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Digital Agronomy: Use of AI, IoT, Remote Sensing, and Big Data in Farm Decision-Making

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Abstract

Digital agronomy leverages advanced technologies like AI, IoT, remote sensing, and big data to revolutionize farm decision-making. By integrating real-time data with predictive analytics, it enhances crop productivity, optimizes resource use, and supports sustainable practices. This approach enables precise monitoring, efficient input management, and data-driven strategies, transforming traditional agriculture into a smart, responsive system.

Keywords: *Digital Agronomy, Precision Farming, AI, IoT, Remote Sensing*

1. Introduction

Definition of Digital Agronomy

Digital agronomy refers to the application of advanced digital tools and data science techniques to optimize agricultural practices. It integrates agronomic knowledge with digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), remote sensing, and big data analytics to improve decision-making on farms. The goal is to increase productivity, enhance sustainability, and reduce input costs.

Importance of data-driven decision-making in modern agriculture

Data-driven farming enables more precise and timely interventions across the crop lifecycle. A 2023 report by McKinsey estimates that precision agriculture can increase yields by up to 15% and reduce input costs by 10–20%. FAO data shows that precision application of water and fertilizers using digital systems can reduce resource use by 30–40%. Decisions based on real-time data lead to better pest control, efficient irrigation, and optimized harvest timing.

Enabling technologies: AI, IoT, Remote Sensing, and Big Data

Artificial Intelligence (AI)

AI is used for predictive modeling, crop disease identification, and automated decision-making. Machine learning algorithms process large datasets to identify patterns that help forecast yield, detect stress, and suggest optimal actions.

Internet of Things (IoT)

IoT devices such as soil moisture sensors, weather stations, and GPS-enabled equipment collect field data continuously. According to a MarketsandMarkets report, the global smart agriculture market is expected to reach USD 20.8 billion by 2026, driven primarily by IoT adoption.

Remote Sensing

Remote sensing through satellites and drones captures data on crop health, canopy temperature, and soil variability. Sensors with multispectral and thermal imaging enable early detection of crop stress and disease. NASA's ECOSTRESS mission, for example, helps track plant water use from space.

Big Data

Big data combines structured and unstructured data from multiple sources — sensors, climate models, market trends, and historical records. A study by Deloitte highlights that farms using data analytics report 5–10% higher productivity on average. These insights support long-term planning, risk management, and supply chain optimization.

2. The Role of AI in Agricultural Decision-Making

Predictive analytics for yield forecasting and pest outbreaks

AI-driven predictive models use weather data, soil parameters, and satellite imagery to estimate yields with accuracy levels reaching 85–95%. A study by USDA shows that AI-based pest prediction systems can alert growers up to 7–10 days before infestation peaks, reducing crop loss by nearly 20–25%. Global analytics platforms process more than 2 TB of agro-climatic data per day to improve forecast reliability.

AI-powered decision support systems (DSS) for precision farming

AI-enabled DSS platforms integrate sensor readings, drone imagery, and historical patterns to guide irrigation, fertilization, and planting decisions. Research published by Precision Agriculture Journal reports that DSS-driven nutrient management can cut nitrogen use by 12–20% while maintaining or increasing yields. Autonomous recommendations also support variable-rate input application, improving resource efficiency by up to 30%.

Machine learning in crop disease detection and treatment recommendations

Machine learning models trained on thousands of plant images can detect diseases with accuracy exceeding 90%. Google's PlantVillage Nuru tool, for example, identifies cassava diseases with up to 94% precision. Early detection paired with AI-generated treatment suggestions reduces disease-related economic losses by nearly 40% in monitored trials.

