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ORIGINAL

A Practical Approach to Increase Crop Production Using Wireless Sensor Technology

Un enfoque práctico para aumentar la producción agrícola mediante la tecnología de sensores inalámbricos

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ABSTRACT

Introduction: the global demand for food production continues to rise due to the growing population and changing consumption patterns. Traditional agricultural practices often fail to meet this demand efficiently, leading to the exploration of innovative technologies to enhance crop productivity. Wireless sensor technology (WST) has emerged as a promising tool to monitor and optimize agricultural practices, providing real-time data on various environmental parameters crucial for crop growth.
Objective: this study aims to evaluate the effectiveness of wireless sensor technology in increasing crop production. By integrating WST into conventional farming practices, we seek to optimize resource usage, reduce waste, and improve crop yields.
Methods: we have proposed an IoT-enabled soil nutrient classification and crop recommendation model to recommend crops. By incorporating machine learning, artificial intelligence (AI), the cloud, sensors, and other automated equipment into the decision-assisting system, farmers will be able to take decisive actions without relying entirely on regional farming offices.
Results: the analysis showed that the plot using wireless sensor technology exhibited a significant increase in crop yield compared to the traditional plot. Soil moisture levels were maintained within optimal ranges, leading to better water usage efficiency. Additionally, the automated system adjusted fertilizer application based on real-time soil nutrient data, resulting in improved plant health and productivity.
Conclusions: the integration of wireless sensor technology in agriculture presents a practical and effective approach to increase crop production. This technology enables precise monitoring and management of critical growth parameters, resulting in higher yields and more efficient resource use. Adopting WST can significantly contribute to meeting the global food demand while promoting sustainable farming practices.

Keyword: Smart Farming; NPK Sensor; Soil Fertility; Soil Nutrient; Smart Sensors; Internet of Things; Mobile Application.

RESUMEN

Introducción: la demanda mundial de producción de alimentos sigue aumentando debido al crecimiento de la población y a los cambios en las pautas de consumo. Las prácticas agrícolas tradicionales a menudo no logran satisfacer esta demanda de manera eficiente, lo que lleva a la exploración de tecnologías innovadoras para mejorar la productividad de los cultivos. La tecnología de sensores inalámbricos (WST) ha surgido como una herramienta prometedora para supervisar y optimizar las prácticas agrícolas, proporcionando datos en tiempo real sobre diversos parámetros ambientales cruciales para el crecimiento de los cultivos.

Objetivo: este estudio pretende evaluar la eficacia de la tecnología de sensores inalámbricos para aumentar la producción de los cultivos. Mediante la integración de WST en las prácticas agrícolas convencionales, buscamos optimizar el uso de recursos, reducir los residuos y mejorar el rendimiento de los cultivos.
Métodos: hemos propuesto un modelo de recomendación de cultivos y clasificación de nutrientes del suelo basado en IoT. Al incorporar el aprendizaje automático, la inteligencia artificial (IA), la nube, los sensores y otros equipos automatizados al sistema de ayuda a la toma de decisiones, los agricultores podrán tomar medidas decisivas sin depender por completo de las oficinas agrícolas regionales.
Resultados: el análisis mostró que la parcela que utilizaba tecnología de sensores inalámbricos presentaba un aumento significativo del rendimiento de los cultivos en comparación con la parcela tradicional. Los niveles de humedad del suelo se mantuvieron dentro de unos márgenes óptimos, lo que mejoró la eficiencia en el uso del agua. Además, el sistema automatizado ajustó la aplicación de fertilizantes en función de los datos de nutrientes del suelo en tiempo real, lo que se tradujo en una mejora de la salud y la productividad de las plantas.
Conclusiones: la integración de la tecnología de sensores inalámbricos en la agricultura constituye un enfoque práctico y eficaz para aumentar la producción de los cultivos. Esta tecnología permite controlar y gestionar con precisión los parámetros críticos de crecimiento, lo que se traduce en mayores rendimientos y un uso más eficiente de los recursos. La adopción de WST puede contribuir significativamente a satisfacer la demanda mundial de alimentos, al tiempo que promueve prácticas agrícolas sostenibles.

