AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 05 (May, 2026)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Precision Farming -A Novel Approach for Sustainable Agriculture

***Komal[1], Virendra Singh[2] and Meetha Lal Meena[2]**
[1]M.Sc. (Agronomy), D.S. Educational Institute, Iradat Nagar, Agra, India
[2]R.B.S. College Bichpuri Agra, Affiliated with Dr. Bhīmrao Ambedkar University, Agra-283105 (U.P.), India
*Corresponding Author's email: komaldhatterwal2@gmail.com

The chapter on "Precision Farming" highlights the critical need for a major paradigm shift in Indian agriculture, driven by shrinking land resources and a rapidly growing population. It underscores the urgency of enhancing productivity on existing arable land and intensifying cropping practices. The author points out that the current subsistence-based agricultural model fails to maximize resource potential, thereby restricting optimal crop yields. To address these limitations, precision farming is introduced as an innovative production strategy. By meticulously managing the spatial variability of soil, this approach aligns input application directly with specific soil conditions and crop requirements—effectively minimizing waste, improving resource efficiency, and preserving environmental integrity.

Introduction

In light of India's diminishing land resources juxtaposed with its burgeoning population, a significant paradigm shift in agriculture is imperative. India commands a mere 2.2% of the global land area yet bears the weight of 17.6% of the world's population. This incongruity underscores the pressing need to enhance the productivity of existing arable land and intensify cropping practices. Presently, Indian agriculture predominantly operates under subsistence conditions, constrained by limited land and resources. Consequently, the full potential of these resources remains largely untapped, hindering the attainment of higher yields. While the advent of green revolution technologies, such as improved seeds and fertilizers, sparked a remarkable surge in production and productivity during the early sixties, this growth has since plateaued or even regressed. Various factors contribute to this stagnation, including imbalanced fertilizer usage, prolonged monocropping, emergence of new pests and diseases, dwindling soil organic carbon, salinization from excessive irrigation, and groundwater depletion. Consequently, the current agricultural model falls short of embodying sustainability principles.

Definition of precision agriculture

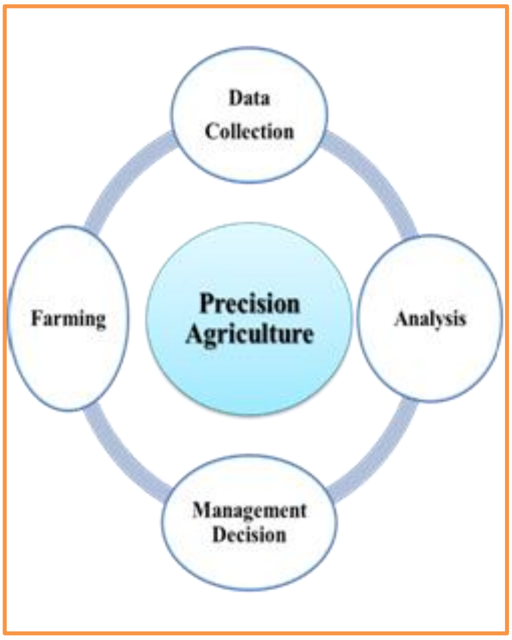
Precision agriculture, also known as smart agriculture, is an agricultural management concept that utilizes information technology to improve the quality and quantity of agricultural products while minimizing environmental impact.

- In the past, it was difficult for researcher to correlate production techniques and crop yields with resource variability.
- Precision agriculture is an integrated information and production based Farming system that is designed to increase long term, site specific and whole tams production efficiency, productivity and profitability while minimizing. unintended impacts on and the environment.

What is Precision Agriculture

Precision agriculture is the form of farming where site-specific management practices are adopted paying due to consideration to the spatial variability of land to maximize crop production and minimize cost of production with least environmental damage. **Father of Precision farming Prof. Pierre C. Robert.** Precision agriculture (PA) is the science of improving crop yields and assisting management decisions using high technology sensor and analysis tools. PA is a new concept adopted throughout the world to increase production, reduce labor time, and ensure the effective management of fertilizers and irrigation processes. In recent years, a novel production approach known as precision farming has gained traction, offering an enhanced management strategy that targets inputs precisely: applying them at the right place, time, and dosage rather than uniformly across vast areas. The primary objective of precision farming, particularly concerning cropping, is to align resource application and agronomic practices with the specific soil conditions and crop needs. This methodology essentially revolves around the meticulous management of spatial variability inherent within the soil.