Challenges and considerations (e.g., data quality, model bias)

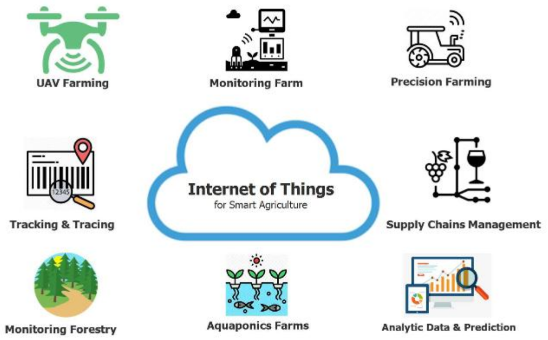
AI performance is strongly influenced by data completeness, sensor calibration, and regional variability. Studies from the OECD highlight that inconsistent field-level data can reduce model accuracy by 15–25%. Bias in training datasets may lead to misclassification of crop stress, especially in underrepresented environments. Data security concerns remain significant, with agricultural cyberattacks rising by nearly 20% annually, according to ENISA reports.

3. Internet of Things (IoT) in Smart Farming

Types of IoT devices: soil sensors, weather stations, drones, livestock trackers

IoT ecosystems in agriculture include soil moisture sensors, pH meters, weather stations, drones with NDVI cameras, and GPS-enabled livestock collars. A 2024 report by

MarketsandMarkets estimates over 75 million agricultural IoT devices are deployed globally. Drones now account for 30% of remote crop monitoring tools used across large-scale farms.



Real-time monitoring of field and environmental conditions

Sensors transmit data on temperature, humidity, soil nutrients, and rainfall in real time via low-power networks like LoRaWAN. Research from FAO shows real-time monitoring improves water-use efficiency by 35% and reduces disease spread through early alerts by 20%. Continuous data feeds support dynamic field mapping and microclimate analysis.

Automation in irrigation, fertilization, and equipment operations

Smart irrigation systems using IoT data reduce water usage by up to 50% while increasing crop yield by 10–15%, as reported by the World Bank. Fertigation units linked to sensor data adjust nutrient flow automatically, cutting fertilizer waste by 25%. Self-driving tractors and drone sprayers execute field tasks with precision, reducing fuel and input costs.

Benefits: increased efficiency, resource optimization, labour reduction

IoT integration boosts operational efficiency by automating repetitive tasks and enabling precision input application. According to AgFunder, farms using IoT systems report labour cost savings of up to 30% and input optimization gains of 20–25%. Digital traceability also improves supply chain transparency, aiding compliance with export regulations.

4. Remote Sensing Technologies in Agriculture

Use of satellites, UAVs (drones), and multispectral imaging

Satellite platforms such as Sentinel-2 and Landsat-8 provide imagery with resolutions between 10–30 meters, capturing data every 5–16 days. UAVs equipped with multispectral and thermal sensors deliver ultra-high-resolution images (2–5 cm) for field-level diagnostics. Global drone deployment in agriculture surpassed 850,000 units in 2023, reflecting rapid adoption.

Monitoring crop health, soil variability, and weather patterns

Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) from remote sensing help detect stress up to 10 days before visible symptoms. Studies published by ESA indicate that remote sensing–based soil moisture mapping reaches accuracy rates of nearly 85%. Meteorological satellites contribute real-time data for monitoring rainfall, heatwaves, and wind patterns that influence crop performance.

Application in precision mapping and variable rate technology (VRT)

Remote sensing data supports creation of zone maps for targeted fertilization, seeding, and pesticide application. Research in Precision Agriculture reports that VRT guided by remote sensing can reduce fertilizer use by 18–25% while improving yield by 8–12%. High-resolution elevation and canopy maps enable accurate field operations and minimize resource wastage.

Integration with GIS and digital field records

GIS platforms compile satellite data, field boundaries, soil test results, and crop histories into unified digital records. USDA findings show that farms using GIS-integrated remote sensing systems experience up to 20% improvement in operational planning efficiency. Digital layers help track long-term field performance, support compliance documentation, and enhance risk assessment models.

