



POPULAR SCIENCE ARTICLE

Smart Farming and Modern Agricultural Technologies

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Abstract:

Farmers today face rising input costs, shrinking water resources, unpredictable weather, labour shortages and growing pressure to feed more people from the same land. Smart farming responds to these pressures by combining sensors, satellites, drones, mobile applications, artificial intelligence and automated machinery so that decisions are based on data as well as experience. This article traces how farming moved from traditional practice to digital agriculture and explains, in simple language, the main technologies involved: precision agriculture, the Internet of Things (IoT), remote sensing and drones, artificial intelligence, robotics and automation, smart irrigation, protected cultivation, livestock monitoring, and digital markets and traceability. It describes how each technology works in the field, what it offers growers and the environment, and the practical, social and economic barriers that keep these tools out of many farmers' hands, with special attention to small and marginal farmers.

Keywords: Smart farming, precision agriculture, Internet of Things, drones, artificial intelligence, digital agriculture

Introduction

Imagine a farmer who knows, without walking a single row, which corner of the field is running dry, which patch of the crop is under pest attack and exactly how much fertilizer each plot needs. Imagine an irrigation pump that switches itself on only when the soil truly needs water, or a small aircraft that sprays an entire field in minutes while the farmer watches safely from the bund. This is not science fiction. Across the world, and increasingly in India, fields are being read by sensors, photographed from the sky and analysed by software.

For centuries, farming decisions rested on experience, inherited wisdom and a watchful eye on the sky. These remain deeply valuable, but they are no longer enough on their own. The world must produce more food, fibre and fodder while using less water, fewer chemicals and less land, and climate change makes every season harder to predict. Rainfall arrives late or in sudden bursts, heat waves shorten crop duration, and new pests spread into areas where they were never seen before.

Smart farming, also called digital agriculture or Agriculture 4.0, adds data to the farmer's experience. Instead of treating a whole field as one uniform block, it lets farmers give each part of the field what it actually needs, at the right

time and in the right amount (Wolfert *et al.*, 2017; Walter *et al.*, 2017). The idea is simple even if the technology behind it is complex: measure, understand, decide and act. This article walks through the main smart technologies, shows where they help, and honestly discusses what stands in the way.

From tradition to digital: How farming evolved

Farming has passed through several stages. Early agriculture relied on human and animal power. The mechanical age brought tractors and threshers, and the Green Revolution added high-yielding varieties, irrigation and chemical fertilizers, which greatly increased production but also encouraged uniform, blanket application of inputs. The present digital stage builds on this history. Its central idea is that a field is not uniform, and that managing the differences within it can save resources and raise returns (Zhang *et al.*, 2002; Rose and Chilvers, 2018).

Smart farming therefore does not throw away earlier knowledge. It adds new eyes, new memory and new speed to the farmer's judgement. A weather forecast on a phone, a soil health card, a satellite picture of the crop or a motor controlled by a mobile app are all small steps on the same road.

Precision agriculture: Right input, right place, right time

Precision agriculture is the foundation of smart farming. Fields are rarely uniform, since soil texture, fertility, moisture and pest pressure vary from one spot to another, sometimes within a few metres. Precision methods use the Global Positioning System (GPS), grid soil sampling, yield monitors and digital field maps to measure this variation and manage it.

Machines fitted with variable-rate technology can apply seed, fertilizer, lime or pesticide in different amounts across the same field, guided by a prescription map. A patch of poor soil may receive more organic matter or nutrients, while a fertile patch receives less. Auto-steer systems keep tractors on exact paths, avoiding overlaps and skips. The result can be lower input of soil and water from over-application (Bongiovanni and Lowenberg-DeBoer, 2004; Gebbers and Adamchuk, 2010).

Even where expensive machinery is out of reach, the thinking behind precision agriculture can be used. Soil testing before fertilizing, dividing a field into management zones, and using leaf colour charts for nitrogen are low-cost ways to apply the same principle.

