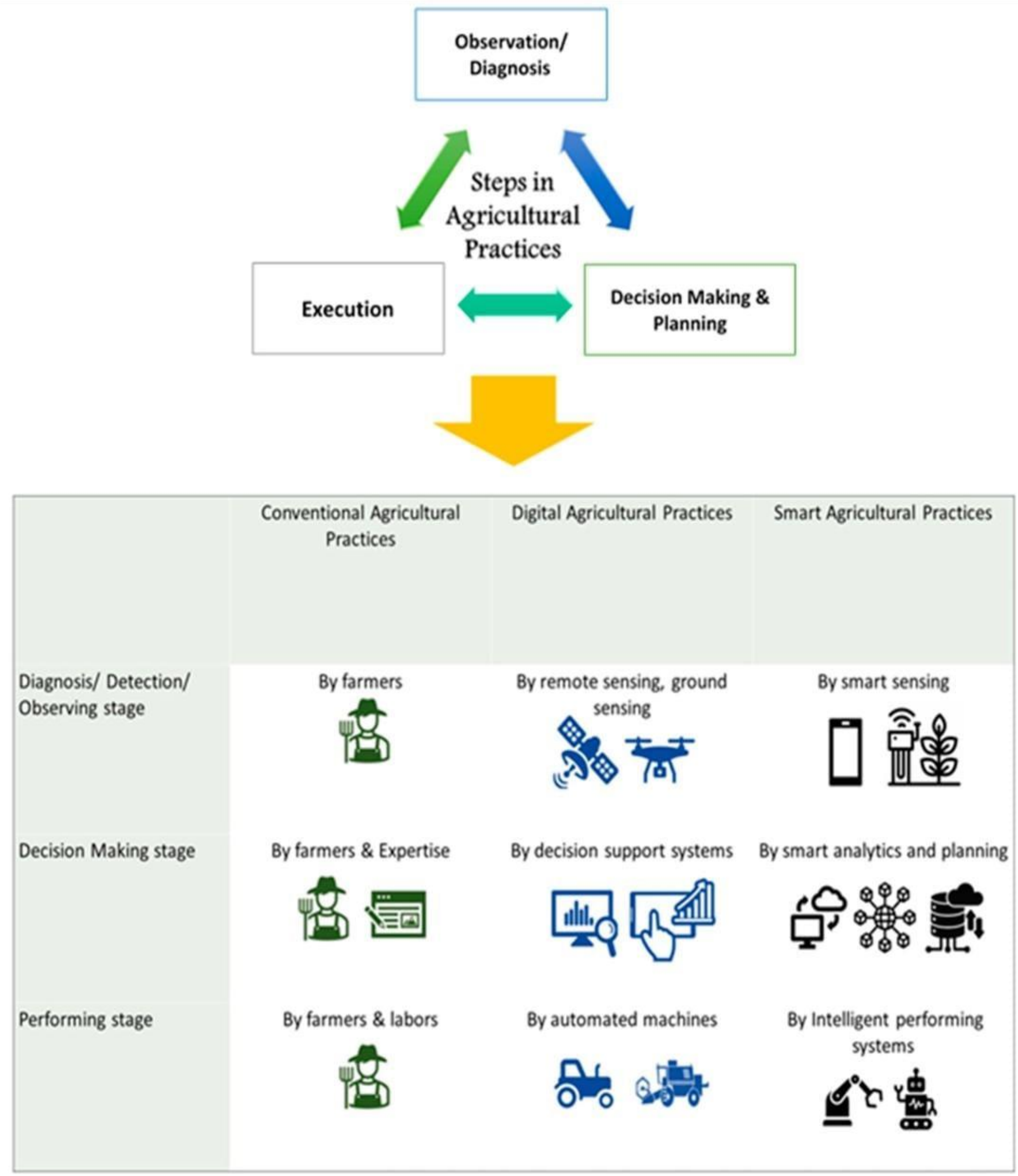

Figure 01. Three-phase cycle of an automation system and the evolution of automation of those phases in agriculture with emerging advanced technologies (Cravero and Sepúlveda,2021)

5.2 Planning, Decision Making, and Execution

Precision agriculture leverages data-driven technologies to make informed decisions and apply actions tailored to the specific needs of different field areas, addressing the non-homogenous nature of soil, climate, and diseases (Jang et al., 2023).Conventional agriculture's uniform approach led to unsustainable practices and resource wastage.In contrast, precision agriculture utilizes variable rate technologies to optimize the application of fertilizers, water, seeds, and crop protection chemicals based on field-specific requirements, reducing chemical residues and input wastage while increasing crop yield and net profit. Advanced irrigation systems, guided by soil moisture sensors, ensure precise water application, improving irrigation water use efficiency (IWUE).Technological advancements also allow for automated chemical spraying and seeding, enhancing efficiency and reducing labor costs. This site-specific management approach increases accurate decisions per unit area, conserves inputs, and minimizes environmental impacts. Grid sampling and local resource management systems further enhance precision by collecting detailed field data and translating it into variable rate applications (Filipe et al., 2020).

