

| RESEARCH ARTICLE

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PRECISION AGRICULTURE AND ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE CROP PRODUCTION: A REVIEW OF EMERGING TECHNOLOGIES AND FUTURE APPLICATIONS

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| ABSTRACT

The increasing demand for food, declining natural resources, climate variability, and environmental concerns have accelerated the adoption of advanced technologies in agriculture. Precision Agriculture (PA) and Artificial Intelligence (AI) have emerged as transformative approaches for improving agricultural productivity, resource efficiency, and sustainability. Precision agriculture enables site-specific management of crops using advanced sensing and monitoring technologies, while AI facilitates data-driven decision-making through machine learning, computer vision, and predictive analytics.

| KEYWORDS

Precision Agriculture, Artificial Intelligence, Smart Farming, Crop Production, Machine Learning, Sustainable Agriculture

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Abstract:-

The increasing demand for food, declining natural resources, climate variability, and environmental concerns have accelerated the adoption of advanced technologies in agriculture. Precision Agriculture (PA) and Artificial Intelligence (AI) have emerged as transformative approaches for improving agricultural productivity, resource efficiency, and sustainability. Precision agriculture enables site-specific management of crops using advanced sensing and monitoring technologies, while AI facilitates data-driven decision-making through machine learning, computer vision, and predictive analytics. This review examines the principles of precision agriculture, the role of artificial intelligence in crop production, major technological advancements, benefits, limitations, and future prospects. The review highlights the potential of integrating AI-driven solutions with precision farming systems to enhance food security and environmental sustainability.

Introduction:-

Agriculture is undergoing a significant transformation due to rapid technological advancements and increasing pressures on food production systems. Global population growth, climate change, water scarcity, and land degradation have created an urgent need for more efficient and sustainable agricultural practices. Traditional farming methods often rely on uniform field management, which may result in inefficient resource utilization. Precision Agriculture (PA) seeks to optimize agricultural inputs by considering spatial and temporal variability within fields. Artificial Intelligence (AI) further enhances precision

agriculture by enabling automated data analysis, predictive modeling, and intelligent decision-making. Together, these technologies provide opportunities to increase productivity while reducing environmental impacts.

Concept of Precision Agriculture:-

Precision Agriculture refers to the management of agricultural practices based on detailed information about field variability.

The primary objectives include:-

- Maximizing crop productivity
- Improving resource-use efficiency
- Reducing environmental impacts
- Enhancing profitability

Precision agriculture relies on data collected from multiple sources including sensors, satellites, drones, and field monitoring systems.

Components of Precision Agriculture:-

Global Positioning System (GPS):-

GPS technology enables accurate field mapping and site-specific management.

Applications include:-

- Field navigation
- Soil sampling
- Yield mapping
- Machinery guidance

Geographic Information Systems (GIS):-

GIS integrates and analyzes spatial data for agricultural planning and decision-making.

Benefits include:-

- Soil variability analysis
- Crop monitoring
- Resource management
- Risk assessment

Remote Sensing:-

Remote sensing technologies provide valuable information regarding crop health and field conditions.

Sources include:-

- Satellites
- Unmanned aerial vehicles (UAVs)
- Drones
- Aircraft imaging systems

Artificial Intelligence in Agriculture:-

Artificial Intelligence refers to computer systems capable of performing tasks that typically require human intelligence.

AI technologies commonly applied in agriculture include:-

- Machine learning
- Deep learning
- Computer vision
- Expert systems
- Neural networks

These technologies process large volumes of agricultural data to generate actionable insights.

Machine Learning Applications in Crop Production:-

Machine learning algorithms identify patterns within datasets and support predictive analysis.

Applications include:-**Yield Prediction:-****AI models estimate crop yields based on:-**

- Weather data
- Soil characteristics
- Crop management practices

Accurate predictions assist farmers in planning harvest and marketing activities.

Disease Detection:-

Machine learning systems can identify crop diseases from images and sensor data.

Benefits include:-

- Early disease diagnosis
- Reduced crop losses
- Improved treatment decisions

Pest Monitoring:-

AI-based monitoring systems detect pest infestations before severe damage occurs. Early detection supports targeted intervention strategies.

Computer Vision in Smart Agriculture:-

Computer vision uses image-processing techniques to interpret visual information.

Major applications include:-

- Weed identification
- Fruit detection
- Crop counting
- Disease recognition
- Harvest automation

Computer vision technologies improve accuracy and reduce labor requirements.

Internet of Things (IoT) and Precision Farming:-

The Internet of Things enables real-time monitoring of agricultural systems through interconnected devices.

Common IoT devices include:-

- Soil moisture sensors
- Weather stations
- Temperature sensors
- Nutrient monitoring systems

Real-time data supports informed management decisions and efficient resource utilization.

Precision Irrigation Systems:-

Water scarcity represents a major challenge for global agriculture.

Precision irrigation systems optimize water use by delivering water according to crop requirements.

Benefits include:-

- Reduced water consumption
- Improved crop performance
- Lower production costs
- Enhanced sustainability

AI-driven irrigation systems can automatically adjust water application based on environmental conditions.

Variable Rate Technology (VRT):-

Variable Rate Technology allows site-specific application of agricultural inputs.

Applications include:-

- Fertilizer application
- Seed placement
- Pesticide spraying
- Irrigation management

VRT improves input efficiency and reduces environmental pollution.

Drones and Unmanned Aerial Vehicles:-

Drones have become valuable tools in modern agriculture.

Applications include:-

- Crop surveillance
- Disease detection
- Nutrient assessment
- Precision spraying
- Yield estimation

Drone-based monitoring provides rapid and cost-effective field assessments.

Environmental Benefits of Precision Agriculture:-**Precision agriculture contributes to environmental sustainability through:-**

- Reduced fertilizer losses
- Lower pesticide usage
- Improved water efficiency
- Reduced greenhouse gas emissions
- Enhanced soil conservation

These benefits support sustainable agricultural development.

Economic Benefits:-**Adoption of AI and precision farming technologies can increase farm profitability through:-**

- Improved yields
- Reduced input costs
- Enhanced resource management
- Better risk management

Long-term economic gains often outweigh initial technology investments.

Challenges and Constraints:-

Despite its potential, precision agriculture faces several challenges.

High Initial Costs:-

Advanced technologies may require substantial investments.

Technical Expertise:-

Successful implementation requires specialized knowledge and training.

Data Management Issues:-

Large datasets require efficient storage, processing, and interpretation systems.

Infrastructure Limitations:-

Limited internet connectivity and technological infrastructure may restrict adoption in rural areas.

Future Trends:-**Future developments are expected to include:-**

- Fully autonomous farming systems
- AI-powered farm robots
- Digital twin technologies
- Advanced predictive analytics
- Blockchain-based agricultural traceability

These innovations may further improve agricultural sustainability and productivity.

Policy Implications:-**Governments can support technology adoption through:-**

- Research funding
- Capacity-building programs
- Digital infrastructure development
- Technology subsidies
- Agricultural extension services

Supportive policies can accelerate precision agriculture adoption worldwide.

Conclusion:-

Precision agriculture and artificial intelligence are transforming modern farming systems by enabling data-driven decision-making, efficient resource utilization, and sustainable crop production. Technologies such as machine learning, computer vision, IoT, remote sensing, and variable rate technology provide farmers with powerful tools for optimizing agricultural operations. While challenges related to costs, expertise, and infrastructure remain, continued technological advancements and supportive policies are expected to expand adoption. The integration of AI and precision agriculture represents a critical pathway toward achieving food security, environmental sustainability, and resilient agricultural systems.

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