

## Technological Trends In Agriculture

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### I. Introduction

Agriculture is a vital and environmentally friendly sector, providing essential food sources like vegetables, proteins, and oils. It underpins food security and offers a reliable livelihood. However, challenges such as labor shortages, climate change, pest damage, limited funding, inefficient input use, and low profitability discourage many from pursuing it.

To overcome these issues and boost productivity, adopting advanced technologies is essential. These innovations enhance decision-making, reduce risks, improve efficiency, manage variability, and promote sustainability. They help conserve resources, maintain soil fertility, protect against climate impact, and increase output quality.

Despite its importance, agriculture still lags behind developed nations in technology adoption. Advancing farming practices through new technologies is crucial to meet modern challenges. This progression is reflected in four key agricultural eras:

1. Traditional Agriculture (Agriculture 1.0, 1784–1870): Based on human and animal labor with low operational efficiency.
2. Mechanized Agriculture (Agriculture 2.0, 20th Century): Introduced high-yield seeds, fertilizers, pesticides, and machinery; faced issues of resource inefficiency.
3. Automatic Agriculture (Agriculture 3.0, 1992–2017): Adopted micro-irrigation, digital platforms like e-NAM, and precision farming; challenged by low intelligence integration.
4. Smart Agriculture (Agriculture 4.0, 2017–present): Driven by technologies like IoT, big data, and cloud computing for intelligent, unmanned operations.

To ensure sustainable growth, embracing smart agriculture and technology-driven solutions is essential for the future of farming.

#### Recent Trending Technologies

##### 1. Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) is a technology-driven method of growing crops in closed ecosystems, such as greenhouses or plant factories, where variables like light, temperature, and humidity are carefully managed. Its goal is to maintain optimal growing conditions, protect crops from external elements, and improve resource efficiency. CEA maximizes the use of water, energy, space, capital, and labor while reducing pest and disease threats, increasing sustainability, yield, and lowering operational costs.

**Key CEA methods include:**

- Hydroponics: Growing plants without soil using nutrient-rich water, with reduced water usage.
- Aeroponics: Growing plants with roots suspended in air and misted with nutrients, requiring no substrate.
- Aquaponics: Integrates fish farming with plant cultivation, where fish waste provides nutrients for plants.
- Vertical Farming: Cultivating crops in stacked layers using a mix of natural and artificial light, optimizing space and growth efficiency.

## 2. Aerial imagery in Agriculture

Aerial imagery is captured using satellites, planes, or drones, with image resolution depending on camera quality and flight altitude. Its key advantage is offering a bird's eye view of farmland. In orchards, it helps calculate tree volume for precise spray application, reducing overuse. Near-infrared (NIR) imaging is particularly useful in agriculture due to vegetation's high reflectance in this band, enabling calculation of the Normalized Difference Vegetation Index (NDVI):

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

~ -1: Water

0.3–0.5: Stressed/unhealthy vegetation

0.5–1: Healthy vegetation

Drones and satellite imaging help detect crop variability, allowing for better crop management and increased profitability.

## 3. Agriculture Sensors

Agriculture sensors are used in smart farming to collect data that help farmers monitor and optimize crop growth by responding to environmental changes. These sensors are mounted on weather stations, drones, and robots, and are often controlled via dedicated mobile apps. Depending on connectivity, they operate using Wi-Fi or cellular networks, enabling remote control and real-time monitoring through smartphones.

### Agricultural Sensors – Functional Description

- Location Sensors: Use GPS satellites to determine latitude, longitude, and altitude within a specific area.
- Optical Sensors: Use light to assess soil properties like clay, organic matter, and moisture; mounted on satellites, drones, or robots.
- Electro-Chemical Sensors: Detect specific ions to measure soil pH and nutrient levels.
- Mechanical Sensors: Measure soil compaction or mechanical resistance.
- Dielectric Soil Moisture Sensors: Assess moisture levels by measuring the soil's dielectric constant.
- Air Flow Sensors: Measure soil air permeability; can be fixed or mobile.

## 4. Telematics

Telematics is the transmission of computerized data over long distances and is used in agriculture for monitoring vehicles and machinery both on farms and on the road. It allows stakeholders to collect and analyze equipment data to improve operational efficiency. Through remote monitoring, telematics helps detect issues, automate field tasks, and manage fleets for smoother pickups and deliveries, ultimately enhancing farm productivity.