Palabra clave: Agricultura Inteligente; Sensor NPK; Fertilidad del Suelo; Nutrientes del Suelo; Sensores Inteligentes; Internet de las Cosas; Aplicación Móvil.

INTRODUCTION

Agriculture is an essential part of human life. Agriculture is necessary for our life. In accordance to a latest global population census, India has become the world's most populous country. To feed such a big population, agricultural practices must be developed to boost crop yield. Analyzing soil nutrients is a crucial step in understanding the fertility of the soil and ensuring optimal crop production. The composition of soil can vary widely, and different crops have specific nutrient requirements. Nitrogen is a major component of soil organic matter and contributes to soil fertility. It enhances microbial activity and decomposition of organic matter. Phosphorus is important for soil fertility and is often added to enhance the phosphorus content in deficient soils. Potassium enhances soil structure, Cation Exchange Capacity (CEC), and nutrient availability.[(1)] It also plays a role in balancing nutrient ratios. Soil pH influences nutrient availability. Most crops prefer a slightly acidic to neutral pH (6,0-7,5).

Soil fertility is the cornerstone of successful agriculture, and the triumvirate of nitrogen (N), phosphorus (P), and potassium (K) stands as the primary determinant of soil health and, consequently, crop production. These three essential nutrients play pivotal roles in various biochemical processes that drive plant growth, development, and overall productivity.

Nitrogen (N)

Nitrogen is the engine of vegetative growth and a key component of amino acids, proteins, and chlorophyll. Its availability in the soil directly influences the plant's ability to synthesize essential molecules and harness energy through photosynthesis. Adequate nitrogen promotes lush foliage, vigorous root development, and increased biomass.[(2)] Nitrogen is particularly crucial during the early stages of plant growth when rapid vegetative expansion occurs. Additionally, nitrogen plays a vital role in the nitrogen cycle, contributing to soil organic matter and microbial activity, which in turn sustains soil fertility.

Phosphorus (P)

Phosphorus is the powerhouse behind energy transfer and storage within plants. It is an indispensable element for processes like ATP synthesis, cell division, and the formation of nucleic acids. In terms of crop production, phosphorus is closely associated with root development and flowering.[(3)] A sufficient supply of phosphorus ensures robust root systems, leading to improved nutrient uptake and overall plant resilience. Furthermore, phosphorus accelerates crop maturity, positively impacting the timing of flowering and fruiting. In the realm of soil fertility, phosphorus enhances microbial activity and contributes to the formation of stable soil organic matter.

Potassium (K)

Potassium, the third component of the NPK trio, is instrumental in a myriad of physiological functions within plants. It activates enzymes, regulates water uptake, and enhances overall plant health. Adequate potassium levels in the soil result in crops that exhibit increased stress resistance, improved disease tolerance, and enhanced fruit quality.[4] Potassium also plays a crucial role in maintaining the plant's water balance, mitigating the impact of environmental stresses. Beyond its influence on crop production, potassium contributes to soil fertility by promoting soil structure, Cation Exchange Capacity (CEC), and nutrient balance. It acts as a counterbalance to nitrogen and phosphorus, ensuring a harmonious nutrient environment for plant growth.

The importance of nitrogen, phosphorus, and potassium in soil fertility and crop production cannot be overstated. These three nutrients are intricately linked to the foundational processes that govern plant life, from photosynthesis and energy transfer to root development and stress response. Balancing and optimizing their presence in the soil through targeted fertilization practices are critical for ensuring sustainable and productive agriculture. As we navigate the challenges[5] of feeding a growing global population, a comprehensive understanding of NPK dynamics will be pivotal in fostering agricultural practices that are both efficient and environmentally sustainable.

In this research, we have tried to design a system that will find the nutrients present in the sample soil of the particular ground using IoT based wireless sensors. Based upon the result of the test, farmers would be able to:

- Know which crop is suitable for the given soil of crop-field.
- Know the nutrients that should be applied to the given field.
- Increase the crop productivity.

