

Precision Agronomy for Improving Crop Productivity and Resource-Use EfficiencyKiran N. More¹, Apeksha M. Suryawanshi², Shrikrishna B. Narale³**Introduction:**

Agriculture is entering an era in which producing more food with fewer resources has become essential. Increasing population, shrinking landholdings, declining soil fertility, water scarcity, rising input costs and climate variability are creating serious challenges for farmers. Traditional crop management generally involves applying the same quantity of seed, fertilizer, irrigation and plant-protection chemicals uniformly across a field. However, agricultural fields are rarely uniform. Soil fertility, moisture availability, crop growth, weed population, pest incidence and yield potential may vary considerably from one part of a field to another. Managing these variations effectively is the foundation of **precision agronomy**. Precision agronomy is an advanced approach to crop production that uses field-specific information, digital technologies and scientific decision-making to manage crops according to their actual requirements. It integrates Global Positioning

System (GPS), Geographic Information System (GIS), remote sensing, satellite imagery, drones, sensors, artificial intelligence (AI), Internet of Things (IoT), weather information and variable-rate application technologies. The basic principle is to apply the right input, at the right rate, in the right place and at the right time. By following this principle, farmers can improve crop productivity while reducing unnecessary expenditure and minimizing environmental impacts. Precision agronomy is therefore not merely about using sophisticated machines; it is fundamentally a knowledge-based approach to improving the efficiency, profitability and sustainability of crop production.

Concept and Importance of Precision Agronomy

Precision agronomy recognizes the variability that exists within agricultural fields and attempts to manage this variability scientifically. A field may contain areas with high, medium or low soil fertility, different

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water-holding capacities and differences in crop growth and productivity. Conventional uniform management may result in over-application of inputs in some areas and under-application in others. Precision agronomy uses spatial and temporal information to understand these variations and develop site-specific management strategies. The approach combines agronomic knowledge with technologies such as GPS, GIS, remote sensing, drones, sensors, satellite imagery, yield monitors, artificial intelligence and variable-rate application systems. The major objective is to optimize the use of land, water, nutrients, energy, labour and other agricultural resources while maintaining or increasing crop productivity.

The importance of precision agronomy is increasing because agricultural inputs are becoming more expensive and natural resources are becoming increasingly limited. Water scarcity, declining soil fertility and environmental pollution associated with excessive fertilizer and pesticide use are major concerns for modern agriculture. Precision management can help farmers apply inputs according to actual crop and soil requirements, thereby reducing wastage and improving economic returns. At the same time, changing weather patterns and climate-related stresses require timely information for better crop management. Precision technologies can

provide farmers with information about crop conditions, soil moisture, nutrient status and weather conditions, allowing them to take appropriate management decisions at the right time.

GPS and GIS in Precision Agronomy

Global Positioning System technology provides accurate geographical positioning and has become an important component of precision agriculture. GPS can be used for field boundary mapping, soil sampling, machinery guidance, yield mapping and variable-rate application of agricultural inputs. Accurate positioning helps machinery operators follow predefined paths and reduces unnecessary overlap during field operations. This can save fuel, labour, seed, fertilizer and pesticides.

Geographic Information System technology complements GPS by allowing spatial information to be collected, stored, analyzed and displayed. Soil fertility, crop yield, soil moisture, topography and other field characteristics can be incorporated into GIS-based maps. These maps help identify management zones within a field. Farmers can then develop specific management strategies for different zones according to their productivity and resource requirements. The integration of GPS and GIS therefore provides an important foundation for site-specific crop management.

Remote Sensing and Satellite Technology

Remote sensing is another important component of precision agronomy. It provides information about crop and soil conditions without requiring direct physical contact with plants. Satellite imagery can be used to monitor crop growth, vegetation health, water stress and changes in field conditions over large areas. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) are widely used to assess crop vigour and identify differences in plant growth.

Remote sensing can help detect crop stress before it becomes clearly visible to the human eye. Variations in vegetation indices may indicate differences in crop biomass, nutrient availability, water status or pest and disease pressure. Repeated satellite observations can provide information throughout the crop-growing season and support timely management decisions. The increasing availability of high-resolution satellite imagery is creating new opportunities for monitoring agricultural fields at both farm and regional scales.

Role of Drones in Precision Crop Management

Unmanned aerial vehicles, commonly known as drones, provide high-resolution images of agricultural fields and are increasingly being used in precision agronomy. Drones equipped with RGB,

multispectral or thermal cameras can capture detailed information about crop canopy, plant health, temperature and water stress. Compared with conventional field scouting, drone-based monitoring can cover large areas quickly and identify localized problem areas.

Drone imagery can be particularly useful for identifying nutrient-deficient areas, weed patches, pest and disease hotspots, poor crop establishment and water-stressed regions. Once problem areas have been identified, farmers can undertake targeted field operations rather than treating the entire field uniformly. This can reduce input use and improve the efficiency of crop management. Drone technology is also becoming useful for crop mapping, plant population assessment and yield estimation.