Precision farming system aligns the availability of resources with the capabilities of the crop while leveraging insights into soil spatial variability. Enhanced agro-ecological characterization and the development of models for technology transfer, utilizing comprehensive soil and agro-climatic data, are crucial elements for advancing precision farming. Moreover, precision farming encompasses practices aimed at enhancing the efficiency of external inputs, such as seeds, fertilizers, and irrigation, by tailoring their application to meet specific crop requirements and agro-ecological conditions. By doing so, precision farming minimizes resource wastage and upholds environmental integrity. Precision farming, also known as site-specific farming, endeavors to apply management inputs at a finer spatial scale, primarily determined by economic and technical considerations. As the spatial scale increases, the challenges associated with understanding and modeling behavior become more intricate. Consequently, it becomes imperative to identify a practical optimum scale of operation within the field that can be effectively managed using available technology. Hence, precision farming encompasses the following key steps: (Searcy, 1994).



1. Assessing within field variation at an appropriate spectral scale.
2. Managing variability.

Why is precision agriculture?

- The primary goal of precision agriculture is to improve efficiency, sustainability, and productivity in agricultural operations.
- **Resource Efficiency:** Precision agriculture enables farmers to use resources such as water, fertilizers, pesticides, and energy more efficiently.
- **Yield Optimization:** Through the use of technologies like GPS, drones, and sensors, farmers can gather detailed data about their fields, including soil characteristics and crop health.
- **Environmental Sustainability:** Precision agriculture practices help minimize the environmental impact of agriculture by reducing chemical runoff, soil erosion

Objectives of Precision Agriculture

- **Optimizing Resource Use:** Precision agriculture aims to maximize the efficiency of resource utilization, including water, fertilizers, pesticides, and energy.
- **Improving Crop Quality**: Precision agriculture enables farmers to monitor crop health and quality more closely, leading to improved crop uniformity, flavor, and nutritional content.
- **Reducing Environmental Impact**: Precision farming aims to minimize the environmental footprint of agriculture by reducing chemical runoff, soil erosion, and greenhouse gas emissions.
- **Facilitating Data-Driven Decision Making:** Precision agriculture emphasizes the use of data analytics and decision support systems to inform management decisions.

Precision agriculture in developed countries:

The primary focus of precision farming lies in addressing the inherent variability found in crop and soil properties within fields, a phenomenon that is systematically identified and mapped. Precision farming technology is specifically designed to manage the spatial variability in crop production by regulating cropping operations based on maps or their derived data. Thus, the overarching goal of precision farming revolves around optimizing operations within temporally distinct and spatially variable crop production systems.

Mapping programs

The generation of maps of crop or soil properties is the first and most important step in precision farming. These maps allow the spatial variability to be appreciated and provide the basis for spatially variable control of the crop production. The mapping operation can be classified into

- Remote sensing
- Field mapping
- Manual mapping.

Remote sensing

Remote sensing in precision agriculture Satellite-based remote sensing technologies are widely used to guide the global agricultural production from a regional to global scale. There have been several efforts to use remote sensing to monitor crop conditions and utilize the indicators in process-based crop growth models to generate production estimates. The processes are slow, suitable for assessment over a large region, but not useful to a small farmer, and making it near real-time is a challenge. India has a series of operational satellites with varying spatio-temporal and spectral resolution addressing these requirements. Most of the remote sensing technologies are confined to multispectral broad bands, which have limitations for precise quantitative estimation of soil and plant properties primarily because of the low spectral resolution. Hyperspectral remote sensing is based on an examination of many contiguous narrowly defined spectral channels. It is a relatively new field and offers several advantages over the conventional broadband multispectral remote sensing.

In India, the requirement for a marketable remote sensing technology for precision agriculture is the delivery of information with the following characteristics: low turnaround time (24-48 hr), low data cost (~ 100 Rs./acre/season), high spatial resolution (at least 2 m multi-spectral), high spectral resolution (<25 nm), high temporal resolution (at least 5-6 date per season), and delivery of analytical products in simpler format. Remote sensing with high spectral and spatial-temporal resolution has considerable potential for soil and crop health monitoring, site specific nutrient management, discerning composite biotic and abiotic stresses and their levels for timely and precise application of inputs. (Birthal and Malavika, 2022).

A diverse array of sensors is deployed to capture crop and soil properties accurately. Mapping endeavors rely on precise locators to definitively establish the geographical coordinates of the measured quantities. The predominant method in spatially variable crop production is leveraging the Global Positioning System (GPS), notably differential GPS

(DGPS). Additionally, computer systems play a pivotal role in recording and storing both sensor measurement data and location information. In theory, these data types could be stored on separate computers and merged during the mapping process. (Mutta, D. J. 1993).

