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Precision farming: Innovations, techniques and sustainability

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Abstract
Precision farming, also known as precision agriculture, has emerged as a transformative approach in modern agricultural practices. Its fundamental objective is to enhance efficiency, productivity, and sustainability by utilizing advanced technologies and data-driven methodologies. The need for precision farming has grown in response to the challenges posed by a rapidly expanding global population and the imperative to increase food production while minimizing the environmental footprint. This approach involves the precise application of resources such as water, fertilizers, and pesticides, tailored to the specific needs of different parts of a field. Sustainability lies at the core of precision farming, as it reduces wastage of resources, prevents overuse of inputs, and minimizes environmental contamination. For small-scale farmers, precision farming proves to be especially beneficial. It equips them with tools to make informed decisions, optimize resource allocation, and manage their land more effectively. Through targeted interventions based on accurate data, small-scale farmers can witness improved yields, reduced costs, and increased profitability. By embracing precision farming, these farmers not only can uplift their own livelihoods but also contribute to the broader goals of global food security and sustainable agricultural practices.

Keywords: Precision farming, sustainability, small scale farmers

Introduction

Agriculture meets the majority of human survival needs. The Green Revolution, or third agricultural revolution, of improved crop varieties, synthetic fertilizers, pesticides, and irrigation throughout the 1960s and 1980s increased crop yield and food security, particularly in poor countries. As a result, despite the fact that the world's population has doubled and food demand has tripled during the 1960s, global agriculture has been able to supply the need with only a 30% increase in cultivated area. Food and agricultural product consumption is expected to increase by more than 70% by 2050. The restricted amount of arable land, agricultural intensification, i.e. higher use of fertilizers, pesticides, water, and other inputs, will meet a large portion of this growing demand (Sishodia *et al*. 2020) [17].

However, increasing the use of chemicals such as fertilizers and pesticides would also degrade the ecosystem. Furthermore, as climate change causes unpredictable weather patterns and environmental concerns grow, precision agriculture enables farmers to better adjust and manage risks. It promotes sustainability by lowering the environmental impact of farming practices, conserving water, and reducing the use of chemicals. We need to implement a sustainable solution to lessen the environmental impact without losing crop yield.

Precision farming, also known as precision agriculture or smart farming, is a cutting-edge approach to modern agriculture that optimizes crop output and resource utilization through advanced technologies. It involves the exact monitoring and management of different aspects of farming, such as soil health, irrigation, pest control, and crop growth, using data-driven tools such as GPS, remote sensing, and artificial intelligence (Abit *et al*. 2018) [1]. Precision farming enables farmers to make informed decisions that maximize yields, eliminate resource waste, and minimize environmental impact by gathering real-time data and implementing personalized tactics.

This revolutionary strategy not only improves the productivity and profitability of farming operations, but it also contributes to sustainability initiatives by reducing agriculture's ecological footprint. Precision farming is an important step towards confronting the challenges of feeding the world's rising population while protecting the planet's natural resources. Precision farming holds great promise for small-scale farmers, providing them with a vital toolkit for increasing productivity and sustainability. While precision agriculture is frequently associated with large commercial operations, its concepts may be scaled down and altered to meet the specific demands and resources of smallholders.

Small-scale farmers can receive important data on soil health, weather conditions, and crop performance using low-cost technologies such as smartphone apps, drones, and low-cost sensors. This knowledge enables them to make more educated decisions, better allocate resources, and boost yields (Hakim *et al*. 2021) [6]. Small-scale farmers can cut input costs and minimize environmental effects by accurately adapting irrigation, fertilization, and pest management to their fields, thus boosting their economic viability. Furthermore, the knowledge and skills developed via precision farming can assist these farmers in adapting to climate change problems and achieving sustainable agricultural practices, assuring their long-term resilience and food security.

