



## Low-cost Sensors for Soil and Crop Monitoring: Making Precision Agriculture Affordable.

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### INTRODUCTION

Precision agriculture focuses on using data to make farming more efficient, productive, and sustainable. However, many farmers, especially small and marginal ones, are unable to adopt advanced agricultural technologies due to high costs, complex systems, and lack of technical support. Low-cost sensors for soil and crop monitoring are emerging as a practical solution to this problem. These sensors help farmers measure important parameters such as soil moisture, temperature, pH, and crop health directly from their fields. By providing real-time and location-specific data, they support better decisions related to irrigation, fertilization, and crop management. With the increasing availability of smartphones and basic digital connectivity in rural areas, sensor-based farming is becoming easier to adopt. Affordable sensing technologies are helping bridge the gap between traditional experience-based farming and modern data-driven agriculture, making precision agriculture more inclusive and accessible.

### II. Background / Concept

Low-cost agricultural sensors are simple electronic devices designed to collect essential field data at an affordable price. Unlike high-end precision farming systems that use complex machinery and software, these sensors focus only on critical parameters needed for everyday farming decisions. Commonly measured factors include soil moisture, soil temperature, soil pH, electrical conductivity, and basic indicators of crop health.

These sensors are usually connected to microcontrollers and transmit data to mobile phones or small display units. The idea is not to replace farmer knowledge but to support it with real-time information. By simplifying data collection and interpretation, low-cost sensors allow farmers to take timely action without needing advanced technical expertise or heavy investment.

### III. Current Challenges

1. **High cost of traditional precision agriculture tools:** Most precision agriculture technologies such as satellite imaging, advanced drones, and automated machinery are expensive. The initial investment, along with maintenance costs, makes them unaffordable for small and marginal farmers who operate on limited budgets.
2. **Limited technical knowledge among farmers:** Many farmers are unfamiliar with digital tools, sensors, and data interpretation. Without proper training or guidance, even simple technologies can feel difficult to use, leading to hesitation in adoption.
3. **Difficulty in maintaining complex equipment:** Advanced agricultural systems often require regular calibration, software updates, and professional servicing. In rural areas, access to technical support is limited, making maintenance a major challenge.
4. **Lack of real-time field-level data:** Traditional farming relies heavily on visual observation and experience. This makes it difficult to detect early changes in soil or crop conditions, leading to delayed or incorrect decisions.
5. **Dependence on manual work:** Without accurate data, farmers often over-irrigate or overuse fertilizers as a precaution. This increases costs, reduces efficiency, and negatively affects soil and environmental health.

### IV. Modern Solutions or Technologies

Modern low-cost sensor technologies focus on solving practical farming problems without adding complexity or heavy financial burden. The main goal is to provide useful field-level data in real time so that farmers can take timely action. Most of these technologies are designed to work with minimal infrastructure, low power consumption, and easy maintenance. By combining affordable sensors with microcontrollers and mobile apps, precision agriculture is being simplified and localized for everyday farm use.

- **Low-cost sensors:** Soil moisture sensors show how much water is in the soil, helping farmers irrigate only when needed and avoid both water stress and wastage.
- **Soil temperature sensors:** Soil temperature affects germination and growth and monitoring it helps farmers choose the right time for sowing and irrigation.

- **pH and electrical conductivity (EC) sensors:** pH sensors show soil acidity, while EC sensors indicate nutrient levels, helping farmers manage fertilizers effectively.
- **Crop health monitoring sensors:** These sensors use light reflection or color changes to detect crop stress, nutrient deficiency, or early disease symptoms before visible damage occurs.
- **Microcontroller-based systems:** Low-cost microcontrollers process sensor data and generate alerts, making them ideal for simple and affordable farming solutions.
- **Mobile app and SMS-based interfaces:** Data from sensors is displayed on smartphones in simple formats such as alerts, color indicators, or recommendations, making it easy for farmers to understand and act upon.
- **Wireless communication modules:** Bluetooth/GSM allow data transfer from the field to the farmer's phone without physical monitoring, reducing labor and time.