The efficient management of nutrient resources is paramount in modern agriculture to ensure sustainable crop production. This research paper presents a practical approach to enhancing crop production through the utilization of NPK (Nitrogen, Phosphorus, Potassium) sensor technology.[6] The paper begins by providing an overview of the significance of nutrient management in agriculture and the challenges associated with traditional methods of nutrient application. It then delves into the principles and functionality of NPK sensors, highlighting their ability to accurately measure soil nutrient levels in real-time. The research methodology involves field trials conducted across various agricultural settings to assess the efficacy of NPK sensor technology in optimizing nutrient application.[7] Results from these trials demonstrate the effectiveness of NPK sensors in improving crop yields while minimizing nutrient wastage and environmental impact. Here, figure 1 is showing a typical NPK sensor.

Figure 1. A typical NPK Sensor

Furthermore, the paper discusses the integration of NPK sensor data with precision agriculture techniques, such as variable rate application and site-specific nutrient management, to tailor nutrient inputs based on spatial variability within fields.[8] Key findings reveal that the implementation of NPK sensor technology leads to significant improvements in crop productivity, resource efficiency, and overall profitability for farmers. Moreover, the paper addresses practical considerations for the adoption of NPK sensors, including cost-effectiveness, ease of use, and compatibility with existing farm equipment and management practices. In conclusion, this research paper underscores the potential of NPK sensor technology as a practical and sustainable approach to increasing crop production while mitigating the challenges associated with nutrient management in agriculture.[9] By providing real-time insights into soil nutrient status and enabling precision nutrient application, NPK sensors offer a valuable tool for enhancing agricultural productivity and sustainability in the face of evolving global food demands and environmental concerns.

Research Methodology

The research begins with an extensive review of existing literature on nutrient management in agriculture, including traditional methods of nutrient application, challenges associated with these methods, and the emergence of sensor-based technologies for precision agriculture. Agricultural fields representing diverse soil types, crop varieties, and management practices are identified as study sites. These sites are chosen to ensure the applicability and generalizability of research findings across different agricultural contexts.

- Experimental Design: field trials are designed to evaluate the effectiveness of NPK sensor technology in optimizing nutrient application and enhancing crop productivity. A randomized complete block design

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or a split-plot design may be employed, with treatments including NPK sensor-guided nutrient application and conventional nutrient management practices as controls.

- Data Collection: soil samples are collected from each study site to determine baseline nutrient levels prior to nutrient application. NPK sensors are deployed in the field to continuously monitor soil nutrient concentrations throughout the growing season. Data on crop growth parameters such as plant height, leaf area, biomass accumulation, and yield are also recorded. Here, figure 2 is showing the data collection process in field.