## 5. Farm Bot

FarmBot is an open-source robotic system designed for small-scale, soil-based food production. It performs planting, watering, soil testing, and weeding using components like Raspberry Pi, Arduino, and weather-resistant materials. Operated via web or mobile app, it includes:

- Seed Injector: Sows seeds at precise depth and spacing.
- Watering Nozzle: Irrigates based on crop needs.
- Soil Sensors: Monitor moisture levels.
- Weeding Tool: Removes weeds efficiently.

FarmBot is the first fully automated, end-to-end food production system tailored for small farms and home gardens.

## 6. Carbon trading

Carbon trading is the process of buying and selling permits and credits that allow the permit holder to emit carbon dioxide. A carbon credit is a permit or certificate allowing the holder, such as a company, to emit carbon dioxide or other greenhouse gases. The ultimate goal of carbon credits is to reduce the emission of greenhouse gases into atmosphere. Each carbon credit represents one ton of CO<sub>2</sub> either removed from atmosphere or saved from being emitted. Carbon trading cover emissions of 6 main greenhouse gases- carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), hydro fluorocarbons (HFCs), perfluoro carbons (PFCs) and Sulphur hexafluoride (SF<sub>6</sub>). Objectives of carbon trading is to reduce carbon emissions, to provide better environmental situation and to mitigate global warming, to provide a financial incentive for companies to reduce pollution, promotion of sustainable production processes and also sustainable lifestyle across the globe. Carbon trading has been a central pillar of the EU's efforts to slow climate change. The world's biggest carbon trading system is the European Union Emissions Trading System.

## 7. Artificial intelligence (AI)

Artificial Intelligence (AI) enables computers or robots to perform tasks typically requiring human intelligence. In agriculture, AI helps detect plant diseases, pests, and nutrient deficiencies. AI-powered sensors identify weeds and determine the precise herbicide application area. It is also used for livestock health monitoring and improving harvest quality and accuracy. By bringing precision to large-scale farming, AI significantly boosts productivity.

## 8. Immersive Technology

Immersive Technology enhances or creates new realities using 360° environments. It includes four types: Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR).

- Virtual Reality (VR): Creates a fully simulated 3D environment using head-mounted displays (HMDs). It helps farmers survey fields, assess soil quality, choose crops, and receive virtual training.

- **Augmented Reality (AR):** Overlays digital content onto the real world. Farmers can view the farm dashboard, monitor production quality, detect pests, and learn equipment use through immersive e-learning.
- **Mixed Reality (MR):** Blends VR and AR by projecting digital images into the real world using HMDs, offering interactive training and real-time visual data without blocking the real environment.
- **Extended Reality (XR):** A collective term that includes all VR, AR, and MR technologies.

These tools improve decision-making, training, and farm management through interactive and engaging experiences.

**9. Big data :** Big data refers to extremely large datasets analyzed to uncover patterns, trends, and associations, particularly in human behavior and interactions. In agriculture, it enables personalized, field-specific solutions from pre- to post-production, resulting in higher yields, reduced input use per hectare, and lower cultivation costs. It also supports early warning systems for emerging issues and provides effective data visualization for better decision-making.

**10. Internet of Things (IoT) :** IoT connects devices that monitor, collect, and exchange data through wired or wireless networks. In agriculture, it provides context-specific, real-time information to farmers. IoT systems can track transport needs for moving produce and enable traceability for consumers and traders. By using networks of sensor nodes, IoT shifts agriculture from a human- and machine-centered approach to an information- and software-driven model, enhancing efficiency and decision-making.

**11. Edge computing :** In large-scale farming, sending all sensor data to cloud servers can overload networks and slow down response times. Edge computing addresses this by processing data locally, reducing server load and latency. It supports applications like pest identification, product traceability, unmanned machinery, and smart farm management. By enabling on-site decision-making without relying on cloud connectivity, edge computing enhances process reliability, reduces waste, and promotes sustainable agriculture.

## Conclusion

Technologies play a vital role in the agriculture sector. If there are no technological changes, the agricultural sector will face a lot of difficulties. The implementation of latest technologies makes the management and monitoring of agriculture very simple and easy. Technologies save the energy and time of farmers. Providing technical guidance and awareness to farmers regarding technologies will uplift the agricultural sector. Government should give various schemes and subsidies to the farming community to encourage adoption of latest technologies.

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