### V. Benefits

The real strength of low-cost sensor-based farming lies in its ground-level impact. These technologies do not promise futuristic automation but deliver practical, immediate improvements in how farms are managed. Field studies and pilot projects have shown that even basic soil moisture monitoring can reduce water usage by 20–30%, while optimized fertilizer application can cut input costs by 15–25%. Beyond numbers, the biggest benefit is improved decision-making confidence among farmers. By replacing guesswork with data, low-cost sensors create a more predictable and resilient farming system.

- **Water efficiency at scale:** As agriculture uses nearly 70% of freshwater, sensor-based irrigation helps even small farms reduce water use and manage resources wisely.
- **Cost reduction without yield compromise:** Farmers save money on water, fertilizers, and pesticides while maintaining or improving crop yield, making farming more profitable and sustainable.
- **Empowerment of small and marginal farmers:** Access to real-time data levels the playing field, allowing small farmers to benefit from precision practices once limited to large commercial farms.
- **Foundation for sustainable agriculture:** Reduced chemical use, healthier soils, and

efficient resource management contribute to long-term environmental protection and climate resilience.

## VI. Economic / Social / Environmental Impact

Low-cost sensors create strong positive impacts across economic, social, and environmental dimensions. Economically, they help farmers reduce expenses by optimizing water, fertilizer, and pesticide use. Even small savings per crop cycle can significantly improve income for small-scale farmers. Increased yield and reduced crop loss further strengthen financial stability. Socially, sensor-based farming empowers farmers with knowledge and confidence. Access to real-time data reduces dependence on middlemen or external advice. It also attracts young people toward agriculture by integrating technology with traditional farming practices, helping modernize the sector. Environmentally, these sensors promote sustainable resource usage. Controlled irrigation conserves water, while precise fertilizer application reduces chemical runoff and soil degradation. Healthier soil and crops contribute to long-term agricultural sustainability. Overall, affordable sensor technology supports balanced growth by improving productivity while protecting natural resources.

## VIII. Limitations

- **Less precise results:** Low-cost sensors provide reasonably good estimates but may not match the precision of high-end commercial equipment used in large-scale precision farming
- **Sensor degradation:** Continuous exposure to moisture, heat, dust, and soil can reduce sensor lifespan and affect performance over time
- **Need for basic training and awareness:** Farmers require simple guidance to understand sensor readings and use the data correctly for decision-making

- **Dependence on power supply:** Sensors rely on batteries or small power sources, which need regular replacement or charging to ensure uninterrupted operation
- **Connectivity challenges in rural areas:** Limited mobile network or internet access in remote locations can affect real-time data transfer and remote monitoring

## VII. Future Scope

In the future, low-cost sensors are expected to become more accurate, durable, and user-friendly. Integration with AI-based mobile apps, government support programs, and cooperative farming models can further improve adoption. Mass production will also reduce costs further, making precision farming a standard practice.

## CONCLUSION

Low-cost sensors are playing a crucial role in democratizing precision agriculture by making advanced farming practices accessible beyond large commercial farms. By focusing on essential field data, simple system design, and affordability, these tools allow small and medium farmers to benefit from modern agricultural techniques without heavy financial investment. Real-time information on soil and crop conditions helps farmers make timely decisions, leading to improved productivity, reduced input wastage, and better resource management.

Although challenges such as accuracy, maintenance, and connectivity still exist, continuous technological improvements, farmer training, and institutional support are steadily addressing these issues. As awareness and adoption increase, low-cost sensor technology has the potential to form a strong foundation for smarter, data-driven, and climate-resilient agriculture. This shift ensures that precision farming becomes an inclusive solution, supporting sustainable food production and empowering farmers at all levels of the agricultural ecosystem.