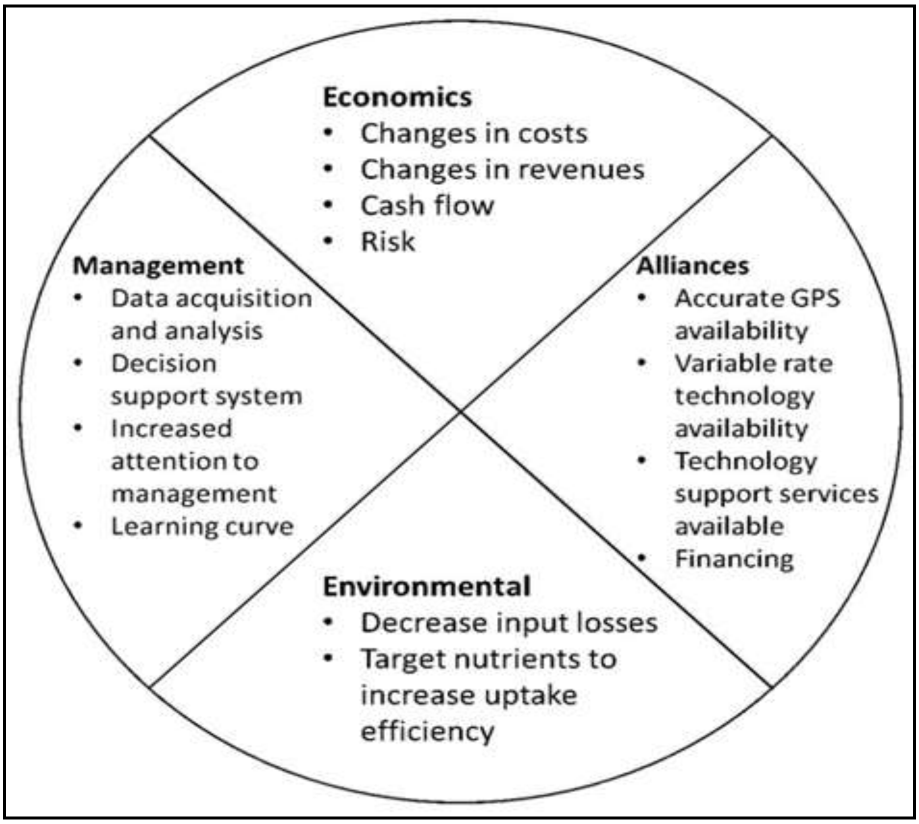

Fig 1: Issues affecting adaptation to precision farming (Kent Shannon *et al*. 2018) [8]

Need of Precision Farming

The ‘Green Revolution’ during 1960s-1980s promoted the use of improved crop varieties, synthetic fertilizers to enhance crop productivity. There’s no doubt that it made our country self-sufficient in food production. Indiscriminate use of different types of chemicals on the soil has led to the degradation of natural resources. The status of the Indian environment shows that, in India, about 182 million ha of the country’s total geographical area of 328.7 million ha are affected by land degradation; of this, 141.33 million ha are due to water erosion, 11.50 million ha are due to wind erosion, and 12.63 and 13.24 million ha are due to water logging and chemical deterioration, respectively (Shanwad *et al*. 2004) [16]. Therefore, we need to adopt a sustainable way of producing crops.

Scopes of Precision Farming in India

Precision farming is divided into two types: 'soft' and 'hard' (Mondal & Basu *et al*. 2009) [12]. It can be stated that the balanced application of soft and hard PA will determine its performance in India. Farmers' field sizes are the biggest impediment to precision farming implementation in India. Although the majority of Indian farmers have small and marginal land holdings, they have been using soft precision farming methods for decades. Today, India is self-sufficient in food production, but quantity alone is insufficient to compete in the global market. Excellent quality and high output will be the essential factors in competing with others, and precision farming has a wide scope in this area (Mondal & Basu *et al*. 2009) [12]. The proper amount of nutrient application is required to boost quality and quantity. However, due to the old method of soil sampling, nutrient administration in the fields is incorrect. Remote sensing and GIS technologies, for example, have the potential to significantly improve this area. 20% of the land area in states such as Punjab, Haryana, Rajasthan, and Gujarat are larger than 4ha. These locations can be exploited for precision farming applications in India.

Technologies involved in precision farming

- **GIS (Geographic information systems):** GIS are computer hardware and software systems that produce maps by combining feature attributes and location data (Brase 2018) [2]. Computerized GIS maps differ from traditional maps in that they include information such as yield, soil survey maps, rainfall, crops, soil nutrient levels, and pests. GIS is a type of computerized map, but its true function is to examine characters and geography using statistics and spatial methodologies. Later on, this information can be applied to various managerial practices. GIS determines crop requirements, allowing for more efficient resource usage.
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1. Work in low visibility field situations such as rain, fog, and dust.
2. Locate their machines in an instant.
3. Crop conditions can be monitored without having to visit the field for a short period of time.
4. Navigate to the desired place to collect soil samples.
5. Locate the pest and weed infestations as soon as possible so that control practices can be applied.

