

IMPLEMENTATION OF IoT FOR NUTRITION MONITORING AND CONTROL IN OPTIMIZING HYDROPONIC CROP PRODUCTION IN GREENHOUSE

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Abstract. This community service program aims to enhance the efficiency and productivity of hydroponic kale cultivation by leveraging the Internet of Things (IoT) technology. The activity partners are greenhouse managers in Beurawe Village, Kuta Alam District. The primary challenges faced by partners include limited monitoring tools for pH and EC levels of nutrient solutions, minimal technical expertise, and a lack of knowledge about plant nutrition and digital marketing. The solutions offered include training in the installation and use of an IoT System implemented using pH and TDS sensors connected to a Wemos D1 Mini microcontroller and displaying data in real-time through a digital dashboard, the preparation of a kale nutrient module, the implementation of a data-based automation system, and digital marketing training. This program is expected to increase the efficiency and productivity of hydroponics, especially in nutrient monitoring and control. Increasing the efficiency and productivity of hydroponics, especially in nutrient monitoring and control and being able to increase water use efficiency by up to 15%, reduce nutrient use by 20%, and increase plant productivity by 20%. This activity involves lecturers and students and supports MBKM policies and the development of sustainable technology-based precision agriculture in the community.

Keywords: greenhouse, hydroponics, Internet of Things (IoT), nutrient monitoring

Abstrak. Program pengabdian kepada masyarakat ini bertujuan untuk meningkatkan efisiensi dan produktivitas budidaya tanaman kale hidroponik melalui penerapan teknologi Internet of Things (IoT). Mitra kegiatan adalah pengelola greenhouse di Desa Beurawe, Kecamatan Kuta Alam, Permasalahan utama mitra meliputi keterbatasan alat pemantauan kadar pH dan EC larutan nutrisi, minimnya keterampilan teknis, serta kurangnya pengetahuan tentang nutrisi tanaman dan pemasaran digital. Solusi yang ditawarkan mencakup pelatihan instalasi dan penggunaan Sistem IoT yang diimplementasikan menggunakan sensor pH dan TDS yang terhubung dengan mikrokontroler Wemos D1 Mini dan menampilkan data secara real-time melalui dashboard digital, penyusunan modul nutrisi kale, penerapan sistem otomatisasi berbasis data, serta pelatihan pemasaran digital. Program ini diharapkan dapat meningkatkan efisiensi dan produktivitas hidroponik, khususnya dalam monitoring dan kontrol nutrisi. Meningkatkan efisiensi dan produktivitas hidroponik, khususnya dalam monitoring dan kontrol nutrisi dan mampu meningkatkan efisiensi penggunaan air hingga 15%, menurunkan penggunaan nutrisi 20%, dan meningkatkan produktivitas tanaman 20%. Kegiatan ini melibatkan dosen dan mahasiswa serta mendukung kebijakan MBKM dan pengembangan pertanian presisi berbasis teknologi yang berkelanjutan di masyarakat.

Kata Kunci: greenhouse, hidroponik, Internet of Things (IoT), monitoring nutrisi

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INTRODUCTION

Rising global population, urbanization, and limited productive agricultural land are driving the development of more efficient, sustainable, and environmentally adaptive crop cultivation systems. One approach that is gaining attention is hydroponics, a method of growing plants without soil, in which plant roots obtain nutrients directly from a controlled mineral solution. This system has been proven to increase water use efficiency, optimize planting space, and reduce dependence on soil conditions (Resh, 2019).

Hydroponics is a modern cultivation method that grows plants without soil, where the roots of the plants are immersed in a mineral-rich nutrient solution. This technology is increasingly being applied due to its ability to save more than 90% of water usage compared to conventional systems, through a nutrient solution recirculation mechanism (Sani et al., 2022). In a hydroponic system, all plant nutrient requirements are met through a nutrient solution that is



delivered directly to the roots. An imbalance in nutrient concentration, whether in the form of excess or deficiency, can disrupt plant physiology, reduce the rate of photosynthesis, and cause toxicity or nutrient deficiency (Nguyen et al., 2021). Therefore, the stability of the nutrient solution is a very crucial component.

In hydroponic systems, all plant nutrient requirements are met through nutrient solutions that are delivered directly to the roots. Based on plant nutrition theory, macro and micronutrients must be available in the right concentrations so that physiological processes such as photosynthesis, respiration, and protein synthesis can occur optimally (Marschner, 2012). An imbalance in nutrient concentration, whether in the form of excess or deficiency, can disrupt plant physiology, reduce the rate of photosynthesis, and cause toxicity or nutrient deficiency (Nguyen et al., 2021). Therefore, the stability of the nutrient solution is a crucial component in hydroponic systems.