Soil and Crop Sensors

Sensors provide real-time or near-real-time information about soil and crop conditions. Soil sensors can measure parameters such as soil moisture, temperature, electrical conductivity and other soil properties, while crop sensors can provide information about vegetation, biomass and crop nutrient status. Soil-moisture sensors, for example, can help determine whether irrigation is required and can prevent unnecessary application of water.

The use of sensors allows crop management to become more responsive to

actual field conditions. Instead of relying only on fixed schedules, farmers can use sensor information to make decisions about irrigation, fertilization and other operations. Sensor-based systems can be particularly useful when integrated with automated irrigation or fertilizer application systems.

Precision Nutrient Management

Nutrients are essential for crop growth, but excessive or poorly timed fertilizer application can reduce economic efficiency and contribute to environmental pollution. Precision nutrient management aims to supply nutrients according to soil fertility, crop requirements and expected yield potential. Soil testing, grid-based soil sampling, management-zone approaches, plant analysis, crop sensors and variable-rate fertilizer application can all contribute to more precise nutrient management.

Nitrogen management is particularly important because nitrogen is highly dynamic in soil and can be lost through leaching, volatilization and gaseous emissions. Applying nitrogen according to crop demand can improve nitrogen-use efficiency and reduce losses. Split application of nitrogen, sensor-based nitrogen management and site-specific fertilizer recommendations can help synchronize nutrient availability with crop demand. Precision nutrient management therefore has the potential to reduce fertilizer

costs while maintaining or improving crop productivity.

Precision Water Management

Water is one of the most important and increasingly scarce resources in agricultural production. Conventional irrigation practices often apply water according to a fixed schedule without considering actual soil moisture, crop growth stage or weather conditions. Precision water management uses information from soil-moisture sensors, weather stations, crop growth models and evapotranspiration estimates to determine irrigation requirements.

Drip irrigation and sprinkler systems can deliver water more efficiently than conventional surface irrigation under suitable conditions. When combined with soil-moisture monitoring and automated control systems, irrigation can be scheduled according to crop demand. This can reduce water wastage, pumping costs and nutrient leaching while maintaining adequate soil moisture for crop growth. Precision water management is particularly important in areas facing groundwater depletion and irregular rainfall.

Precision Weed Management

Weeds compete with crops for water, nutrients, light and space and can cause substantial yield losses. However, weed distribution is often uneven within a field. Uniform herbicide application may therefore

result in unnecessary chemical use in areas where weed populations are low or absent. Precision weed management attempts to identify weed-infested areas using cameras, drones, sensors, remote sensing and image-processing technologies.

Artificial intelligence and computer-vision techniques are increasingly being developed to distinguish crops from weeds. Once weed patches are identified, targeted herbicide application or mechanical weed control can be carried out. Such approaches can reduce herbicide consumption, production costs and environmental contamination while improving weed-control efficiency.

Precision Pest and Disease Management

Pests and diseases also show considerable spatial variability within agricultural fields. Some areas may experience severe infestation while other areas remain relatively healthy. Precision pest and disease management uses regular field monitoring, remote sensing, drones, sensors and artificial intelligence to identify affected areas and support early intervention.

Early detection is important because pest and disease problems can spread rapidly under favourable environmental conditions. Precision monitoring allows farmers to identify hotspots and apply control measures only where necessary. This approach complements Integrated Pest Management by

reducing unnecessary pesticide applications and encouraging more rational use of plant-protection chemicals.

Yield Mapping and Site-Specific Management

Yield mapping provides valuable information about the spatial variability of crop productivity. Yield monitors installed on harvesting machinery can record crop yield at different locations within a field. The resulting yield maps can identify high-yielding and low-yielding areas and reveal persistent productivity differences.

When yield maps are combined with information on soil fertility, soil moisture, topography, crop establishment and management practices, farmers can identify factors responsible for yield variability. This information can be used to develop site-specific management strategies for subsequent seasons. Yield mapping therefore creates an important feedback mechanism in precision agriculture by linking crop performance with field conditions and management practices.

Variable-Rate Technology

Variable-rate technology enables agricultural inputs to be applied at different rates across a field according to site-specific requirements. Instead of applying a uniform rate of fertilizer, seed or pesticide throughout the field, the application rate can be adjusted

according to soil fertility, crop condition or yield potential.

Variable-rate technology can improve the efficiency of fertilizers, seeds, pesticides and soil amendments. It can reduce over-application in areas where inputs are not required and ensure adequate application in areas where additional inputs are needed. The effectiveness of variable-rate technology depends on the quality of field data, accuracy of management maps and proper calibration of application equipment.

Artificial Intelligence and Machine Learning

Artificial intelligence and machine learning are rapidly expanding the possibilities of precision agronomy. Modern farms generate large quantities of data from satellites, drones, sensors, weather stations, machinery and field observations. AI can process these datasets and identify patterns that may not be easily recognized through conventional observation.