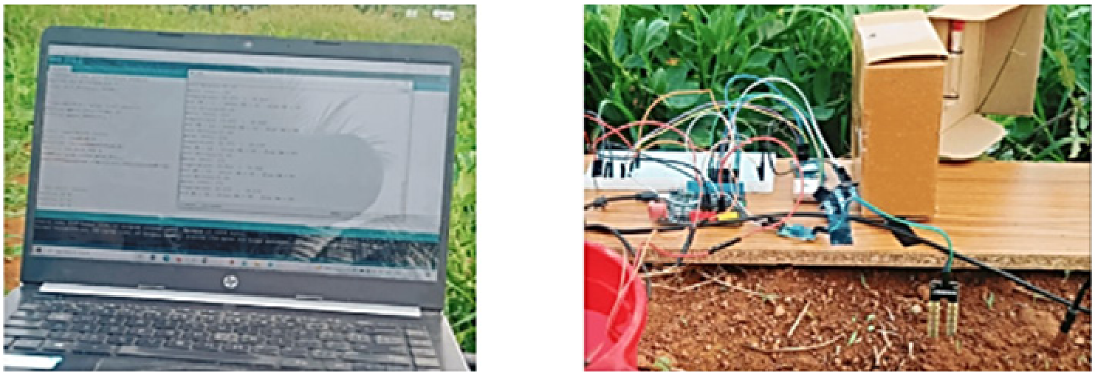

Figure 2. Data Reading on Serial Monitor and arduino connectivity with sensor

- Nutrient Application: nutrient application rates are determined based on NPK sensor readings, with adjustments made according to crop nutrient requirements and recommendations. In control plots, nutrient application follows conventional practices, which may include extensive application rates or predetermined schedules.
- Data Analysis: statistical analysis techniques, such as analysis of variance (ANOVA), regression analysis, and spatial analysis, are employed to compare the performance of NPK sensor-guided nutrient application with conventional practices. Key performance indicators such as crop yield, nutrient use efficiency, and economic returns are assessed to evaluate the efficacy of NPK sensor technology.
- Integration with Precision Agriculture Techniques: the research explores the integration of NPK sensor data with precision agriculture technologies, such as geographic information systems (GIS) and global positioning systems (GPS), to implement variable rate nutrient application and site-specific management strategies.
- Socioeconomic Assessment: in addition to agronomic assessments, the research may include a socioeconomic analysis to evaluate the adoption potential of NPK sensor technology among farmers, considering factors such as cost-effectiveness, ease of use, and perceived benefits.
- Validation and Interpretation of Results: research findings are validated through rigorous analysis and interpretation, considering the practical implications for farmers, agricultural advisors, and policymakers. The implications of NPK sensor technology for enhancing crop production, resource efficiency, and environmental sustainability are discussed in light of the research outcomes.

By following this comprehensive research methodology, the study aims to provide valuable insights into the practical application of NPK sensor technology for increasing crop production and improving nutrient management in agriculture.

Benefits of Sensor-Based Agriculture

By achieving greater accuracy in the application of water and fertilizers, resource efficiency is significantly improved. This precision allows for the optimal use of these essential inputs, minimizing waste and ensuring that crops receive exactly what they need to thrive. Consequently, crop yields see a marked increase due to the finely tuned growing conditions, which support healthier and more robust plant development. Additionally, the environmental impact is greatly mitigated as the risk of fertilizer runoff and leaching is substantially reduced. This careful management conserves natural ecosystems by preventing excess nutrients from contaminating nearby water bodies and soils, thus maintaining ecological balance.[10] The combined benefits of resource efficiency, yield improvement, and reduced environmental impact highlight the importance of precision agriculture in promoting sustainable farming practices. By leveraging advanced technologies and data-driven approaches, farmers can enhance productivity while safeguarding the environment, ultimately contributing to a more sustainable and resilient agricultural system. This holistic approach not only boosts the efficiency and profitability of farming operations but also plays a crucial role in preserving the health of our planet's ecosystems for future generations.[11]

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Traditional Farming Practices

Uniform application of water and fertilizers often leads to inefficiencies in resource use, as not all areas receive the optimal amount needed for maximum productivity. This practice typically results in lower crop yields due to suboptimal growing conditions.[12] Furthermore, the potential for resource wastage and environmental degradation is significantly higher, with excess water and fertilizers contributing to runoff and pollution, harming nearby ecosystems.

METHOD

Experimental Design

- **Study Sites:** two fields of similar size and soil composition, one using sensor technology and the other employing traditional methods.
- **Crops:** a consistent crop type is planted in both fields to ensure comparability.
- **Duration:** one growing season, from planting to harvest.

Data Collection

Data collection encompasses several key areas to enhance efficiency and sustainability. Resource utilization involves the precise measurement of water and fertilizer usage, allowing farmers to monitor and optimize their inputs to reduce waste and improve crop growth. Crop yield is assessed by measuring the total biomass and the quantity of marketable produce, providing a clear picture of the productivity of different farming practices. Environmental impact is analyzed through the examination of runoff water for nutrient content and pesticide residues, as well as regular soil health indicators such as pH, nutrient levels, organic matter content, and microbial activity, ensuring that farming practices do not degrade soil quality or harm surrounding ecosystems. Economic analysis is conducted through a cost-benefit approach, taking into account the initial investment in sensor technologies and the economic returns from increased yields and improved resource efficiency. By integrating these data points, farmers can make informed decisions that balance productivity with environmental stewardship and economic viability, ultimately leading to more sustainable agricultural practices.