Kale (*Brassica oleracea* var. *acephala*) is a leafy vegetable that requires very stable nutrient conditions to produce optimal growth in hydroponic systems. Recent studies show that the ideal pH for kale is in the range of 5.5–6.5, while the ideal TDS or EC level is around 1.8–2.5 mS/cm, and small changes in these parameters can have a direct impact on growth and leaf quality (Hidayat et al., 2023). Additionally, excessive EC fluctuations have been shown to increase nitrate levels in plant tissues and reduce the sensory quality of kale leaves (Ahn et al., 2024).

Greenhouse partners face limitations in the use of tools and technology to monitor pH levels and Electrical Conductivity (EC) of nutrient solutions in real time. As a result, farmers still rely on inaccurate manual methods to assess plant nutrient conditions. In addition, limited technical knowledge and minimal training for greenhouse managers result in less responsive adjustments to changes in nutritional requirements. This situation has an impact on the decline in plant quality and productivity.

Theoretically, the concept of precision agriculture emphasizes the use of digital technology to manage agricultural inputs in a timely, precise, and targeted manner (Pierce & Nowak, 1999). In the context of hydroponics, this approach is realized through continuous, data-driven monitoring of nutritional parameters. However, greenhouse partners still face limitations in the use of tools and technology to monitor the pH and EC levels of nutrient solutions in real time. As a result, farmers still rely on manual methods that are periodic, inaccurate, and potentially cause delays in decision-making.

In addition to technological limitations, human resources are also a challenge. The lack of technical training and understanding of nutritional data interpretation means that crop requirements are not adjusted responsively. This situation leads to nutritional instability, reduced productivity, and inconsistent crop quality.

In line with the development of the Industrial Revolution 4.0, the application of Internet of Things (IoT) technology offers innovative solutions in hydroponic system management. IoT enables the integration of pH and EC sensors, real-time data collection systems, cloud-based analysis, and faster and more accurate decision-making (Li et al., 2020). The application of this system not only increases production efficiency but also supports agricultural sustainability through the reduction of nutrient waste and the optimization of resource use.

Through this activity, it is hoped that greenhouse managers can improve their capabilities in sustainable nutrient management. The implementation of an IoT-based system enables real-time monitoring and control of nutrients, making the cultivation process more efficient and precise. This activity aims to empower partners through the application of IoT technology to improve hydroponic efficiency, including device installation, sensor training, digital monitoring, data analysis, and kale marketing strategies.

METHOD

This community service activity was carried out over a period of three months, starting from case studies to the IoT installation process, as well as guidance on IoT usage and digital marketing techniques. The activity took place at the Beurawe Village Greenhouse, Kuta Alam District, Banda Aceh Regency. The activity was carried out in several stages, namely the partner

preparation stage, the implementation stage, and the monitoring and evaluation stage. First, the preparation stage included field surveys to identify partner issues, licensing, and activity planning. Second, the implementation stage included initial socialization and education on the importance of applying IoT technology in hydroponic systems for watering and nutrient control, technical training, installation and operation assistance, and digital marketing strategy training. Third, the monitoring and evaluation stage involves conducting periodic monitoring and evaluation of the success of IoT technology implementation and its impact on productivity, as well as measuring the level of technology adoption by partners.

RESULTS AND DISCUSSION

The implementation of this community service activity went well and according to the predetermined work plan. The activity was carried out in collaboration with the Beurawe Village Greenhouse hydroponic farmer group, with the aim of increasing the efficiency and productivity of hydroponic crop cultivation through the application of Internet of Things (IoT) technology and capacity building in digital promotion management.

Overall, the results of this community service reinforce the findings of previous research and community service that the application of IoT technology in hydroponics has a significant positive impact on efficiency, productivity, and product quality. However, the uniqueness of this activity lies in its comprehensive approach that combines technological aspects, farmer capacity building, and digital promotion strategies. This integrated approach has the potential to become a sustainable community service model that can be replicated in hydroponic farmer groups in other regions. The methods used are as follows (Ramadhan et al., 2025):

Stage 1. Preparation

The preparation stage began with a series of important activities that formed the basis for the implementation of the community service program. This process included field surveys to identify partner issues, particularly those related to hydroponic nutrient instability, difficulties in manual monitoring, and technical obstacles faced by farmers in the Beurawe Village Greenhouse. In addition, the team also obtained permits from the greenhouse manager and related parties to ensure that all activities could proceed smoothly in accordance with applicable procedures. After obtaining a complete picture of the field conditions, the team systematically developed an activity plan, including determining the IoT equipment requirements, installation methods, implementation schedule, and training strategies for partners so that the activity objectives could be optimally achieved.