AI-based systems can support disease identification, weed recognition, crop-yield

Major Precision Agronomy Technologies and Their Applications

Technology	Major application	Contribution to resource-use efficiency
GPS	Field mapping, navigation and machinery guidance	Reduces overlap and saves fuel and inputs
GIS	Spatial analysis and management zones	Supports site-specific decisions
Satellite remote sensing	Crop monitoring and stress detection	Enables timely and targeted management
Drones	High-resolution crop monitoring	Detects localized crop stress, weeds and pests
Soil sensors	Soil moisture and soil-property monitoring	Improves irrigation and nutrient decisions
Crop sensors	Crop biomass and nutrient-status assessment	Supports precise fertilizer management
Yield monitors	Yield mapping	Identifies spatial yield variability
Variable-rate technology	Site-specific input application	Reduces input wastage
Drip irrigation	Precise water delivery	Improves water-use efficiency
Weather stations	Weather and microclimate monitoring	Supports timely field operations
Artificial intelligence	Prediction and automated decision support	Improves management accuracy
IoT devices	Real-time farm monitoring	Enables continuous and automated management

prediction, irrigation scheduling, nutrient-deficiency detection and pest forecasting. Machine-learning models can analyze historical and real-time data to predict crop performance and identify potential risks. The future of precision agronomy is therefore likely to shift from simple data collection towards intelligent decision-support systems capable of providing timely and field-specific recommendations.

Precision Agronomy for Improving Crop Productivity

The primary objective of precision agronomy is not simply to reduce agricultural inputs but to optimize their use so that crop productivity can be improved. When nutrients are supplied according to crop requirements, plants can utilize them more efficiently. When irrigation is provided at critical growth stages, water stress can be minimized. Similarly, early identification of weeds, pests and diseases can prevent avoidable yield losses.

Precision agronomy can also reduce variability in crop performance by identifying low-productivity areas and addressing the underlying causes. In some situations, improving the productivity of low-yielding zones can provide greater benefits than increasing inputs in already high-yielding areas. Therefore, precision management can improve not only average yield but also the stability and efficiency of crop production.

Precision Agronomy and Resource-Use Efficiency

Resource-use efficiency is a central objective of precision agronomy. Agricultural sustainability requires efficient use of water, nutrients, energy and other resources while maintaining adequate productivity. Precision fertilizer management can reduce nutrient losses, precision irrigation can reduce water wastage, precision spraying can minimize pesticide use and GPS-guided machinery can reduce unnecessary field operations.

The concept can be summarized as producing more output from each unit of input. Improving nutrient-use efficiency means obtaining more crop yield per unit of nutrient applied. Improving water-use efficiency means producing more crop per unit of water consumed. Similarly, energy-use efficiency involves obtaining greater agricultural output with lower energy consumption. Precision agronomy provides technological and analytical tools for achieving these improvements.

Precision Agronomy and Sustainable Agriculture

Precision agronomy has considerable potential to contribute to sustainable intensification of agriculture. Increasing agricultural productivity without causing excessive degradation of soil, water and biodiversity is one of the major challenges

facing modern agriculture. By improving the accuracy of input application, precision technologies can reduce unnecessary use of fertilizers, pesticides, irrigation water and fuel.

The environmental benefits can be particularly important when precision technologies are combined with conservation agriculture, integrated nutrient management, integrated pest management and climate-smart farming practices. Precision agronomy should therefore not be considered an independent technology package but as a management approach that can strengthen existing principles of sustainable agriculture.

Challenges in Adoption

Despite its considerable potential, precision agronomy faces several challenges. The initial cost of advanced equipment, limited technical knowledge, inadequate digital infrastructure and difficulties in interpreting complex datasets can restrict adoption. Small and fragmented landholdings can also make individual ownership of expensive machinery economically difficult. Farmers may also be uncertain about the economic returns from new technologies.

Successful adoption therefore requires more than simply providing technology. Farmers need training, demonstrations, technical assistance and locally validated recommendations. Agricultural universities, research institutions, extension agencies,

Krishi Vigyan Kendras, Farmer Producer Organizations and private service providers can play an important role in developing and promoting practical precision-agriculture solutions.

Precision Agronomy for Small and Marginal Farmers

Precision agriculture is often associated with large farms and expensive equipment, but many precision technologies can be adapted for smallholder farming. Farmers can access drones, sensors, soil testing, satellite-based monitoring and machinery through custom-hiring centres, cooperatives, Farmer Producer Organizations and specialized service providers.

The concept of precision-as-a-service can be particularly useful. Under this approach, farmers do not need to purchase expensive drones, sensors or specialized machinery. Instead, service providers can collect field information and provide recommendations or carry out precision operations for a service fee. Such models can reduce the initial investment requirement and make precision agronomy more accessible to small and medium-sized farmers.

Conclusion

Precision agronomy is an important approach for improving crop productivity and resource-use efficiency through site-specific and data-driven crop management. The use of

GPS, GIS, remote sensing, drones, sensors, artificial intelligence and variable-rate technologies enables farmers to apply water, fertilizers, pesticides and other inputs according to actual crop and soil requirements. These practices can reduce input wastage, lower production costs, improve yields and promote sustainable agriculture. Wider adoption of affordable, farmer-friendly precision technologies can play an important role in building productive, profitable and resource-efficient farming systems.

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