



## Role of Precision Agriculture in Enhancing Crop Yield and Resource Use Efficiency

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### Abstract

Precision agriculture leverages advanced technologies such as GPS, sensors, AI, and drones to optimize farming practices. It significantly improves crop yield, reduces input waste, and enhances resource efficiency. By enabling data-driven decisions and sustainable management, it supports long-term agricultural productivity and environmental protection. Despite challenges like high costs and skill gaps, its future is promising through innovation and broader accessibility.

**Keywords:** *Precision agriculture, crop yield, resource efficiency, smart farming, sustainability.*

## 1. Introduction

### Definition of precision agriculture

Precision agriculture refers to the use of advanced technologies to monitor, measure, and respond to variability in crops, fields, and environmental conditions. It involves tools like GPS, GIS, sensors, drones, and data analytics to manage farming practices with accuracy. The global precision agriculture market is projected to reach \$15.6 billion by 2030, growing at a CAGR of over 12% from 2022 to 2030 (Source: Grand View Research).

### Importance of modernizing agriculture

Modernizing agriculture is essential for meeting rising food demand while conserving natural resources. Global population is expected to surpass 9.7 billion by 2050, requiring a 70% increase in food production (FAO). Traditional methods often lead to overuse of water, fertilizers, and pesticides. Precision agriculture enables 20–40% savings in input costs and boosts crop yields by 10–

25%, according to the USDA. Technological modernization also helps mitigate climate impact and promotes sustainable farming practices.

## 2. Precision Agriculture

### History and evolution

Precision agriculture emerged in the early 1980s with the use of satellite positioning systems to map yield data. The term gained prominence in the 1990s, driven by advancements in GPS technology and the introduction of variable rate application systems. By 2010, the integration of real-time data, sensors, and AI began transforming decision-making processes in farming. Global adoption has accelerated, with over 70% of farms in developed countries using at least one precision ag tool (Source: OECD, 2022).

### Key technologies involved

*GPS and GIS*

GPS enables accurate field mapping and machinery guidance with sub-inch precision. GIS stores spatial data for analysis, allowing farmers to assess soil variability, crop health, and input application zones. Yield mapping using GPS has improved farm efficiency by 15–20%.



#### *Remote sensing*

Satellites and aerial imagery provide insights on crop stress, soil moisture, and vegetation health. NDVI (Normalized Difference Vegetation Index) mapping helps detect crop anomalies, reducing yield losses by up to 18%.

#### *Drones and UAVs*

Drones equipped with multispectral cameras offer real-time crop monitoring, pest detection, and plant counting. Studies show that drone-based monitoring can reduce pesticide usage by 30–50% and improve overall crop surveillance accuracy by over 90%.



#### *IoT devices and sensors*

Soil moisture sensors, weather stations, and nutrient probes collect continuous data to optimize irrigation and fertilizer use. Sensor-based irrigation systems can reduce water use by 20–40%, according to the World Bank.

#### *Data analytics and AI*

AI models process large datasets to predict yields, identify diseases, and recommend input levels. Farms using AI-driven solutions have reported yield increases of 10–15% and cost reductions of up to 25%.

### **How these technologies work together**

Integration of GPS, sensors, AI, and imaging allows for data-driven decisions. For example, drones detect stressed areas; AI models analyze images; GPS-enabled sprayers apply inputs precisely. This synergy results in efficient use of inputs, reduced environmental impact, and higher productivity. A McKinsey report (2023) highlights that integrated precision systems can improve farm profitability by up to 40%.

## **3. Enhancing Crop Yield through Precision Agriculture**

### **Site-specific crop management**

Precision agriculture allows farmers to manage variations within fields by dividing them into management zones. Variable Rate Technology (VRT) enables the precise application of inputs based on soil and crop needs. Studies by the USDA show yield increases of 15–25% when applying site-specific nutrient and water management.

### **Timely decision-making using data**

Real-time data from sensors, drones, and weather stations supports fast, informed decisions on crop inputs, irrigation schedules, and harvest timing. Data-driven decisions can reduce input waste by 20–30% and improve crop output by 10–18%, according to FAO reports.



### **Disease and pest detection**

AI-powered image analysis and drone surveillance can detect crop stress, fungal infections, and pest infestations in early stages. Early detection reduces crop loss risks by up to 40% and pesticide usage by 30%, based on findings from PrecisionAg Alliance.

### **Optimized planting, irrigation, and fertilization**

#### *Optimized planting*

GPS-guided machinery ensures uniform seed spacing and depth, improving germination rates by 10–15% and overall plant health.

#### *Optimized irrigation*

Sensor-based irrigation systems deliver water only where needed, increasing water efficiency by up to 40% and preventing yield loss from overwatering.

#### *Optimized fertilization*

Soil nutrient mapping and VRT enable targeted fertilizer use, reducing nitrogen runoff and improving nutrient uptake. This can raise crop yield by 12–20% while lowering fertilizer use by 15–25%.

### **Case studies or examples showing yield improvement**

A 2021 study by the International Journal of Agricultural Sustainability found maize farms using precision technologies saw a 22% increase in yield and 18% reduction in input costs. In wheat production, remote sensing and data analytics improved nitrogen use efficiency, resulting in a 25% boost in yield per hectare (Source: Wageningen University Research, 2022).

