

Precision Agronomy: Using Data to Increase Crop Yield and Reduce Costs

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INTRODUCTION

Agriculture is currently facing unprecedented challenges due to rapid population growth, climate change, declining natural resources, and increasing demand for food security. Traditional farming systems, which often rely on uniform input application across entire fields, tend to overlook spatial variability in soil properties, moisture levels, and crop health. This results in inefficient use of resources, increased production costs, and negative environmental impacts such as soil degradation and water pollution. In this context, precision agronomy has emerged as a promising solution to address these challenges by adopting a data-driven approach to agricultural management. Precision agronomy utilizes technologies such as sensors, satellite imagery, data analytics, and automated machinery to monitor and manage variability within fields. By collecting and analyzing real-time data, farmers can optimize the application of inputs such as water, fertilizers, and pesticides according to the specific needs of different areas within a field. This targeted approach not only enhances crop productivity and profitability but also contributes to sustainable agricultural practices by minimizing waste and environmental harm.

2. Concept and Principles of Precision Agronomy

Precision agronomy refers to the practice of site-specific crop management based on detailed spatial and temporal data. It involves the systematic observation, measurement, and response to variability in crops and soil conditions to improve agricultural efficiency. The fundamental principle of precision agronomy is to apply the right input, at the right place, at the right time, and in the right amount. This approach is guided by several key principles, including the management of spatial variability, data-driven decision-making, optimization of agricultural inputs, and promotion of sustainability and resource efficiency.

The implementation of precision agronomy relies on four core components: data collection, data analysis, decision support, and actuation. Data collection involves the use of sensors, drones, and satellites to gather information on soil and crop conditions. Data analysis utilizes advanced tools such as artificial intelligence, machine learning, and geographic information systems

(GIS) to interpret the collected data. Decision support systems (DSS) assist farmers in making informed management decisions, while actuation technologies such as variable rate technology (VRT) enable precise application of inputs. Together, these components form an integrated system that enhances agricultural productivity and efficiency.



3. Technologies Used in Precision Agronomy

Precision agronomy is supported by a wide range of advanced technologies that facilitate data collection, analysis, and application. Global Positioning System (GPS) and Geographic Information System (GIS) technologies play a crucial role in mapping fields and analyzing spatial variability, enabling accurate input application and yield monitoring. Remote sensing technologies, including satellite imagery and unmanned aerial vehicles (drones), provide valuable insights into crop health, stress levels, and nutrient deficiencies by capturing high-resolution images of agricultural fields. The Internet of Things (IoT) further enhances precision agriculture by deploying sensors that

monitor soil moisture, temperature, humidity, and other environmental parameters in real time. These sensors generate continuous streams of data that help farmers make timely decisions. Artificial intelligence and machine learning algorithms are increasingly being used to analyze large datasets, predict crop yields, detect pests and diseases, and optimize irrigation and fertilization practices. Additionally, variable rate technology (VRT) allows farmers to apply inputs such as fertilizers, seeds, and pesticides at variable rates across different parts of a field, thereby reducing waste and improving efficiency. The integration of these technologies creates a comprehensive system that supports precise and efficient agricultural management.



4. Role of Data in Precision Agronomy

Data plays a central role in precision agronomy, serving as the foundation for informed decision-making and efficient farm management. Various types of data are collected, including soil data (such as nutrient levels and moisture content), weather data (temperature, rainfall, and humidity), crop growth data, and yield data. The integration of these diverse datasets enables a comprehensive understanding of field conditions and crop performance. Big data analytics has become increasingly important in precision agriculture, as it allows for the processing and analysis of large volumes of data from multiple sources. By leveraging big data, farmers can improve yield predictions, optimize input use, and reduce production risks. Advanced data analytics tools enable real-time monitoring and predictive modeling, which enhance the ability to respond to changing environmental conditions and crop needs. As a result, data-driven decision-making improves both productivity and resilience in agricultural systems.

5. Impact on Crop Yield

One of the primary benefits of precision agronomy is its positive impact on crop yield. By enabling more efficient and targeted management practices, precision agriculture helps improve crop performance and productivity. Improved nutrient management ensures that crops receive the appropriate amount of fertilizers based on their specific needs, reducing nutrient deficiencies and enhancing growth. Early detection of pests and diseases through remote sensing and AI-based systems allows for timely intervention, preventing significant crop losses. Efficient irrigation management, supported by soil moisture sensors and weather data, ensures optimal water use and reduces water stress in crops. Studies have demonstrated that the adoption of precision agriculture technologies can lead to yield increases of 15–20%, while also improving the accuracy of yield predictions through machine learning models. These improvements contribute to greater agricultural productivity and food security.