6. Global Precision Farming and Prospects in Bangladesh

6.1 Present scenario of precision farming around the world

Yield monitors connected to a GPS-receiver was by most farmers the first real attempt to conduct site-specific management on their fields. The global adoption of yield monitors has been predominated in North-America, Europe and Australia but countries like Argentina, Brasilia and some East Asian countries have also adopted some practices. To date, we are in a stationary state between the early adopters and the early majority, mainly since yield increases aren’t well enough documented to cover the cost of equipment. The adoption of precision farming technologies is likely to follow a normal distribution with the innovators and early adopters as the first to adopt the technology and then later on will the majority of farmers follow up. The adoption of precision farming is currently in a stationary phase between the early adopters and the majority **(Figure 02)**.

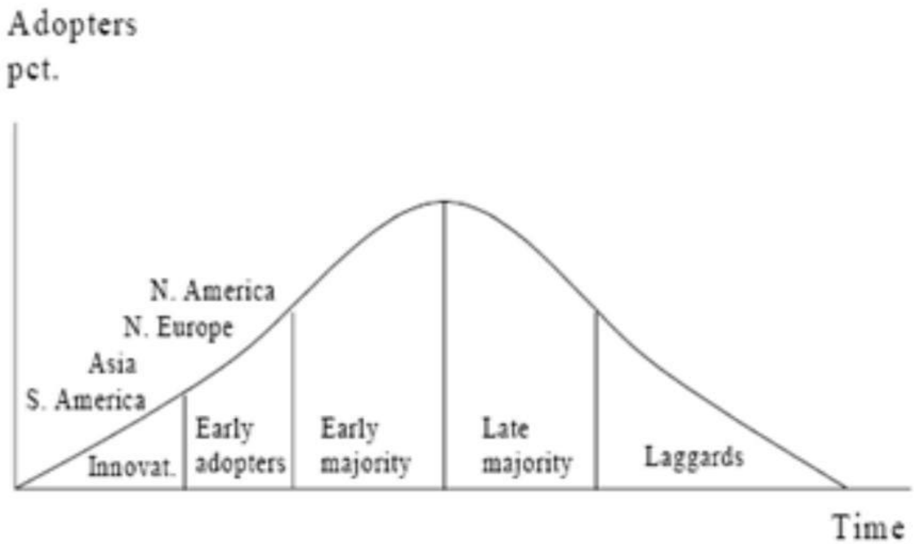

Figure 02: Global adoption of precision farming practices (Blackmore, 2008)

Yield mapping with GPS is common in the US, UK, and Denmark. Yield monitoring without GPS is notable only in the US. Directed soil sampling using yield maps or spatial information is growing in the US and UK. Aerial photography or remote sensing is more prevalent in the US compared to the UK and Denmark. Soil conductivity mapping is more common in the UK and Denmark than in the US. Conventional soil surveys are significant in the UK. In the US, field topography mapping is important for irrigation purposes that shown in **Table 01** .

Practice	DK	UK	US
Information Gathering	-------------------- % ----------------		
Grid soil sampling	49	56	50
Directed soil sampling	14	27	39
Yield monitoring (no GPS)	7	17	29
Yield mapping (GPS)	80	100	76
Aerial photography	3	27	40
Remote sensing	3	17	19
GPS-pest monitoring	1	2	3
Soil conductivity mapping	14	19	6
Soil topography mapping	1	4	22

Conventional soil mapping	-	17	
Mean	**19**	**29**	**32**
Taking Action			
VRT fertilization	26	58	47
VRT lime	37	33	26
VRT pesticide	10	10	3
Mean	**24**	**34**	**25**
Other	3	6	14

Table 01. Use of precision practices among countries (Percent of respondents in each country who indicate they have used the practice) (Pedersen et al., 2009)

6.2 Prospect of precision agriculture in Bangladesh

➤Bangladesh is a over populated country and by precision agriculture we can produce more by using available resources to feed these population not only in quantity but also can provide them nutritious food.

➤In Bangladesh, we can use precision agriculture by using the data (rainfall, temperature, humidity,sunshine, wind speed etc.) available in different institutions.

➤Precision agriculture helps to produce and improve crops at minimum cost which is very essential for Bangladesh as it is a developing country where money or investment is a very big problem.

➤In Bangladesh, precision agriculture has great prospect as our country is highly natural calamity sensitive country and through it we can easily take measure to prevent our agricultural products from damage caused by natural calamities.

➤Though, precision agriculture is very costly but the benefit from it is more than its cost for most of the developing country. (Haque et al., 2016)

7. Machine Based Technology in Precision Agriculture

In the present, we are in the early stage of a new agricultural revolution with data-intensive approaches, which deploy machines at each and every step in agriculture (**Figure 01**), namely diagnosis, decision making, and performing (Cravero and Sepúlveda,2021). Human power is only involved in monitoring and maintaining . Apart from the gradual modification of agricultural practices by the three previous industrial revolutions, the ongoing fourth industrial revolution is shaping the current status of agriculture, leading to Agriculture 4.0. This new discipline is characterized by data-driven management;new tool-based production, sustainability, professionalization; and the reduced environmental footprint of farming with modern smart technologies, such as robot technology (including drones, big data, artificial intelligence, computer vision, 5G, cloud computing, the Internet of Things, and blockchain technology. This makes agricultural production systems more autonomous and intelligent (Javaid et al.,2022; Shaikh et al., 2022). Therefore, the following involvements can be identified as new trends and precision agriculture **(Figure 3)**, where new capabilities are introduced to smart farming.

