



Biosensors for Sustainable Farming: Growing More with Less

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Abstract

Biosensors are predominant and an innovative tool in agriculture, offering farmers an easy go advance tool to monitor soil and crop health and environmental in real time. They are useful in monitoring vital parameters, including soil water content, nutrient conditions, pest and disease infestations, and taking correct and prompt decisions. Through biosensors, farmers are able to maximize irrigation and fertilizer utilisation, improve pest management and minimize loss of inputs that eventually results in high productivity and sustainability. In contrast to the traditional method of using observation and experience, biosensors provide reliable information that can aid in making decisions based on precision. Not only do they enhance the performance of crops, but also make the soil and the environment healthy by reducing resource wastage. However, the high prices and accessibility are still a problem especially among the small and marginal farmers. Biosensors are expected to be an inseparable component of sustainable and precise farming systems in the near future with the continued technological growth and reduction of the costs.

Keywords: Biosensors, Crop health, Precision farming, Smart agriculture

Introduction

Biosensors are a new technology that bears a lot of potential in enhancing sustainability and operational efficiency of the modern farming system. The devices offer immediate monitoring of essential factors including soil moisture levels and nutrient presence and pest activity and disease development to support fast and accurate decision-making. Research evidence shows biosensors help farmers optimize their irrigation plans and fertilizer usage and pest control strategies which leads to lower resource waste and better environmental protection and enhanced agricultural yields. The implementation of biosensors in farming operations through case studies proves their ability to enhance resource management and enable farmers to detect crop stress at an early stage. The adoption of biosensors faces ongoing barriers because they remain expensive and difficult to access and install especially for smallholder farmers operating in areas with limited resources. The future development of biosensors alongside decreasing costs will make them accessible to more farmers thus establishing them as fundamental components of precision agriculture

and sustainable food production systems.

What are Biosensors?

Biosensors function as devices which detect biological or chemical environmental changes to produce readable signals. The sensors monitor three essential agricultural factors which include soil moisture levels and nutrient availability and pest and disease detection. The sensors detect changes at an early stage which enables farmers to obtain immediate data for making strategic decisions. The biosensor system provides farmers with immediate alerts about dry or over-stressed soil conditions which enable them to respond right away. Bio-sensors help farmers optimize their crop management through sustainable practices which boost yields while reducing water and fertilizer and pesticide consumption (Mondal *et al.*, 2022).

Why Farming Needs Smarter Tools?

One of the issues modern-day farming faces is climate change, exhaust ion of resources and the world population growth. Traditional farming activities tend to be founded on trial and error or the out-of-date mode of operation;

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therefore, inefficiency occurs, including overuse of water, fertilisers and pesticides. The solutions to these issues can be provided using more innovative tools that give real-time and precise information regarding soil health, crops and resource utilisation (Mondal *et al.*, 2022). These tools enable farmers to make better decisions, optimise the inputs and reduce wastage, whereby the yields of crops are either saved or improved. Due to the increasing demand to adopt green agriculture practices, new innovative tools are required to help farmers meet those demands, become more productive and cause less environmental harm, creating a more sustainable future in agriculture (Aarif *et al.*, 2025).

How Biosensors Help Farmers?

The advantages of biosensors to farmers are the provision of real-time information on the most significant factors that affect the development of crops such as soil health, water usage, nutrients, pests and diseases. Such sensors are placed on the field and continuously supply the farmers with information that provides them with a real-time image of what is happening with their crops. Indicatively, a moisture sensor like an irrigation sensor can establish the level of moisture that a farmer can utilise to streamline irrigation and make sure that no water is wasted (Ahmed *et al.*, 2023). The nutrient sensors regulate the health of the soil and because of this fact; the fertilisers can be used correctly. In addition, biosensors can identify early infections to pests or diseases and the farmers can act before the circumstances are out of hand. The real-time information assists the farmers in making more suitable choices, producing more crops, decreasing resource consumption and finally engaging in more productive and efficient production (Dyussebayev *et al.*, 2021). Applications of biosensors in agriculture are given in figure 1.

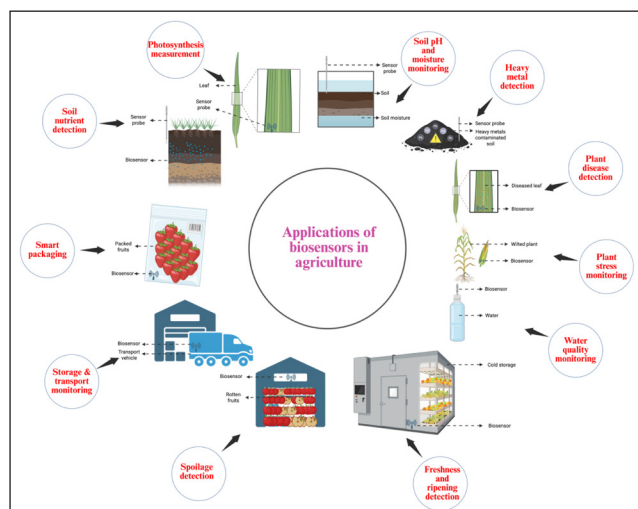


Figure 1: Applications of biosensors in agriculture

Saving Water, Fertilisers and Energy

Biosensors save agricultural water, fertiliser and energy by minimising waste and guaranteeing a good yield. Such sensors can assist farmers in making a more effective choice on how the resources are used and the result is a more efficient use of the inputs and reduced wastage, with real-time data (Getahun *et al.*, 2024). An example is soil moisture

sensors that can control the irrigation process by applying the required amount of water only at the appropriate time, thereby reducing the amount of water wastage. Likewise, the nutrient sensors introduce the appropriate quantity of nutrients at the appropriate time, thus avoiding unnecessary wastage and causing less environmental damage. In a case study of the vineyards in California, smart sensors cut water use by 25% without affecting grape quality and yield, which made farming more efficient and sustainable (Aarif *et al.*, 2025).