Control programme

Maps serve as crucial documents detailing the spatial variability within fields. Field operations are often meticulously controlled to either mitigate or capitalize on this variability, responding to differences in soils, crops, or pest pressures. A common response to variability involves controlling fertilizer application, although soil type and topography maps may inform decisions regarding pesticide application, tillage, irrigation, or planting, depending on agronomic considerations. Similarly, maps depicting crop yield, size, or color can prove invaluable. For instance, remote sensing maps detecting crop stress can guide spatially variable interventions, provided the cause of stress can be identified. Operations such as patch spraying, variable irrigation, or nitrogen side-dressing can be guided by such information. Pest infestation maps are also valuable for targeted application, with patch sprayers leveraging these maps effectively. Additionally, herbicides can be strategically added at required locations during fertilizer application.

Necessary technical capabilities:

1. The control of field operations in a spatially variable manner, such as controlling fertilization, pesticide application, irrigation, tillage, or planting, is essentially the reverse of the mapping operations. A map in a computer is used to control of the actuation of some piece of field equipment will need the following items:

- Control Computer
- Locator
- Actuator

Control computers play a pivotal role in orchestrating field operations. Equipped with maps detailing desired activities relative to geographic locations, these systems receive real-time location data from the Locator. Based on the map stored in memory or data storage, the control computers make decisions regarding the appropriate actions to take. Subsequently, commands are issued to the Actuator. It is crucial to design mechanical equipment with a focus on enhancing dynamic response to minimize potential inaccuracies. Immediate availability of accurate location data is imperative. The commands from the Control Computer are translated into changes in equipment action, typically involving the conversion of electrical signals into displacement or force. Electro-hydraulic or electromechanical systems are commonly employed for this purpose, ensuring swift and precise action by the actuator system.

Contemporary situation

Spatially variable crop production has become a commercial reality in the USA, with soil fertility maps serving as essential guides for chemical fertilizer application. Typically derived from intensive soil sampling and laboratory analysis, these maps are widely utilized in agricultural practices.

However, ongoing debates revolve around the incorporation of additional knowledge such as topography and soil type into sampling and map generation processes, as well as the economic justification for varying sampling intensities. Commercially available controllers enable the adjustment of planting population, while advancements have led to spatially variable control of planting variety and depth. Anticipation surrounds the development of new and more accurate sensing methods for soil, crop, and pest conditions. The proliferation of data communications and networking is facilitating the integration of all farm maps, controllers, and computers into wireless networks. Competition among one-meter resolution satellites and the expanding internet network is expected to provide cost-effective remote sensing data rapidly to farms. Improvements in locator accuracy are anticipated to make widespread controlled traffic a reality. Real-time sensors are envisioned to measure current crop conditions and soil nitrate levels, adjusting nitrogen application accordingly based on algorithmic analysis of map data. It's worth noting that spatially variable crop production can also be achieved through non-electronic means. (Stafford, 1996).

Precision Farming under Indian Context:

Site-specific Nutrient Management (SSNM) utilizes soil test-based fertilizer recommendations as a valuable tool for prescribing location-specific fertilizer schedules across larger areas, typically at the district or state level. Utilizing measured grain yield as a criterion for delineating management zones holds significant promise. A pragmatic approach to field division based on productivity involves measuring **grain yield** variation across the field and subsequently devising a stratified random sampling strategy to assess soil fertility in low, medium, and high-yielding regions before seeding for the upcoming growing season.

Organic matter content: Based on the average soil properties measured within each organic matter management zone, a tailored set of recommended rates for nitrogen (N) and phosphorus (P) can be formulated. Given the relative ease of determining soil organic matter content, organic matter serves as a practical criterion for delineating spatial patterns in crop productivity and soil fertility. However, the effectiveness of site-specific management of nitrogen, phosphorus, and potassium (NPK) hinges upon accurate knowledge of the yield response function at the required spatial resolution. Due to the susceptibility of mineral nitrogen to leaching, denitrification, or immobilization, optimizing the nitrogen rate is essential for each growing season. Conversely, the application of phosphorus and potassium can be guided by the principles of replacing harvested phosphorus and potassium, as soil-available levels of these nutrients change slowly over time. Dawson C. J. (1996).

Site-Specific fertilization of phosphorus and potassium

The principle of site-specific fertilization with phosphorus (P) and potassium (K) relies on straightforward nutrient balances. Typically, agricultural soils with adequate soil fertility contain sufficient nutrient reserves to replenish what is extracted by crops, ensuring long-term soil fertility retention. Yield maps, generated by modern combines, offer insights into the previous year's crop performance. As there exists a strong correlation between yield and plant uptake, these maps facilitate the calculation of site-specific P and K uptake from the previous growing season. By integrating site-specific soil supply, determined through soil analysis, a tailored application map for P and K fertilization can be derived. (Dawson and Johston, 1997).