Figure 3. Different integrated technological contexts to form the fourth agricultural revolution: novel trends in precision agriculture.(Javaid et al.,2022)

7.1 Internet of Things (IoT)

IoTs monitoring and automation from anywhere in the world is replacing human being hence yielding more benefits in agriculture. It is predicted that by the year 2050,the agriculture using IoT will increase the food production by 70% and provide foods up to 9.6 billion people, and 2 billion sensors will be used in 525 million farms. Due to this prediction, IoT based agriculture and farming is becoming popular with the promise to deliver all-time visibility of soil and crop health, used machinery, storage conditions, fertilizer used, energy consumption, and animal behavior.IoT can help farmers in numerous ways. With the deployed sensors/actuators across farms and machinery, farmers can gain as an abundance of insightful data such as temperature,fertilizer used, water used, etc. Once an IoT-enabled smart system is in place, farmers can easily monitor a variety of environmental parameters and do analytics (Javaid et al.,2022). **Table 02** shows a list of IoT-based agricultural applications.From the **Table 02** it is clear that longer latency is intolerable for most of the applications.

Application	Benefit	Network Requirement
Soil & water quality monitoring	(i)Choosing perfect breed of plant, (ii) Applying fertilizer if required, and (iii) Detecting water related disease in pond and agriculture domain	(i) Low latency for immediate action, and (ii) Generate huge amount of periodic traffic to the network
Farm monitoring	Automation and remote monitoring of machines used help to manage a large scale farms	Longer delay may damage the production system
Irrigation management	Optimization of water or other material usages in the farm or agriculture domain	Low latency should be taken for lesser losses
Scientific disease & pest monitoring	(i) Efficient usage of fertilizers and pesticides, and (ii) Increases the crop quality and minimizes the farming cost	(i) The periodic traffic may take a large bandwidth of the network

Intelligent greenhouses	Controlling greenhouse gases	Delay is the most considerable parameter
Controlled use of fertilizers	(i) Maintaining plants growth and crop quality, and (ii) Balancing soil nutrition	Large amount of data may be generated due to the large number of sensors used
Cattle movement monitoring	Saving damages from cattle's movements	Longer delay is intolerable
Remote control and diagnosis	Remotely controlling and diagnosing different farm related equipments	Longer latency may harm the equipment
Asset tracking	A farmer can continuously track the position of vehicles and irrigation systems from any place	Mobility support and less delay are the primarily required parameters

Table 02. Network requirements of different IoT applications in farm and agriculture (Ojha et al., 2015)

7.2 AI In Precision Farming

Artificial Intelligence (AI) is transforming precision farming by using data-driven insights to optimize agricultural practices, enhancing efficiency and productivity. AI analyzes data from sources like soil sensors, weather stations, and satellite imagery, enabling informed decisions on planting, irrigation, fertilization, and pest control .It predicts optimal planting times by assessing weather patterns and soil conditions, helping farmers schedule planting to maximize yields and mitigate weather risks .AI systems monitor crop health in real-time, detecting nutrient deficiencies, diseases, or pests early through drone and satellite images, leading to timely interventions that reduce crop loss and minimize pesticide use. ((Wolfert et al., 2017)

In irrigation, AI optimizes water usage by analyzing soil moisture, weather forecasts, and crop water needs, improving water efficiency and crop growth, especially in water-scarce regions. For nutrient management, AI recommends fertilization strategies based on soil content and crop stages, enhancing nutrient uptake and reducing environmental pollution from excess fertilizers. AI also aids in pest and disease management by processing field sensor and imagery data to predict outbreaks, enabling targeted preventive measures and promoting integrated pest management (Sharma et al., 2020).

7.3 Guidance System (Use GPS)

Guidance systems use GPS (global positioning system) technology to provide farmers with real-time information about their equipment locations and herd- grazing locations, enabling them to optimize field operations such as planting, harvesting, and herding. The limited number of satellites, poor signal strengths, and lack of reliable connectivity were overcome by introducing a GNSS (global navigation satellite system), which then replaced labor-intensive, time-consuming farm operations with more effective methods, such as VRA. Previously, agricultural inputs were performed manually, and during Agriculture 3.0, they were performed mechanically using digitalized machines. With rapid commercialization, agricultural machinery services have emerged that require efficient management to prevent overuse or underuse issues. For the understanding of agricultural machinery, GNSS plays a crucial role in optimizing effectivity and efficiency.The new trend of GNSS-enabled devices in the fully automated steering of tractions is saving time, labor costs, and money .Precision agricultural robots require high-resolution navigation solutions. Similarly, agricultural rovers and robots are effective only when precisely guided in their actions. Some studies introduced DL propagation models in GNSS fused with inertial navigation data sets for precision agriculture. One example is electric seeders with optical fiber detection technology that were developed and tested successfully (Chen et al., 2023). The new development of software-based farm management solutions for GIS encourage the automation of data collection and analysis of supervising, storing, decision making, and farm management.