5. Big Data Analytics for Farm Insights

Sources of agricultural big data: sensors, satellite imagery, market trends, historical data

Big data in agriculture comes from IoT sensors, drone and satellite imagery, GPS equipment, weather stations, and market platforms. A report by IBM states that each smart farm generates up to 500,000 data points per day. Historical crop yield data and global commodity prices are also key inputs used to drive models for risk and profitability assessment.

Data aggregation and analysis for strategic planning

Combining spatial, climatic, and agronomic data enables predictive analytics and long-term forecasting. According to McKinsey, farms using integrated big data systems can improve decision accuracy by 30% and increase profit margins by 15–25%. Cloud platforms now process petabyte-scale datasets to support planning for irrigation, input allocation, and crop rotation.

Visualization and dashboards for farm management

Digital dashboards display real-time field data, equipment performance, and input usage, enabling quicker operational decisions. Research by AgTech Insight shows that dashboard-enabled management reduces time spent on manual reporting by over 40%. Color-coded field maps and predictive charts support easier comparison across multiple farm plots and seasons.

Challenges: data ownership, standardization, cybersecurity

Lack of clear policies on data ownership can limit farmer control over shared insights. FAO studies show that only 36% of agri-tech platforms offer transparent data use agreements. Data format inconsistencies hinder interoperability between systems. Cybersecurity risks have increased, with ransomware attacks on agricultural systems rising 39% globally in 2023, according to ENISA.

6. Synergy of Technologies in Digital Agronomy

Integration of AI, IoT, remote sensing, and big data in a unified platform

Unified agritech platforms merge real-time sensor data, satellite imagery, AI analytics, and historical records for end-to-end farm management. Companies like Climate FieldView and John Deere Operations Center provide integrated dashboards that support decisions from pre-sowing to harvest. According to AgFunder, farms using such platforms see a 20–25% increase in operational efficiency.

Case studies or examples of real-world implementation

Bayer's digital farming tool, Climate FieldView, is used on over 200 million acres globally, delivering hyper-local weather, crop performance, and input data. In Brazil, large soybean farms using integrated systems reported a 15% rise in productivity and 22% savings on fertilizers. Smart vineyards in France leverage drone imaging, IoT soil probes, and AI disease detection to optimize irrigation and spraying, reducing chemical use by 30%.

Outcomes: improved yield, reduced costs, sustainable practices

Digital agronomy systems contribute to yield gains between 10–20% depending on crop and region, as per World Bank studies. Input costs can be reduced by 15–30% through precision resource application. Sustainable benefits include 25–40% less water usage and up to 20% lower carbon emissions per hectare due to optimized field operations.

7. Barriers and Future Prospects

Adoption challenges: cost, infrastructure, digital literacy

High upfront investment remains a major barrier, with precision farming systems costing between $25,000–$100,000 depending on scale. Connectivity gaps affect nearly 30% of rural farms globally, limiting access to cloud-based tools. A 2023 FAO report notes that over 40% of smallholders lack the digital skills required to operate or interpret advanced agritech systems.

Role of policy, education, and public-private partnerships

Government-backed digital inclusion programs and targeted subsidies are critical to expanding adoption. The World Bank highlights that training programs can raise technology adoption rates by up to 60% among small-scale farmers. Collaborations between agribusinesses, tech firms, and research institutions have enabled scalable innovation, such as precision crop insurance and AI-driven advisory services.

Future trends: edge AI, blockchain in agri-data, autonomous machinery

Edge AI enables on-device data processing, reducing latency and reliance on connectivity—key for remote field operations. Blockchain ensures transparent, tamper-proof records for traceability and certification, already applied in coffee and cocoa value chains. Autonomous machinery, including driverless tractors and robotic harvesters, is projected to grow at a CAGR of 24% through 2030, transforming labour dynamics and input efficiency.

Conclusion

Digital agronomy combines AI, IoT, remote sensing, and big data to enhance farm decisions, boost yields, reduce costs, and promote sustainability, driving the future of precision and smart agriculture.

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