The GPS data can be utilized to guide aerial sprayers in spraying different chemicals in the field in a short period of time, reducing the need for human labor and saving time, cash, and human effort.

- **Drones:** Drones are used to spray various chemicals (insecticides, pesticides, herbicides) and fertilizers as well as monitor crop yields in the field using GPS and GIS data. They can deliver the correct amount of chemicals in a short period of time. Applying the appropriate number of pesticides and fertilizers decreases costs and environmental risks.
- **Variable Rate Technology (VRT):** Several variable rate technologies are employed in precision farming, some of them are as follows:

1. Variable rate seeding (VRS) - Variable rate sowing is a technology that adjusts the seed rate based on the soil parameters (soil texture, soil water, and nutrient content) of a specific location in order to maximize seed germination, crop growth, and yield.
2. Variable rate chemical applicator - A variable rate chemical applicator guarantees that the correct amount of chemicals is administered to the field, saving time and money while maintaining crop and soil health.

Precision irrigation technology: New advances in sprinkler irrigation are being introduced for commercial usage by managing the irrigation machines' movements with GPS-based controllers (Hakkim *et al*. 2016) [7].

1. This technology has several advantages, one of which is that it reduces water waste caused by over-irrigation.
2. Weed populations can be controlled because a limited amount of water is delivered around the plant, preventing weeds from growing.
3. Less weed infestation leads to higher agricultural output.

- **Remote Sensing:** Remote sensing is the collection of data via sensors mounted on satellites or aircraft, which is subsequently utilized for soil mapping, identifying crop water stress, crop nutrient stress, crop diseases, and so on. These details can be used in management practices of soil and crops.
- **Grid Sampling:** Grid sampling divides the entire field into smaller pieces. Soil sampling inside these sections aids in determining the actual nutrient content of the soil as well as the field's actual fertilizer demand.
- **Yield monitoring and mapping:** During harvesting, certain characteristics such as grain moisture content, grain flow, grain volume, and so on are measured using sensors and recorded using geo-spatial tools; these measurements are then utilized to build maps. When maps are made year after year, farmers can compare their output and make informed decisions. When used correctly, yield data provides critical feedback in identifying the effects of fertilizer, lime, seed, pesticides, and cultural practices such as drainage, irrigation, and tillage. (Kent Shannon *et al*. 2018) [8].
- **Crop Scouting:** It is the process of monitoring crop conditions such as weed and pest infestation, crop nutrient and water requirement status, and crop nutrient and water requirement status using a GPS receiver on a piece of equipment that may mark the specific location and make it easy to return to the same spot for management practices. These data can then be utilized to explain yield fluctuations.
- **Data management:** the adoption of precision agriculture necessitates the development of management abilities as well as relevant information databases. The effective use of information allows farmers to have clear objectives and make sound decisions. Effective information utilization necessitates an entrepreneurial mindset and a willingness to explore.

Agronomic inputs of precision farming

- **Fertilizers:** Nowadays, practically all farmers utilize fertilizers in crop production. However, the majority of them apply the incorrect quantity of fertilizer to their fields, which hurts the crop and diminishes soil health. As a result, it is critical to apply the proper source of fertilizer at the right time and at the right rate in order to improve soil fertility, increase crop productivity, and save money.
- **Pesticides:** Using pesticides at the incorrect rate might have a harmful influence on crops. If pesticides are used at a lower rate than desired, insect control will be challenging. On the other hand, if we use pesticides at higher rates than necessary, it would harm the crops and diminish
- **Seeds:** Genetic advancements have been connected to increased water use efficiency, the production of transgenic crops, and the development of plant cultivars that allow for higher fertilizer rates (Kent Shannon *et al*. 2018; Lee & Ehsani *et al*. 2015) [8, 9]. Genetically modified seeds are more resistant to harsh environmental stress and have higher yielding characteristics than conventional seeds, resulting in higher profits for farmers.