7.4 Robotics and Autonomous System

Most recently, autonomous farming has involved a high degree of the use of robotics, sensors, drones, and remote sensing to perform various agricultural tasks, such as planting, spraying, harvesting, and weeding, while reducing labor costs and improving efficient decision making . RASs are a combination of emerging modern technologies that have key applications in both agricultural production processes and production patterns. Mobile robots equipped with various sensors, actuators, and ML algorithms are key enablers to automatically handle variability and uncertainty in farming practices. Key applications of RAS in agricultural patterns are in plant factories, 3D food printing, and biodiverse farming, whereas autonomous farming, aerial monitoring, and automated husbandry have become new applications in agricultural production processes. However, agricultural RASs are required to be improved to fulfill efficient work with accurate guidance, autonomous navigation, and accurate detection of dynamic agricultural environments (changing appearances, growth stages, weather conditions, object overlapping, etc.). Intelligent actions, such as robot-assisted plant phenotyping, fruit counting, fruit harvesting, fruit counting, leaf peeling, selective spraying, and 3D mapping, are demonstrated and currently employed applications of RASs (Fragassa et al., 2023). Auto-steered agricultural vehicles are also used in many field operations, such as tilling, planting, chemical applications, and harvesting. These machines, like harvesters, sprayers, tractors, planters, and mechanical weed controls, use guidance systems either with light bars or a GNSS (Chen et al., 20230. These guidance systems visualize the positions of equipment to prevent skips and overlaps, which is important in variable rate applications.

7.5 Telematics

Broadband connectivity is required when addressing challenges in the adoption, cost, and environment of smart technologies. Inadequate connectivity leads to inefficiencies, impacting machine downtime, human error, and real-time information availability. Limited connectivity not only affects profitability but also hampers the adoption of real-time-reliant precision agriculture. Producers with adequate connectivity are expected to be more efficient, highlighting the importance of connectivity in agriculture. The transformative potential of 5G and beyond mobile networks in driving business and societal change is being recognized. Considering environmental concerns and climate change, the role of mobile networks in fostering sustainability and innovation is questioned. Sectors like smart agriculture, forestry, biodiversity monitoring, and water management are crucial for sustainable resource utilization. Evaluating the capabilities of 5G and 6G networks, including current and future support, is essential for identifying use cases and the requirements in these domains . As an example, a study in Thailand designed telematics-equipped tractors to assist farmers in efficiently managing their machinery, optimizing performance and enhancing overall productivity. In addition to improved management capabilities, these tractors offered features such as theft prevention, effective maintenance monitoring, and machine operation tracking (Nootjaroen, 2020).

7.6 Role of Nano Technology in Precision Farming

Nanotechnology is a multidisciplinary field of research. Efforts have recently been made to increase agricultural yield through extensive nanotechnology research. Nanoparticles are adsorbed to plant surface and taken up through natural nanometer plant opennings. Several pathways exist or predicted for nanoparticles association and uptake in plants**(Figure 04).**The green revolution ended in the indiscriminate use of pesticides and chemical fertil- izers, resulting in the loss of soil biodiversity and the development of pathogen and pest resistance. Only nanoparticles or nano chips enable the delivery of materials to plants and the development of advanced biosensors for precision farming. Nano encapsulated herbicides, pesticides and conventional fertilizers helps in sustained. and gradual release of nutrients and agrochemicals resulting in accurate dosage to the plants. (Teodoro et al., 2010; Park et al., 2006)

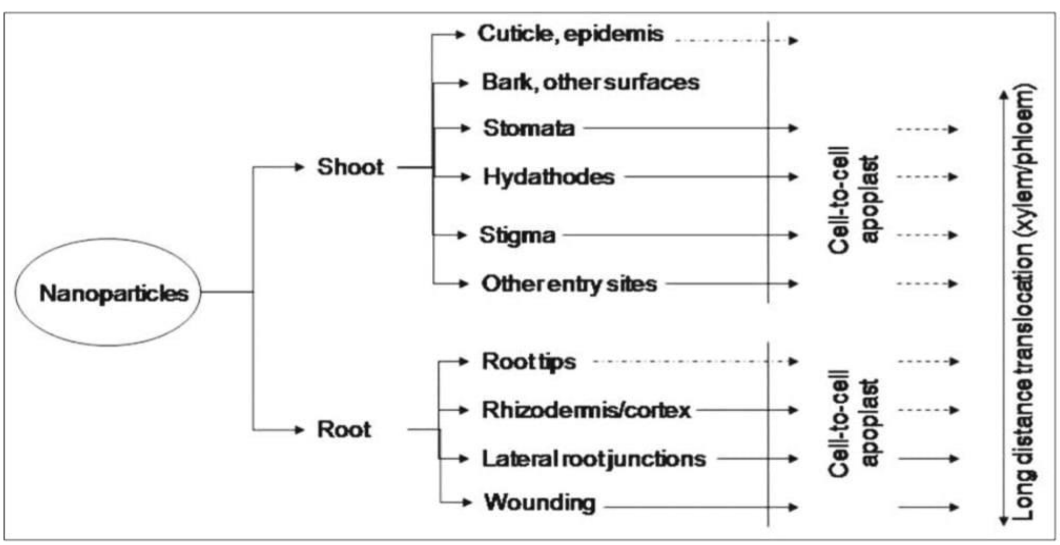

Figure 04. Uptake of nano-particles in plant system (Mahajan et al., 2011)

8. Renewable Energy in Agriculture

The sustainable energy approach promotes renewable energy in the agriculture sector, especially in remote or rural areas all over the world where solar energy is available in abundance (Patlitzianas et al., 2008).