6. Cost Reduction and Economic Benefits

Precision agronomy offers significant economic advantages by reducing production costs and increasing farm profitability. By minimizing the overuse of inputs such as fertilizers, pesticides, and water, farmers can achieve substantial cost savings. The use of automated machinery and data-driven decision-making also reduces labor requirements and operational expenses. Furthermore, precision agriculture enhances efficiency by ensuring that resources are used optimally, thereby maximizing returns on investment. Research indicates that fertilizer and pesticide costs can be reduced by 15–20%, while overall farm profitability can increase by 15–30% through the adoption of precision farming practices. These economic benefits make precision agronomy an attractive option for modern farmers seeking to improve their financial performance.

7. Environmental Benefits

In addition to economic advantages, precision agronomy contributes significantly to environmental sustainability. By reducing the excessive use of chemical inputs, it minimizes soil and water pollution and promotes healthier ecosystems. Efficient water management practices help conserve water resources, which is particularly important in regions facing water scarcity. Precision agriculture also plays a role in reducing greenhouse gas emissions by optimizing input use and improving energy efficiency. Studies have shown that precision irrigation systems can achieve water savings of up to 26%, while also reducing environmental impacts. These benefits highlight the importance of precision agronomy in promoting sustainable agricultural practices.



8. Applications of Precision Agronomy

Precision agronomy has a wide range of practical applications in modern agriculture. In nutrient management, site-specific fertilizer application ensures that crops receive the right amount of nutrients based on soil conditions. In irrigation management, smart irrigation systems use real-time data to optimize water application, reducing waste and improving efficiency. Pest and disease management is enhanced through AI-based detection systems that identify issues at an early stage, allowing for timely intervention. Yield monitoring, supported by GPS-based systems, enables farmers to track crop performance and identify areas for improvement. These applications demonstrate the versatility and effectiveness of precision agronomy in addressing various agricultural challenges.

9. Challenges in Precision Agronomy

Despite its numerous benefits, precision agronomy faces several challenges that limit its widespread adoption. One of the major barriers is the high initial investment required for equipment and technology, which may be unaffordable for small-scale farmers. Data management issues, including the complexity of integrating data from multiple sources and the lack of standardization, also pose significant challenges. Additionally, there is a need for

technical knowledge and training to effectively use precision agriculture technologies. Infrastructure constraints, such as poor internet connectivity in rural areas, further hinder the implementation of data-driven farming systems. In countries like India, small landholdings present another challenge, as they limit the scalability of precision agriculture technologies.

10. Adoption in Developing Countries (India Focus)

The adoption of precision agronomy in developing countries, including India, remains limited due to several socio-economic and infrastructural factors. High costs, lack of awareness, and limited access to technology are major constraints faced by farmers. However, government initiatives promoting digital agriculture and smart farming are gradually encouraging the adoption of precision agriculture practices. Efforts are being made to develop low-cost technologies and provide training to farmers to enhance their capacity to use these tools. Despite these initiatives, adoption remains uneven, highlighting the need for more inclusive and accessible solutions tailored to the needs of smallholder farmers.

11. Future Trends

The future of precision agronomy lies in the continued integration of advanced technologies

under the concept of Agriculture 4.0. This includes the use of AI, robotics, and IoT to create fully automated and intelligent farming systems. Edge AI and low-cost technologies are expected to play a crucial role in making precision agriculture accessible to small farmers. Blockchain technology has the potential to improve data security and transparency in agricultural systems. Autonomous farming, involving the use of robots and drones, is also emerging as a key trend that could revolutionize agricultural practices. These innovations are expected to further enhance the efficiency and sustainability of precision agronomy.

12. Research Gaps

Despite significant advancements, several research gaps remain in the field of precision agronomy. There is a need for region-specific models that account for local climatic and soil conditions. Improved data integration frameworks are required to effectively combine data from different sources. Additionally, there is a need to develop affordable and scalable technologies that can be adopted by smallholder farmers. Addressing these gaps will be essential for the widespread adoption and success of precision agronomy.

CONCLUSION

Precision agronomy represents a powerful approach to modern agriculture, offering significant potential to increase crop yield and reduce production costs through data-driven decision-making. By integrating advanced technologies such as AI, IoT, and remote sensing, it enables efficient resource use and promotes sustainable farming practices.

However, challenges related to cost, data management, and limited adoption in developing regions must be addressed to fully realize its benefits. With continued research, innovation, and supportive policies, precision agronomy can play a crucial role in ensuring global food security and sustainable agricultural development.

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