Site-specific Nitrogen fertilization

The nitrogen cycle's complexity renders a simplistic nutrient balance inadequate for calculating nitrogen fertilization quantities. Relying solely on a yield map for such calculations is not feasible. Instead, various components of the nitrogen cycle, alongside factors such as water balance, local weather conditions, soil characteristics, crop type, and management practices, must be considered to accurately determine real-time nitrogen application rates.

Use of crop simulation models to determine optimum management practices in precision farming

An alternative, and potentially complementary, approach involves the use of crop simulation models. These models provide a cost-effective means of leveraging agronomic knowledge derived from numerous precision experiments, typically conducted on small and relatively homogeneous plots, to larger, spatially variable fields. Utilizing a crop simulation model, one can determine yield and fertilizer response curves across a spectrum of incident solar radiation levels, which may vary due to factors like slope and aspect within an average field. Optimization techniques are then employed with this data to generate recommended fertilizer doses for each area of the field, based on two primary objectives: maximizing yields for a given fertilizer input or minimizing fertilizer usage without sacrificing overall yield.

Minimum data set required for simulation

The data requirements for crop modeling vary depending on the intended purpose of the model. Models may be utilized for long-term management decision-making, model development, or model testing. For testing a model for long-term management decision-making, the minimum required data includes:

Meteorological

For testing a model for long-term management decision-making, the essential data includes:

- Daily maximum and minimum temperatures
- Precipitation
- Solar radiation (sunshine hours)
- Wind speed and direction
- Humidity

Soil

SMSS-SCS characterization entails measurements of water content, NO3, NH4, and extractable P. These measurements are to be taken once around planting time, delineated by layer. The top layer should not exceed 15 cm, with subsequent layers extending to 30 cm depth, drawn to a maximum depth of 2 meters or bedrock.

Crop

Key parameters for crop modeling include yield components, timing of phenological events, and dry matter as well as NP (nitrogen and phosphorus) contents of plant parts.

Timing of measurement

At harvest, around flowering.

Management: All management interventions must be meticulously recorded, encompassing details such as the date, depth, and implementation of tillage; the date, rate, depth, and pattern of sowing; the date, rate, and method of irrigation; the date, rate, depth, method, and product used for fertilization, pesticides, and herbicides; as well as the date of harvesting.

Pest Damage

- Pest damage should be estimated, at least qualitatively.
- The steps in assessing and managing variability for initiating precision farming are enumerated briefly:

A. Assessing soil spatial variability

Step-I: Grid size identification/standardization

a. Selection of the most important soil/plant factors such as pH, organic matter, yield that reflect spatial variability.

b. Performing variability analysis using geo-statistics/statistical techniques
c. Grid size with least variability will be considered as the standard grid Size.

Step-2: At each identified grid, soil and plant samples will be collected to measure the most intrinsic soil physico-chemical properties influencing yield.

d. Identification of rapid method of measuring soil properties

Step-3: Preparation of GIS maps of soil and yield variability

e. Overlay analysis of variability maps (Intrinsic soil properties, yield, moisture etc.)
f. Identification of important soil/plant factors responsible for yield variability.

B. Managing soil spatial/Yield variability

We propose to manage variability for mainly two aspects viz., optimum plant population and greater fertilizer use efficiency.

Optimization of plant population as per available soil moisture

- For a fixed date of sowing, pre-sowing irrigation will be staggered so that the soil moisture at sowing would be different in different plots.
- For each moisture level, varying seed rates will be applied to establish the relationship between soil moisture and plant population.
- This information will be used for working out the desired seed rate at varying soil moisture levels.

Optimization of plant population as per varying soil moisture and seeding depth

- For a fixed date of sowing, pre-sowing irrigation will be staggered so that the soil moisture at sowing would be different in different plots.
- For each moisture level, seed will be placed at varying depths to establish the relationship between soil moisture and plant population.
- This information will be used for working out the desired seeding depth at varying soil moisture levels.

Conclusion

The "Precision farming" underscores the significance of precision farming as a management strategy to increase productivity and economic returns while reducing environmental impact by considering variability within and between fields. Precision farming involves optimizing operations within temporally distinct and spatially variable crop production systems. The chapter emphasizes the importance of mapping programs in generating maps of crop or soil properties, which serve as the basis for spatially variable control of crop production. These maps enable precise management of spatial variability through controlled field operations tailored to specific soil, crop, and pest conditions. The utilization of technologies such as remote sensing, field mapping, and manual mapping, along with tools like the Global Positioning System (GPS) and differential GPS (DGPS), plays a crucial role in implementing precision farming practices. By aligning resource application with crop requirements and agro-ecological conditions, precision farming minimizes resource wastage, enhances efficiency, and promotes sustainable agricultural practices. The conclusion highlights the potential of precision farming to improve farm management, promote rural development, and contribute to the sustainable intensification of agriculture.

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