Energy in agriculture is important in terms of crop production and agro-processing for adding value. Human, animal and mechanical energy is extensively used for crop production in agriculture. Energy requirements in agriculture are divided into two groups, being direct and indirect. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, interculture, threshing, harvesting, and transportation of agricultural inputs and farm produce. It is seen that direct energy is directly used on farms and on fields. Indirect energy, on the other hand, consists of the energy used in the manufacture, packing and transport of fertilizers, pesticides, seeds and farm machinery. As the name implies, indirect energy is not directly used on the farm. Calculating energy inputs in agricultural production is more difficult in comparison with the industry sector due to the high number of factors affecting agricultural production. However, a considerable number of studies have been conducted in different countries on energy use in agriculture (Omer, 2008; Baruah, 1995; Thakur and Mistra, 1993).

8.1 Types of Renewable Energy Sources

The various sources of energy, e.g. solar, wind, hydraulic, biomass, organic wastes, biofuels, and combined heat and power provide a simple, sustainable, effective solution for the conservation of valuable non-renewable fossil resources without resulting in environmental pollution.Solar energy can be utilized in its varied forms, e.g. solar PV, direct solar thermal, and renewable fuels and wind can offer the solution to the world’s energy problems and ultimately make the environment sustainable for future generations by reducing environmental pollution from fossil fuel energy usage. **Table 03** shows the sources of renewable energy in agricultural farms.

Energy source	Technology	Size
Solar Energy	Domestic solar water heaters	Small
	Solar water heating for large demands	Medium-large
	PV roof grid-connected systems generating electric energy	Medium-large
Wind Energy	Wind turbines (grid connected)	Medium-large
Hydraulic energy	Hydro plan in derivation schemes	Medium-small
	Hydro plan in existing water distribution networks	Medium-small
Biomass	High efficiency wood boilers	Small
	CHP plant fed by agricultural waste or energy crops	Medium
Animal manure	CHP plant fed by biogas	Small
Combined heat and power (CHP)	High efficiency lighting	Wide
	High efficiency electricity	Wide
	Householders' appliances	Wide
	High efficiency boilers	Small-medium
	Plants coupled with refrigerating absorption machines	Medium-large

Table 03. Sources of renewable energy in agricultural farms (Omer, 2008).

8.2 Solar Power

Solar technologies produce electrical or thermal energy. Photovoltaic (PV) cells (or "solar cells") that convert sunlight directly into electricity are made of semiconductors such as crystalline silicon or various thin-film materials. Solar thermal technologies collect heat from the sun and then use it directly for space and water heating or convert it to electricity through conventional steam cycles, heat engines, or other generating technologies (Concentrating solar systems). In the future, solar energy could produce hydrogen to provide transportation fuels, chemicals, and electricity, and to serve as energy storage at times when the sun is not shining .In agriculture, PV can economically provide electricity where the distance is too great to justify new power lines.

The second most widely used application of solar energy is to produce heat, which has applications for various agricultural processes as follows:

➤Drying crops and grains by simply exposing them to the heat of the sun is one of the oldest and most widely used applications of solar energy. But allowing crops to dry naturally in the field exposes them to the elements and contamination as well as birds and insects.

➤Modern solar crop driers are still very simple, but also more effective and hygienic. The basic components of a solar dryer are an enclosure or shed, screened drying racks or trays, and a solar collector. The collector can be as simple as a glazed box with a dark-colored interior to absorb the solar energy that heats air. The heated air in the collector moves, by natural convection or a fan, up through the material to be dried.

➤Another use of solar energy for higher agricultural productivity is water heating – particularly in livestock operations. If one is raising poultry, pens and equipment must be cleaned periodically. Simple solar water heaters are available to provide low to medium temperature hot water for this purpose. These systems require a solar collector, a storage tank, plumbing and pumps. Commercially available systems are widely available and offer simple installation. Cleanliness is essential in the case of processing poultry in farms. Again, a commercially available solar water heater can provide water at 60 ◦C in any amount needed. (U.S. Department of Energy,Office of Energy Efficiency and Renewable Energy, 2006).

8.3 Wind Energy

Wind technology harnesses kinetic energy from wind to generate mechanical and electrical power. Wind turbines convert wind into electricity and come in various sizes: utility-scale turbines range from 750 kilowatts (kW) to 5 megawatts (MW), often exceeding 1 MW and forming wind farms that supply power to the grid. Small wind turbines, ranging from 0.4 to 100 kW, serve applications from battery charging to powering homes and small commercial operations. Wind energy, a renewable source, produces no harmful emissions and is increasingly cost-effective, with U.S. installations generating 9,149 MW of capacity by 2005, equivalent to the annual electricity consumption of over 2 million households. Modern wind turbines can generate electricity competitively at a few cents per kilowatt-hour in high-wind areas. Small systems, crucial for agriculture, can provide mechanical energy or generate electricity efficiently, especially in remote areas without transmission wires, and can supplement other energy sources in hybrid systems. An estimated 60% of the U.S. is suitable for small turbine use, with 24% of the population in rural areas conducive to such installations. Advances in technology are likely to enhance the adoption of wind power in agriculture, reducing energy costs and increasing self-sufficiency (Bergey, 2000).