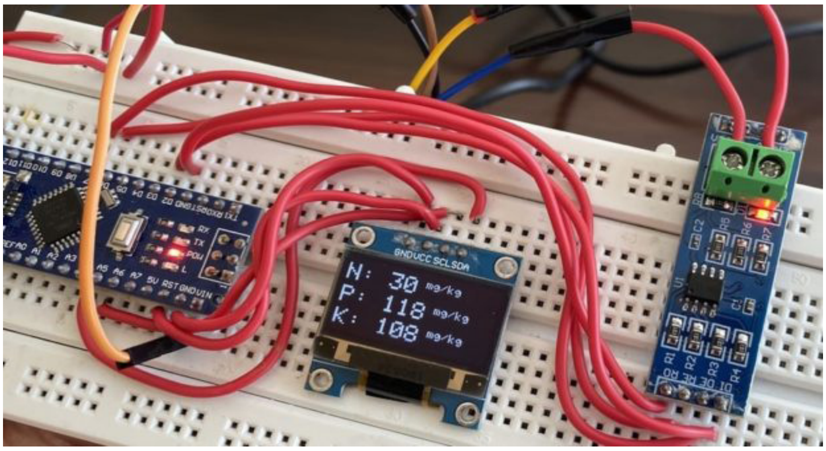

Figure 3. Data Reading of Nitrogen, Potassium and Phosphorus in soil

RESULTS AND DISCUSSION

The findings support the hypothesis that sensor technology significantly enhances crop production efficiency and yield. By utilizing sensor technology, farmers can achieve a substantial reduction in resource use, applying water and fertilizers with greater precision. This precision not only optimizes crop growth conditions but also minimizes waste, contributing to better overall resource management. Additionally, the environmental impact is notably reduced, as more efficient use of inputs decreases the risk of runoff and leaching, thereby conserving surrounding ecosystems. These benefits underscore the sustainability advantages of adopting sensor technology in agriculture.

For farmers, the implications are substantial. Investing in NPK (nitrogen, phosphorus, and potassium) and soil moisture sensors can lead to considerable economic gains by improving crop yields and reducing input costs. The increased efficiency in resource use translates to lower expenses and higher profitability. Furthermore, the environmental benefits align with growing demands for sustainable farming practices, enhancing the long-term viability of farming operations. By adopting these advanced technologies, farmers can not only boost their economic performance but also contribute to environmental conservation, making sensor technology a worthwhile and forward-thinking investment for modern agriculture. This dual advantage of economic and environmental gains makes the case for widespread adoption of sensor technology in farming practices.

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Table 1. Characteristics according to sensors type

Parameters taken	Sensor- Based Fields	Traditional Fields
Resource Utilization	NPK and Soil Moisture Sensors: reduced water and fertilizer use by approximately 30 % compared to the traditional field.	Traditional Methods: higher consumption of resources, often applied uniformly without regard to actual field conditions.
Crop Yield	Yield increase of 20-25 % compared to the traditional field.	Lower yield, with signs of both over-fertilization and under-watering in different sections.
Environmental Impact	Significantly lower levels of nutrient runoff and better soil health due to targeted application.	Higher nutrient runoff, indicating inefficient use of fertilizers and potential environmental harm.
Economic Analysis	Higher initial investment, but greater economic returns due to increased yields and lower resource costs.	Lower initial costs but reduced profitability due to lower yields and higher resource consumption.

CONCLUSIONS

The integration of wireless sensor technology in agriculture presents a practical and effective approach to increase crop production. This technology enables precise monitoring and management of critical growth parameters, resulting in higher yields and more efficient resource use. Adopting WST can significantly contribute to meeting the global food demand while promoting sustainable farming practices. Further research is essential to evaluate the scalability of sensor technology across diverse agricultural settings. Understanding how these technologies perform in various environments will help determine their broader applicability and effectiveness. Additionally, long-term studies are necessary to gain comprehensive insights into the sustainability benefits of sensor-based agriculture. These studies will reveal the lasting impact of using sensors on resource efficiency, crop yields, and environmental health. By investigating both scalability and long-term outcomes, we can better understand the potential of sensor technology to transform agriculture, ensuring it delivers consistent and sustainable benefits across different farming systems.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Formal analysis: Deepa Sonal, Khushboo Mishra, Alimul Haque, Faizan Uddin.
Research: Deepa Sonal, Khushboo Mishra, Alimul Haque, Faizan Uddin.
Methodology: Deepa Sonal, Khushboo Mishra, Alimul Haque, Faizan Uddin.
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