Present scenario of precision farming in India

Even though precision farming is certainly a superior alternative to traditional farming, it i still in its early stages in India due to the following factors:

1. Most farmers in India have tiny or marginal land holdings that are unsuitable for adopting precision farming.
2. A lack of competence, information, resources, and direction.
3. Farmers' lack of risk-taking abilities

ISRO's Space Application Centre, working together with the Central Potato Research Institute in Shimla, has launched a project to investigate the use of remote sensing in precision farming. Precision agriculture research has already begun at many Indian research institutes. The Space Application Centre (ISRO) in Ahmedabad has begun an experiment at the Central Potato Research Station farm in Jalandhar, Punjab, to investigate the function of remote sensing in mapping variability in space and time. The M.S. Swaminathan Research Foundation, Chennai, has selected a hamlet in Tamil Nadu's Dindigul district for a variable rate input application in partnership with NABARD.

The Indian Agricultural Research Institute has devised a strategy to conduct precision farming trials on the institute's farm. PDCSR, Modipuram and Meerut (UP), in partnership with the Central Institute of Agricultural Engineering (CIAE), Bhopal, also pioneered variable rate input application in several cropping systems. Precision farming may enable Indian farmers to reap the benefits of frontier technology without compromising land quality in the next few years (Shanwad *et al*. 2004) [16].

Adoption of precision farming on small farms

Small-scale farmers are often worse off than large holdings due to fewer economies of scale, smaller collateral value, which may limit their financing options, and so on (Mizik 2023) [11]. Because their land holdings are low, their output is minimal, resulting in little cash generation. Because of their low-income generation, they lack the capital needed to apply precise agriculture technologies. Because of their low land holdings, they cannot afford the operational cost per production unit even if they purchase any of the precision farming technologies.

However, precision farming can now be a modular system that allows small-scale farmers to implement precision farming technologies into their fields in stages based on their financial situation and demands. Adoption of precision farming on small scale farms is mostly determined by the people who will run these technologies, their reputation, functionality, and price, as well as the efficiency of these technologies, which will increase production. However, affordability is critical for small farmers, who suffer numerous financial constraints as a result of limited income generation (Mizik 2023) [11].

Although there are various challenges to precision farming application in small scale farms. However, other authors all around the world have proposed various solutions. (Soto *et al*. 2019) [18] studied 971 farmers from five European countries: the United Kingdom, Germany, the Netherlands, Greece, and fornment policies, advisors influence precision farming uptake among precision farming adaptors. (Takácsné György *et al*. 2018) [19] investigated the adoption of precision farming in Hungary and concluded that updating current machinery rather than purchasing new machinery would be more beneficial. This would dramatically boost output in small-scale farms.

(Oliveira-Jr *et al*. 2020) [14] proposed an Internet of Things (IoT) sensing platform for small farmers that is inexpensive, has widely available components, and can be administered using a smartphone. This represents the trade-off between price and quality. However, (Onyango *et al*. 2021) [15] stated that the implementation of precision farming is hampered by a lack of electricity and network connectivity. As a result, (Mehrabi *et al*. 2021) [10] recommended the following: policy initiated and/or supported infrastructure investments; affordable handsets and reduced device costs; available and affordable Internet access for farmers funded by various institutions; and solutions between low- and high-level services.

Small and marginal farmers can adopt precision farming in a variety of ways, including merging their farms and pooling their resources to cover the costs of implementation. Farmers can rent rather than purchase certain precision agricultural inputs. National agriculture policy has a significant impact on precision farming adoption. Precision farming, in addition to possible environmental benefits, can contribute to improved competitiveness and profitability of small and medium-sized farms, owing to increased efficiency; thus, agricultural policies should promote collaborative activities (Vecchio *et al*. 2020) [20].