8.4 Biorefineries

Biorefineries, convert biomass into diverse products like liquid fuels (ethanol, biodiesel), electricity, steam, and high-value chemicals, aiming to enhance energy security and reduce emissions. Current examples include corn-based ethanol and wood-derived products, with future technologies focusing on breaking down plant cellulose for energy and industrial use. Two key processes are biochemical conversion (creating sugars from cellulose) and thermochemical conversion (transforming biomass into gas for fuel and products). Innovations in plant genetics are tailoring crops for biorefinery outputs. High-value bioproducts, like Toyota's bioplastics from sweet potatoes and DuPont's Sorona polymers from corn sugars, highlight the economic potential of biorefinery technology. The U.S. holds substantial biomass resources, particularly from forest and agricultural lands, which could provide 1.3 billion dry tons of cellulose annually with modest land-use adjustments. Municipal solid waste also offers significant biomass potential (Perlack et al., 2005)

9. Integration of Renewable Energy in Farming

The integration of renewable energy into farming practices represents a transformative shift towards smart agriculture real-world deployment **(Figure 05)**. Renewable energy sources like solar, wind, and biomass are increasingly being employed to meet the energy demands of modern farms, leading to reduced dependency on fossil fuels and minimizing environmental impacts. Solar power, for instance, can be harnessed through photovoltaic panels to provide electricity for irrigation systems, greenhouse heating, and even the powering of machinery. Wind energy, while traditionally used for mechanical tasks like pumping water, is now also being converted into electrical energy for broader farm applications. Biomass energy, derived from organic materials such as crop residues and animal manure, can be used for heating and electricity generation, contributing to waste reduction and energy efficiency on farms (Brown & Green, 2019).Solar energy can supply and/or supplement many farm energy requirements. The following are some applications of solar energy technologies in agriculture:

➤Crop and grain drying

➤Solar space and water heating

➤Greenhouse heating

➤Remote electricity supply through solar photovoltaics/wind

➤Solar water pumping in agriculture **(Figure 06)**

➤Generate energy on the farm: renewable fuels for transportation

➤Generate energy on the farm from cattle dung and human waste **(Figure 07)**

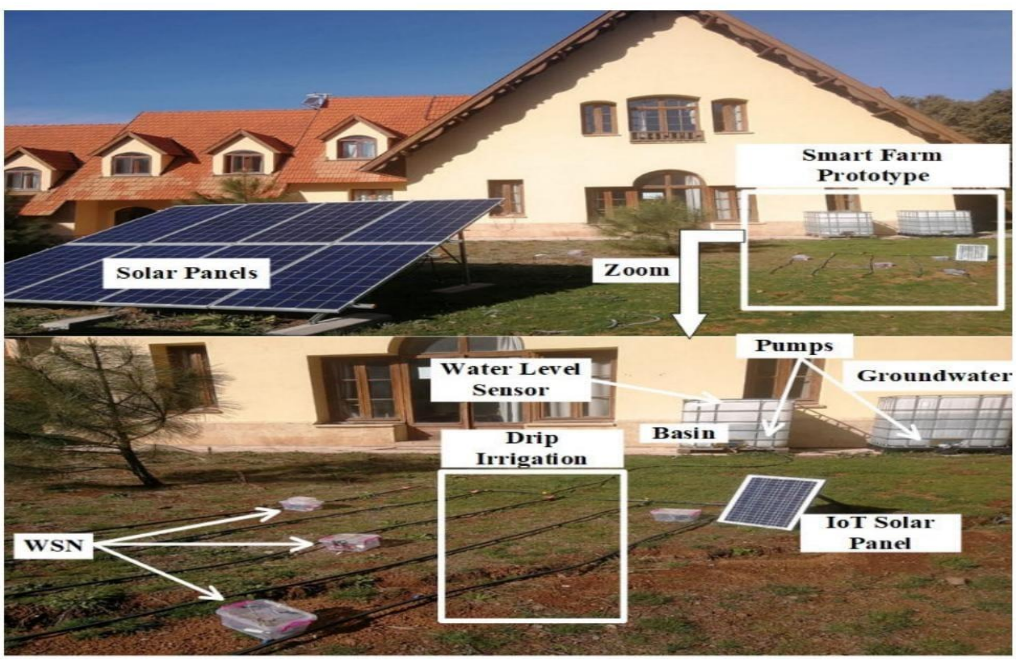

Figure 05. smart agriculture real-world deployment ( )

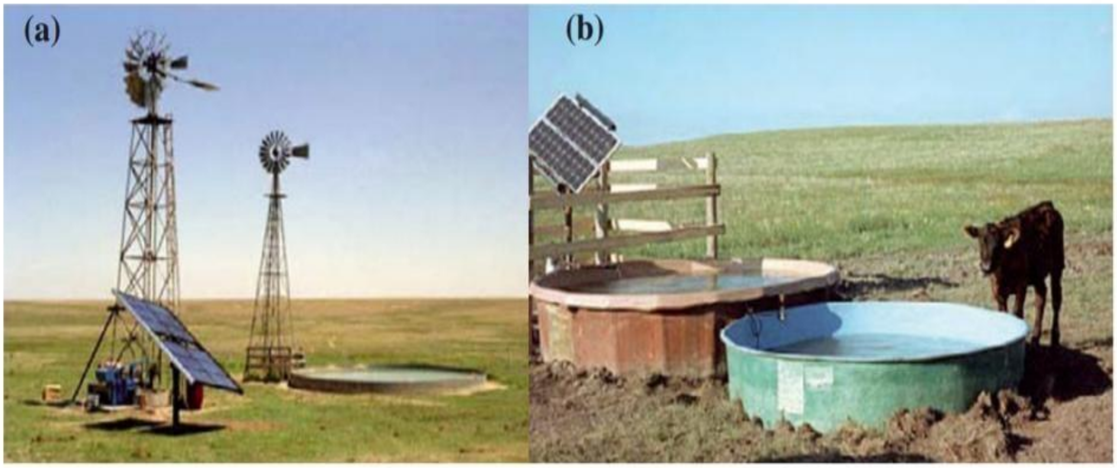

Figure 06. Solar water pumping: (a) PV windmill integrated water pump and (b) PV integrated water pumping application.