Internet of Things: A field that talks back

The Internet of Things (IoT) refers to small, low-cost devices placed in the field that continuously record conditions and send them wirelessly to a phone or computer. Typical sensors measure soil moisture at different depths, soil temperature, air temperature, humidity, rainfall, leaf wetness and light. Some also track water level in tanks and channels, or pest numbers through smart traps (Tzounis *et al.*, 2017).

The real value comes when sensors are linked to action. A farmer can check soil moisture from home, receive an alert when the crop is under stress, or connect the sensors to a controller that opens valves and starts pumps only when water is really needed. In greenhouses, similar systems control fans, foggers, shade nets and fertigation. In poultry sheds and dairy units, sensors monitor temperature, ammonia and animal activity. Kim *et al.* (2020) reviewed how such systems are spreading in agricultural automation.

Smart irrigation: More crop per drop

Water is the most limiting resource in many farming regions, and much of it is lost through over-irrigation, evaporation and leaking channels. Smart irrigation combines drip or sprinkler systems with soil moisture sensors,

weather data and timers. The system waters the crop when the root zone actually dries, rather than on a fixed schedule or a guess. Combined with fertigation, in which fertilizer is delivered through the irrigation water in small, frequent doses, it improves nutrient use efficiency and reduces losses. For farmers who depend on borewell water or face power cuts, mobile-controlled pump starters also save many night-time trips to the field.

Remote sensing and drones: The view from above

Satellites and drones carry cameras that see more than the human eye. Some capture near-infrared and red-edge light, which reveals plant stress well before yellowing or wilting is visible. From these images, indices such as the Normalized Difference Vegetation Index (NDVI) are calculated to show crop vigour as a colour map. Farmers and advisers can then spot nutrient deficiency, waterlogging, drought stress or pest outbreaks, and can estimate crop area and yield. Over the past few decades remote sensing has become one of the most important tools in precision agriculture (Mulla, 2013).

Drones bring this view within a farmer's reach. They can survey a field in minutes, capture very detailed images, and increasingly carry spray tanks. Drone spraying covers an acre in a fraction of the time that manual spraying takes, uses less water, and keeps the farmer away from direct contact with chemicals. Reviews of drone applications describe uses in crop monitoring, spraying, mapping and even pollination support (Tsouros *et al.*, 2019). Rules on flying, pilot training and the cost of equipment remain practical concerns.

Artificial intelligence: Turning data into decisions

Sensors, satellites and drones produce huge amounts of data. Artificial intelligence (AI), and especially machine learning, helps make sense of it. Programmes can be trained on thousands of photographs to recognise crop diseases, identify weeds, count fruits, grade produce or estimate plant height (Liakos *et al.*, 2018; Kamilaris and Prenafeta-Boldú, 2018).

Smartphone apps already let a farmer photograph a diseased leaf and receive a likely diagnosis with management advice. AI models also combine weather, soil and crop data to forecast yield, predict pest and disease outbreaks, and suggest the best dates for sowing, spraying or harvest. Chat-based advisory services in local languages are making expert knowledge available to farmers who are far from an extension office. AI does have limits:

models work well only on the kind of data they were trained on, so advice must always be checked against local conditions and expert opinion (Bhat and Huang, 2021).

Automation and robotics: Easing the labour burden

Labour is becoming scarce and costly in many rural areas, especially at peak seasons. Automation is stepping in. Auto-steer tractors follow exact paths with little driver input, reducing overlap and fatigue. Automatic seeders and transplanters place seed with uniform spacing. Robotic systems can weed between rows, pick delicate fruits such as strawberries and tomatoes, and milk dairy animals. Research on agricultural robotics shows steady progress, although most robots are still expensive and best suited to high-value crops and protected cultivation (Shamshiri *et al.*, 2018). Automation is most valuable for repetitive, time-critical tasks where delay costs yield.

Protected cultivation and livestock: Smart beyond the open field

Smart tools are especially effective in controlled environments. In polyhouses and greenhouses, sensor-driven systems keep temperature, humidity, light and nutrient supply within the ideal range, which supports high yields of vegetables, flowers and nursery plants using little water and land. Vertical farms and hydroponic units take this idea further by growing crops without soil under fully managed conditions.