Figure 1. *Field survey*

Stage 2. Implementation

The implementation stage includes several core activities carried out in a structured manner, starting with initial socialization and education on the importance of applying Internet of Things (IoT) technology in hydroponic systems for real-time monitoring and control of nutrients, followed by technical training related to the introduction of IoT devices, sensor functions, microcontroller configuration, and how to read data through a digital dashboard (Sundaravadivel et al., 2018). Once participants understand the technical basics, the team provides on-site installation assistance in the greenhouse, including sensor installation, calibration, system testing, and network configuration (Cafuta et al., 2021). This activity was then followed by training on system operation so that partners could independently monitor nutrient conditions and maintain the devices (Simbeye et al., 2014; Cho et al., 2018). As additional capacity building, participants were also given training on digital marketing strategies to enhance the branding of hydroponic products, content creation, and the use of social media as a means of market expansion (Fu et al., 2024).



Figure 2. *Application of Internet of Things (IoT) technology in hydroponic systems*



Figure 3. *Digital marketing training*

Stage 3. Implementation

Monitoring and evaluation are carried out periodically to assess the success of IoT technology implementation and its impact on hydroponic crop productivity. These activities include monitoring system performance, sensor accuracy, pH, EC, and TDS data stability, as well as the effectiveness of automatic nutrient control in supporting plant growth (Sulaiman et al., 2025). In addition, the team also evaluates the level of technology adoption by partners through

observation of device usage, consistency of dashboard monitoring, and the partners' ability to perform basic troubleshooting (Brown et al., 2010). The results of this monitoring and evaluation form the basis for system improvements, refinement of assistance methods, and ensure that IoT technology truly provides performance improvements and sustainability in hydroponic cultivation practices at Beurawe Village Greenhouse.

The implementation of community service activities for the Beurawe Village Greenhouse hydroponic farmer group showed results in line with various previous studies and community service programs that emphasized the importance of integrating IoT technology into modern agricultural systems, especially hydroponics. The application of IoT-based pH and Electrical Conductivity (EC) sensors in this activity has been proven to improve the accuracy of nutrient monitoring, accelerate decision-making, and reduce dependence on subjective manual methods.

These results are consistent with the findings of Li et al. (2020), who stated that IoT-based hydroponic systems can improve the stability of nutrient solutions through real-time monitoring, thereby directly impacting the efficiency of water and nutrient use. In this study, the use of integrated sensors and digital monitoring systems resulted in a significant reduction in pH and EC fluctuations, which was also observed in the community service activities in Beurawe Village.

In addition, this community service reinforces the findings of Nguyen et al. (2021), which confirm that nutrient imbalance is a major factor in the decline in small-scale hydroponic productivity. Through IoT-based interventions and sensor data interpretation training, partners in this activity became more responsive to changes in plant nutrient requirements. This shows that strengthening human resource capacity is a key factor in the successful adoption of technology, as also reported in the community service by Sani et al. (2022), which emphasizes that technology without assistance tends to be unsustainable.

From a commodity perspective, the results of this study are in line with the findings of Hidayat et al. (2023), which state that pH stability in the range of 5.5–6.5 and EC 1.8–2.5 mS/cm greatly affect the growth and quality of kale leaves. Greenhouse partners showed an increased understanding of this optimal range, enabling them to maintain more stable nutritional conditions than before the activity was carried out. This stability has the potential to reduce the risk of excessive nitrate accumulation in kale leaves, as identified by Ahn et al. (2024) in their study on the impact of EC fluctuations on the sensory quality of leafy vegetables.

Unlike previous studies that focused solely on technical aspects, this community service activity also integrated capacity building for partners in digital promotion management. This approach complements the findings of Pierce and Nowak (1999) on the concept of precision agriculture, expanding the scope from precision production to post-harvest value management. Thus, this community service not only contributes to increasing production efficiency but also to enhancing the competitiveness of hydroponic kale products through quality- and sustainability-based marketing strategies.

CONCLUSION

The Community Service Program at the hydroponic plant greenhouse partner has had a significant positive impact on increasing production capacity, management efficiency, and community economic empowerment. Through the application of Internet of Things (IoT) technology in pH, EC, and temperature monitoring systems, this activity helps partners optimize nutrient management and plant environmental conditions in real-time, resulting in more stable and productive plant growth. A participatory approach combined with technical training and digital marketing has also improved partners' skills in operating devices, managing monitoring data, and marketing hydroponic products online, which has resulted in improved plant quality, more efficient maintenance time, and expanded market reach. Additionally, this program strengthens business sustainability through institutional strengthening, multi-stakeholder collaboration, and the application of data-driven management. Going forward, planned follow-up actions include the development of an AI-based analytical dashboard, the integration of additional sensors such as light intensity and air humidity, and the preparation of advanced

training modules so that partners can continue to increase productivity and develop technology-based hydroponic business models independently and sustainably.

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