Early Warnings for Crops

Biosensors provide early alerts to farmers because they can detect stress, pests, or diseases before they inflict any visible harm. Various aspects of influence on plant health may be tracked using these sensors, including temperature and moisture levels and plant behaviour changes. The on-going data collection process enables them to detect early warning signs of stress which include water scarcity and pest infestations before visible symptoms appear. Crop health sensors detect small temperature changes in plants and leaf conditions which signal the presence of pests or diseases. Such early identification enables farmers to promptly apply specific treatment to avoid additional harm and expensive losses of crops. Biosensors can assist farmers in safeguarding their crops, enhancing harvests and minimising the necessity of subjecting their products to excessive chemical use.

From Lab to Farm: Success Stories

Biosensors have already been transferred out of the laboratory into the agricultural field, enabling farmer with an effective instrument to check the health of their soil, identify diseases and manage their crops. As an illustration, soil sensors are highly applicable in real-time moisture and nutrient levels monitoring to enable farmers to make data-driven irrigation and fertilisation decisions. Disease-detecting gadgets, including strips and handheld gadgets, have also been discovered to be convenient in the detection of the initial symptoms of plant diseases and consequently early treatment and less wastage of crops is realized. A fascinating case study is in Brazil where farmers are preparing themselves with handheld devices that detect diseases to enable them identify whether there is fungus disease in their soybean crops. The early identification of these infections would enable farmers to make a more precise treatment, which would lead to a radical reduction in the number of pesticides applied and a beneficial outcome in the crop harvest. This is a change in technology of biosensor technology that improves the productivity and sustainability of agriculture (Aarif *et al.*, 2025).

The Green Promise of Biosensors

Biosensors can be considered an indispensable part of sustainable precision farming since they allow farmers to manage their resources and minimize environmental degradation. The sensors give farmers real-time information on the moisture contents of the soil and the quantitative content of the nutrients and the health condition of crops that allow them to administer water and fertilizers and pesticides only as needed. The particular strategy assists

farmers to decrease wastage production, minimize the chemical over-application by focusing on specific application. In farming, soil moisture sensors assist farmers in saving on water since they do not have to irrigate when they are not in need. Nutrient sensors assist farmers in applying fertilizers at certain areas which minimizes runoff as well as environmental pollution. The use of biosensors in farming allows farmers to generate greater harvests at environmentally friendly costs which protect the environment from damage so farming practices can continue across multiple generations. Applications of biosensors across the agricultural value chain are given in figure 2.

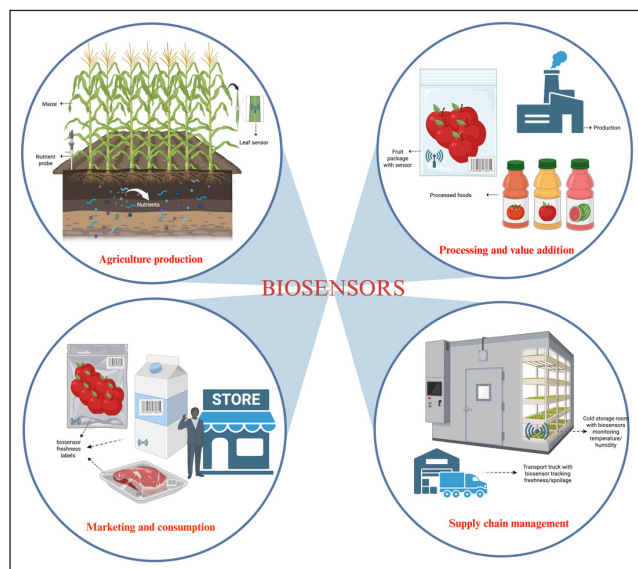


Figure 2: Applications of biosensors across the agricultural value chain

Challenges and the Road Ahead

Although biosensors have many advantages in the agricultural industry, various challenges have yet to be overcome. One of the problems is that these technologies are relatively costly and might lack affordability among small-scale or resource-limited farmers (Ahmed *et al.*, 2023). The high expenses for sensor installation and data analysis and maintenance present a financial burden for certain farmers. The lack of reliable internet access in rural and remote areas creates difficulties for data collection and analysis in real-time. The process of data collection and real-time analysis faces significant obstacles. Biosensors present extensive potential for global agricultural applications despite current implementation obstacles. With the improved technology, biosensors will be cheaper. Farmers worldwide, not only in developed countries but also in developing countries, will be able to use them because of the innovation of such features as wireless connection and more convenient gadgets. The future of farming is quite bright and promising in terms of

making farming more efficient, sustainable and productive worldwide (Dyussebayev *et al.*, 2021).

Conclusion

Biosensors are transforming agriculture in that they help introduce new and more sustainable methods of agriculture. Such technologies help farmers to track functional parameters such as the availability of water, moisture, nutrients and crop health in real time and it may also be possible to optimise water, fertiliser and pesticides, which not only minimises wastage but maximises productivity, leading to environmental sustainability. Case studies also reveal that farmers can use biosensors to make informed decisions to maximise crop yield; some biosensors are soil moisture sensors and disease detection sensors. The future of biosensor technology in farming practice is bright, although there are challenges due to high cost and inaccessibility. With continued improvement in technology and as the price of biosensors keeps falling, biosensors will be the new centre of the future of farming, able to feed the constantly increasing food production needs and at the most affordable cost to the environment.

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