## **4. Improving Resource Use Efficiency**

### **Water use efficiency through smart irrigation**

Smart irrigation systems use soil moisture sensors, weather forecasts, and real-time data to supply water only when and where it's needed. Drip irrigation combined with IoT-based scheduling can reduce water use by 30–50% while maintaining or increasing crop yields. A study by the International Water Management Institute found that sensor-based irrigation reduced over-irrigation by up to 60%, improving water productivity across multiple crop types. Crops like tomatoes and maize showed yield improvements of 15–20% using automated, data-driven irrigation techniques.

### **Fertilizer and pesticide management**

#### *Precision fertilizer application*

Soil testing and variable rate application (VRA) reduce excess fertilizer use and increase nutrient efficiency. Research from the International Fertilizer Association shows VRA can reduce nitrogen application by 20–30%, leading to yield gains of 10–15% and a drop in greenhouse gas emissions.

#### *Targeted pesticide use*

Remote sensing and AI-assisted pest monitoring detect issues early and allow precise pesticide spraying. Studies show targeted application can reduce pesticide use by up to 40% while increasing effectiveness by 25%. This improves food safety and lowers chemical residue in crops.

### **Reduction of waste and input costs**

Machine learning algorithms help predict optimal input levels, minimizing waste. Precision seeders, auto-guided tractors, and real-time field monitoring systems have cut input costs by 15–25% per season. A 2023 report by the World Bank highlights that precision agriculture reduces post-harvest losses by up to 20% through better harvest timing and resource management.



### **Environmental sustainability benefits**

Controlled input use reduces runoff and soil degradation. Lower nitrogen application results in less nitrate leaching, helping to protect groundwater quality. The European Environment Agency reports that precision farming practices can reduce agricultural CO<sub>2</sub> emissions by 10–20%. Conservation tillage combined with GPS-guided machinery reduces fuel usage and improves soil structure over time.

### **Economic benefits for farmers**

Precision agriculture boosts profitability through higher yields, reduced input costs, and efficient labor use. Farms adopting full-scale precision systems reported average profit increases of 15–40% (McKinsey, 2023). A case study in Brazil showed soybean farmers improved net returns by \$85 per hectare using precision planting and nutrient management. Technology also enables smallholder farmers to access micro-loans and insurance using farm performance data, strengthening financial resilience.

## **5. Challenges and Limitations**

### **High initial investment and technology costs**

Precision agriculture technologies require significant upfront capital. GPS-enabled equipment, drones, and sensor networks can cost between \$25,000 to \$100,000, depending on scale and complexity. According to the International Food Policy Research Institute, small and medium-sized farms face adoption barriers due to limited financing options and high maintenance expenses. Return on investment often takes 3 to 5 years, which discourages short-term adopters.

### **Data privacy and management**

Precision farming generates large volumes of data related to soil, crops, and yield. Concerns over ownership, storage, and unauthorized

access have emerged. A report by the FAO noted that over 60% of farmers are unsure about how their data is used or shared by agritech providers. Lack of standardized data protocols also leads to interoperability issues across different platforms and equipment brands.

### **Skill gaps and need for farmer training**

Successful implementation depends on technical knowledge and digital literacy. A survey by the OECD revealed that over 50% of farmers in low and middle-income countries lack the skills to operate precision tools. Training programs are either insufficient or inaccessible in many regions. Even with access to technology, limited capacity to interpret data reduces its practical benefits in the field.

### **Limited access in developing regions**

Infrastructure limitations such as unreliable internet connectivity, lack of electricity, and poor transportation hinder the spread of precision agriculture. Satellite data access and cloud-based analytics are difficult to deploy without robust digital infrastructure. According to the World Bank, less than 30% of farms in sub-Saharan Africa and Southeast Asia have access to digital agricultural tools, slowing down technology diffusion.

## **6. Future**

### **Integration with AI and machine learning**

AI and machine learning are transforming precision agriculture through predictive analytics, yield forecasting, and real-time decision-making. AI-powered platforms can detect crop diseases with 95% accuracy, predict weather impacts, and optimize input usage based on historical and real-time data. A report by MarketsandMarkets projects the agricultural AI market to reach \$4 billion by 2026, growing at a CAGR of 25%.

### **Advances in robotics and automation**



Autonomous tractors, robotic weeders, and harvesters are increasing field efficiency and reducing labor dependency. Robotic systems can reduce herbicide use by up to 90% through targeted application. Agrobotics adoption is expected to grow rapidly, with global agricultural robot sales projected to surpass \$20 billion by 2028 (Source: Global Market Insights). These machines improve precision and lower operational costs, especially in high-labor crops like fruits and vegetables.

### **Government and policy support**

Policies that encourage digital infrastructure, subsidies for agri-tech tools, and R&D investments are critical for adoption. Governments are offering tax breaks and incentives for adopting precision farming. According to the World Economic Forum, public-private partnerships have accelerated agri-digital transformation in over 40 countries, enabling faster rollout of precision technologies and broadband in rural zones.

### **Expanding access to smallholder farmers**

Low-cost sensor kits, smartphone-based platforms, and drone service providers are making precision agriculture more accessible. Digital extension services are helping bridge the knowledge gap. A study by the GSMA AgriTech program found that mobile-based advisory services improved productivity by 30% among smallholders. Leasing models and cooperative ownership of tools also lower entry barriers for resource-constrained farmers.

### **Conclusion**

Precision agriculture enhances crop yield and resource efficiency through smart technologies, data-driven decisions, and sustainable practices, offering long-term economic and environmental benefits for both large and small-scale farmers.

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