Experiments for adoption of precision farming in small scale farms

Precision farming can indeed be adapted for small-scale farming operations, offering numerous advantages despite limited land and resources. To implement precision farming at a smaller scale, farmers can start by leveraging affordable technology solutions such as handheld GPS devices and mobile apps for field mapping and data collection. These tools enable precise delineation of small plots and recording key information about soil quality, nutrient levels, and crop health. By integrating this data, farmers can make informed decisions about fertilizer application, irrigation, and pest control, tailoring their actions to specific areas within their fields. Additionally, adopting low-cost sensors for monitoring environmental conditions like moisture levels and temperature can provide real-time insights, aiding in optimizing irrigation and minimizing water wastage. Furthermore, small-scale farmers can explore community-based initiatives or cooperatives to share the costs of more advanced precision equipment and expertise. Ultimately, implementing precision farming on a smaller scale empowers farmers to enhance productivity, reduce input costs, and improve overall sustainability while adapting to the unique challenges of their operations.

In a series of studies, (Zha *et al*. 2019) [21] developed a satellite-based yield model in China, delineating management zones at the village level to optimize resource utilization and enhance farmers' profits. Similarly, (Cammarano *et al*. 2020) [3] introduced a satellite-based yield model focusing on a limited number of management zones instead of numerous small fields, aiming for greater benefits. (Dobermann *et al*. 2002) [4] emphasized the significance of site-specific nutrient management based on extensive farm experiments conducted at 179 Asian locations. (Natcher *et al*. 2016) [13] highlighted the prevalence of fertilizer micro dosing in Sub-Saharan African countries due to the high cost of fertilizers, often applied at one-fourth of the recommended dose but proven effective when applied correctly. Lastly, (Godwin *et al*. 2003) [5] conducted a comparative analysis of the costs and benefits of various precision farming technologies across the UK, finding that basic systems become feasible at 78 hectares, while the most expensive systems require 308 hectares to justify their investment.

Challenges ION precision farming

Precision farming cannot be implemented in small fields. In India, most farmers have small or marginal land holdings (≤ 4ha) which restricts the promotion of precision farming. Due to cropping system variability in most of the small and marginal land holdings, the common recommendation for precision farming cannot be adopted. However, in four states, namely Punjab, Haryana, Rajasthan and Gujarat, 20% of their land area is greater than 4 ha which can be used for the implementation of precision farming. There is scope for implementing precision farming for major food grain crops such as rice, wheat especially in the states of Punjab and Haryana. However, many horticultural crops in India, which are high profit-making crops, offer high scope for precision farming (Shanwad *et al*. 2004) [16].

Precision farming, while promising, faces several significant challenges that must be addressed for its widespread adoption and success. First, the initial cost of implementing precision farming technologies can be prohibitive for many farmers, particularly those with limited resources. The need for specialized equipment, software, and training can create financial barriers. Additionally, the rapid pace of technological advancements in precision farming can make it difficult for farmers to keep up with the latest developments and select the most appropriate solutions for their specific needs. Data management and privacy are also critical concerns. Gathering and analyzing vast amounts of data from sensors, drones, and satellites requires robust data infrastructure and security measures. Farmers must grapple with issues related to data ownership, sharing, and protection. Furthermore, the digital divide poses a challenge, as not all farmers have equal access to the internet and technology. Bridging this gap is essential to ensuring that precision farming benefits all segments of agriculture, including small-scale and resource-limited farmers. Environmental sustainability is another challenge, as the increased use of technology can inadvertently lead to greater energy consumption and electronic waste. Balancing the environmental benefits of precision farming with its potential drawbacks is crucial. Finally, there is a need for education and training to help farmers acquire the skills and knowledge required to effectively implement precision farming practices. Overcoming these challenges is essential to realizing the full potential of precision farming in addressing global food security and sustainability.

- Precision farming requires high capital expenditures at the initial stage.
- Lack of skill and knowledge in precision farming among farmers.
- Precision farming cannot be implemented in small fields. In India, majority of farmers have small or marginal land holdings.
- Precision farming technologies are still under development.
- Farmers usually do not prefer to shift from traditional farming to precision farming.

Conclusion

Precision farming uses modern technologies for applying resources in the fields which promotes sustainability, saves time, capital and increases the production which ultimately brings more profit to the farmers. Today we are self-sufficient in food production. But we need to improve the quality of our production. To improve the quality, we need to adopt modern technologies in farming that can promote sustainability without compromising the quality and quantity. At present most of these technologies are only being used at their initial level and the prices of the inputs are very high which makes it unaffordable for the small and marginal farmers. There is an urgent need to use these technologies at their best and make it available at the ground level to maximize the crop production while maintaining sustainability.

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