Livestock farming also benefits. Wearable collars and ear tags record an animal's activity, rumination and body temperature, and can flag heat (oestrus) or early illness. Automatic feeders and milking systems keep detailed records of each animal. For fisheries, sensors track dissolved oxygen, pH and temperature in ponds so that farmers can act before fish are stressed.

Digital markets, records and traceability

Smart farming does not end at harvest. Mobile apps and online platforms now provide market prices, weather alerts, crop advisories and direct links to buyers. Digital records of inputs and operations help farmers prove how their produce was grown, which matters for export, organic certification and premium markets. Tools such as blockchain can record each step from farm to shelf in a way that is difficult to alter, building trust between farmers, traders and consumers. Digital payments and farm records can also help farmers access credit and insurance more easily.

Table 1. Technologies at a glance

Technology	What it does on the farm	Main benefit
Precision agriculture	Uses GPS, soil maps and variable-rate machines to treat each part of a field differently	Saves inputs and improves uniformity of yield
IoT sensors	Records soil moisture, temperature, humidity and leaf wetness round the clock	Timely irrigation and early stress alerts
Satellites and drones	Captures multispectral images and sprays crops from the air	Fast field scouting and safer spraying
Artificial intelligence	Identifies diseases, weeds and pests; forecasts yield and weather risk	Better and faster decisions
Robotics and automation	Performs steering, weeding, planting, picking and milking	Reduces labour need and drudgery
Blockchain and digital markets	Records produce journey and connects farmers to buyers	Trust, traceability and fairer prices

Benefits for farmers and the environment

Used well, smart farming offers several advantages:

- **Lower input costs:** Targeted use of water, seed, fertilizer and pesticide lowers cost and waste.
- **Higher and more stable yields:** Timely, informed decisions on irrigation, nutrition and plant protection support better and steadier yields.
- **Environmental protection:** Less nutrient runoff, lower groundwater use and reduced chemical residues protect soil, water and biodiversity.
- **Early warning and risk management:** Alerts about pest attack, disease and extreme weather give farmers time to protect the crop.
- **Labour saving:** Machines and automation cut drudgery and reduce dependence on scarce labour.
- **Better records and market access:** Digital records support traceability, marketing, credit and insurance.

Challenges on the way

Smart farming is not without hurdles, and honest discussion of them is essential. Equipment, sensors and drones can be costly for small and marginal farmers, who make up most of India's farming community, and small, scattered plots make the economics harder. Internet connectivity and electricity supply in rural areas are uneven. Many farmers need training and confidence to interpret digital advice, and language and literacy barriers can

slow adoption. Devices also need maintenance and repair, which must be available locally.

There are wider social questions too. Data collected from farms can be valuable, so ownership, privacy and fair sharing of benefits need clear rules. Without care, digital tools may widen the gap between large and small farmers rather than close it (Klerkx *et al.*, 2019; Rose and Chilvers, 2018).

The way forward: Making smart farming work for every farmer

Several practical steps can help smart farming reach small farmers. Shared ownership models, such as custom hiring centres, farmer producer organizations and cooperatives, spread the cost of drones, sensors and machinery. Drone and machinery services offered on rent let farmers pay only for the work done. Simple, low-cost tools, such as mobile advisories in local languages, soil testing and weather-based alerts, are a sensible first step before investing in advanced equipment.

Training is equally important. Young, technology-friendly rural people can become service providers, drone pilots and data helpers for their villages. Government programmes, universities, research institutes and extension agencies can support this through demonstrations, field schools and clear guidelines. Finally, technology must be tested under local conditions and adapted to local crops, soils and farming systems, so that it supports rather than replaces the farmer's own knowledge.

Conclusion

Smart farming does not replace the farmer's knowledge. It sharpens it. By combining traditional experience with sensors, satellite images, drones, intelligent software and automated machines, farmers can grow more with less, protect soil and water, and cope better with a changing climate. The greatest promise lies in making these tools affordable, understandable and accessible to small farmers, who need them most. With supportive policy, farmer training and shared-service models, smart technologies can help build a productive, profitable and sustainable agricultural future in which the wisdom of the field and the power of data work side by side.

Conflict of interest

The authors declare no conflict of interest.

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