Figure 07. Generate energy from cattle dung and human waste ( )

10. Synergies Between Precision Agriculture and Renewable Energy

Precision agriculture and renewable energy intersect in ways that drive both sectors forward, fostering efficiency, sustainability, and economic viability. Precision agriculture employs advanced technologies such as, GPS-guided machinery, IoT sensors, and data analytics to optimize agricultural practices, enhancing crop yields while minimizing inputs like water, fertilizers, and pesticides. Renewable energy, on the other hand, provides clean power alternatives like solar, wind, and biomass, which are increasingly integrated into agricultural operations. The synergy between these fields is particularly evident in how renewable energy can support precision agriculture's needs for sustainable power sources. For instance, solar panels installed on farms not only generate electricity to power sensors, automated irrigation systems, and machinery but also contribute to reducing the carbon footprint of farming activities (Crabtree, 2021). Additionally, the data-driven nature of precision agriculture benefits from the decentralized and often off-grid nature of renewable energy sources. Wind turbines and bioenergy from agricultural waste can further complement precision farming by providing energy independence, thus reducing reliance on fossil fuels and enhancing the resilience of agricultural systems against energy price volatility (Richards, 2022). This integration also supports the concept of circular agriculture, where energy and resources are recycled within the farm system. For example, the use of bioenergy derived from agricultural residues helps close the loop on nutrient cycles, reducing waste and lowering greenhouse gas emissions. Moreover, the application of precision agriculture technologies can optimize the placement and management of renewable energy systems themselves. By analyzing topographical and climatic data, farms can determine optimal locations for solar and wind installations, maximizing energy production while minimizing land use conflicts. This integration promotes a sustainable model where technology not only aids in precision farming but also aligns with renewable energy objectives to create a resilient, low-carbon agricultural sector. In essence, the symbiosis between precision agriculture and renewable energy leads to a more sustainable and productive farming paradigm, addressing contemporary challenges such as climate change, resource depletion, and food security (Anderson, 2023). Synergies Between Precision Agriculture and Renewable Energy are shown in **Table 04.**

Sector	**Renewable Energy Source**	**Precision Agriculture**
Irrigation	Solar panels assembly	Fuzzy logic and cloud technology
	Solar Photovoltaic cells	Pump used for irrigation
Greenhouse management	Photovoltaic and wind	Wind-PV hybrid generation system, medeling, simulation and analysis.

Monitoring/ Regulating system	Solar-powered prototype nodes	Wireless sensor networks, internet of things (IoT)
	Photovoltaic centrifugal and positive displacement pump	Humidity sensor and global system for mobile(GSM) module
Drying	Solar	PCM(pulse-code modulation) integrated heat pump dryers
Seed sowing	Solar controller	Radio frequency based sowing machine

Table 04. Synergies Between Precision Agriculture and Renewable Energy (Chen et al., 2022)

11.2 Economic and Environmental Impacts of Innovative Farming

11.1 Cost-Benefit Analysis

The integration of precision farming and renewable energy into innovative farming practices has profound economic implications, fundamentally transforming traditional farming models. Precision farming, characterized by the application of technologies like GPS-guided machinery, remote sensing, and data analytics, enhances resource efficiency and crop yields. These technologies allow for site-specific crop management, optimizing inputs such as water, fertilizers, and pesticides, leading to significant cost savings and improved productivity.By reducing input costs and enhancing output through precise interventions, farmers can achieve better financial returns. The economic benefits of precision agriculture are multifaceted, including lower operational costs, increased yield quality, and reduced environmental impact, which collectively contribute to higher profitability and sustainability in agriculture (Zhang & Kovacs, 2012).

Renewable energy sources, such as solar, wind, and bioenergy, further augment the economic viability of innovative farming techniques. Solar panels installed on farms can provide a dual benefit by generating electricity for on-site use and reducing energy costs while also allowing for the possibility of selling excess energy back to the grid, creating an additional revenue stream. Similarly, wind turbines and biogas production from agricultural waste can supplement farm energy needs, contributing to energy cost reductions and enhancing energy security. The adoption of these renewable technologies not only mitigates the volatility associated with fossil fuel prices but also aligns with global sustainability goals, offering potential financial incentives from government subsidies and carbon credits (McKendry, 2002).

The economic advantages of integrating precision farming with renewable energy are underscored by the synergy between these technologies. For instance, the use of renewable energy in precision irrigation systems can significantly lower energy consumption and operational costs, maximizing the efficiency of water use while reducing dependency on conventional energy sources. Moreover, the data-driven insights from precision farming can inform better management of renewable energy resources, optimizing their use and minimizing waste. This integrated approach not only enhances farm profitability but also contributes to a resilient agricultural sector capable of adapting to market and environmental changes. Beyond direct economic benefits, precision farming and renewable energy contribute to broader economic development by fostering innovation and creating new market opportunities. The demand for advanced agricultural technologies and renewable energy solutions stimulates the growth of related industries, generating employment and investment in rural areas (Khanna, 2011). Furthermore, the increased efficiency and sustainability of agricultural practices can enhance food security and stability, indirectly supporting economic growth at a macroeconomic level (Tilman et al., 2011). The shift towards precision and renewable-integrated farming systems exemplifies a paradigm shift in agriculture, emphasizing economic sustainability alongside environmental stewardship.

11.2 Environmetal Sustainability

Its environmental benefits are significant and can help to protect our natural resources for future generations. As innovative farming technologies continue to develop, we can expect to see even greater environmental benefits in the years to come. A study by the American Farm Bureau Federation found that farmers who use precision agriculture technologies achieve the following environmental benefits:

➤ 4% increase in crop production.

➤ 7% increase in fertilizer placement efficiency.

➤ 9% reduction in herbicide and pesticide use.

➤ 6% reduction in fossil fuel use.

➤ 4% reduction in water use.

Here are some examples of how innovative farming techniques can benefit the environment:

Water Conservation

Water is a precious resource essential for sustaining life and supporting agricultural productivity. With growing concerns over water scarcity and the need for sustainable farming practices, it has emerged as a powerful solution. By leveraging advanced technologies such as sensors and data analytics, it empowers farmers to manage water resources more efficiently and responsibly.

Soil Health and Fertility

In recent years, it has emerged as a game-changer in the realm of sustainable farming practices. This innovative approach utilizes advanced technologies to optimize agricultural operations, leading to better soil health and increased productivity. One of its key aspect is the use of variable rate technology for fertilizers, enabling farmers to apply nutrients precisely where they are most needed.

Better Carbon Sequestration

Soil health is closely linked to carbon sequestration, the process by which carbon dioxide is absorbed and stored in the soil. Healthy soils have higher organic matter content, which enhances their carbon sequestration capacity. Its practices, particularly VRT for fertilizers, contribute to improved soil health by increasing organic matter content. This not only aids in mitigating greenhouse gas emissions but also helps in climate change adaptation by making soils more resilient to extreme weather events.

Reduced Chemical Usage

One of the most significant advantages of innovative farming is its role in minimizing the use of pesticides and herbicides, thus promoting environmentally friendly and sustainable farming methods.Its role in minimizing chemical use has been gaining momentum globally. According to the International Federation of Organic Agriculture Movements (IFOAM), its practices have contributed to a 20% decrease in pesticide usage on a global scale over the past decade.This trend is projected to continue as more farmers recognize the benefits of adopting its techniques for sustainable and environmentally responsible farming.

Biodiversity and Wildlife Conservation

As the world grapples with the challenges of agricultural expansion and wildlife conservation, its emergence brings hope for striking a harmonious balance between these seemingly conflicting interests. It, with its data-driven and technology-centric approach, has the potential to complement wildlife conservation efforts. By preserving natural habitats, promoting biodiversity, and protecting endangered species, it demonstrates its compatibility with sustainable land management practices.

12. Challenges and Barriers of Innovative Farming Techniques

Innovative farming techniques, such as precision agriculture, vertical farming, and hydroponics, face significant challenges and barriers despite their potential to enhance agricultural productivity and sustainability. A primary challenge is the high initial investment and ongoing costs associated with advanced technology and infrastructure, which can be prohibitive for small and medium-sized farms. Additionally, the complexity of these technologies demands specialized knowledge and skills, creating a steep learning curve for farmers who may not have access to adequate training or education (Carolan, 2020). Regulatory barriers also pose significant obstacles, particularly concerning the use of genetically modified organisms (GMOs) and the adoption of new agricultural inputs, which can vary widely across regions. Furthermore, the integration of innovative techniques into existing farming systems can be challenging due to the need for adaptation to local conditions, which may not always align with the standard practices developed in more controlled environments. Market acceptance is another hurdle, as consumers and retailers might be skeptical of non-traditional farming methods and products.Addressing these challenges requires a multi-faceted approach, including financial incentives, educational initiatives, regulatory reform, and public awareness campaigns to foster acceptance and adaptation of innovative farming techniques (Klerkx et al., 2017).

13. Conclusion

Precision agriculture, driven by cutting-edge technologies, represents a paradigm shift in modern farming practices. By integrating tools such as the Internet of Things (IoT), big data analytics, and machine learning, precision agriculture enables farmers to optimize resource utilization, reduce waste, and enhance productivity. The adoption of practices like variable-rate fertilization, automated irrigation, and crop health monitoring empowers farmers to make informed decisions at a granular level. Moreover, precision agriculture aligns seamlessly with the urgent need for environmental sustainability. It minimizes chemical inputs, reduces soil erosion, and conserves water, contributing to a healthier ecosystem. The use of GPS-guided machinery ensures precise planting and harvesting, minimizing the impact on surrounding habitats. Simultaneously, the integration of renewable energy sources such as solar-powered irrigation systems and wind turbines further enhances sustainability. These renewable energy solutions not only reduce dependence on fossil fuels but also offer long-term cost savings. As we face climate change challenges, embracing precision agriculture and renewable energy becomes crucial for a sustainable future in farming.

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