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Implementation of IoT-Based Hydroponic Farming to Enhance Production Capacity and Management of Farmer Groups in Probolinggo Regency

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ABSTRACT

This community engagement program aimed to enhance agricultural productivity and management capacity of two farmer groups in Probolinggo Regency—Poktan Karya Luhur II and Poktan Gebangan Makmur—through the adoption of IoT-based hydroponic farming. Activities included designing and installing deep water culture (DWC) and nutrient film technique (NFT) systems with sensors for pH, EC/TDS, temperature, and humidity; training on hydroponic cultivation and food safety; and workshops on bookkeeping and financial literacy. The results showed that farmers could operate the systems independently, monitor crop conditions in real time, and reduce water and nutrient waste. Production cycles became more stable compared to conventional farming, while managerial capacity improved through better record-keeping and cost analysis. Overall, the program increased productivity, efficiency, and farmer self-confidence, demonstrating that sustainable community empowerment requires both technological innovation and organizational strengthening.

Program pengabdian masyarakat ini bertujuan meningkatkan produktivitas pertanian dan kapasitas manajerial dua kelompok tani di Kabupaten Probolinggo—Poktan Karya Luhur II dan Poktan Gebangan Makmur, melalui penerapan hidroponik berbasis IoT. Kegiatan meliputi perancangan dan instalasi sistem deep water culture (DWC) dan nutrient film technique (NFT) dengan sensor pH, EC/TDS, suhu, dan kelembaban; pelatihan budidaya hidroponik dan keamanan pangan; serta workshop pencatatan keuangan dan literasi finansial. Hasil menunjukkan bahwa petani mampu mengoperasikan sistem secara mandiri, memantau kondisi tanaman secara real time, dan mengurangi pemborosan air maupun nutrisi. Siklus produksi menjadi lebih stabil dibandingkan metode konvensional, sementara kapasitas manajerial meningkat melalui pencatatan keuangan dan analisis biaya yang lebih baik. Secara keseluruhan, program ini meningkatkan produktivitas, efisiensi, dan kepercayaan diri petani, serta membuktikan bahwa pemberdayaan berkelanjutan memerlukan inovasi teknologi sekaligus penguatan kelembagaan.)

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A. INTRODUCTION

The rapid conversion of agricultural land and the limitations of arable space in peri-urban areas necessitate innovations in farming systems that are land-efficient, productive, and sustainable. Hydroponics, defined as a soilless cultivation system utilizing nutrient-rich solutions, has emerged as a promising alternative to conventional farming. This method reduces dependency on land, enables year-round production, and optimizes nutrient uptake through the management of pH and electrical conductivity (EC) within recommended ranges (Cekin et al., 2024).

Alongside these cultivation and technological considerations, Probolinggo Regency's agricultural profile further reinforces the urgency of such innovations. Based on Probolinggo Regency in Figures 2025, the region is a major horticultural producer, yielding 651,716 quintals of shallots and 335,791 quintals of chili in 2024, while fruit production such as mango (2,006,174 quintals) and banana (1,090,704 quintals) also plays a significant role. However, production remains vulnerable to seasonal fluctuations, highlighting the need for more stable and controlled cultivation methods such as IoT-based hydroponics. In Sumberasih Subdistrict—where one of the partner farmer groups in this community engagement program is located—the harvested area for shallots reached 40 hectares, while several other commodities showed minimal or zero production. This variation indicates constraints in land availability, irrigation stability, and overall farming resilience. These conditions highlight the need for more resilient and space-efficient cultivation methods such as Internet-of-Things (IoT)–based hydroponics.

Comparative studies indicate that closed hydroponic systems such as deep water culture (DWC) and nutrient film technique (NFT) deliver higher yields, better water efficiency, and more consistent photosynthetic performance compared to conventional soil-based cultivation. Alongside the advances in cultivation techniques, the integration of the Internet of Things (IoT) has further strengthened hydroponics through real-time monitoring and automation of critical parameters, including pH, EC/total dissolved solids (TDS), temperature, and humidity. IoT-based systems—employing microcontrollers, sensors, and mobile applications allow remote supervision, automated nutrient adjustment, and reduced human error, thereby enhancing reliability and productivity in controlled environment agriculture (Ciptadi & Hardyanto, 2018), (Mashudi et al., 2023). Nevertheless, the adoption of hydroponics and IoT requires careful consideration of food safety and operational risks. Recent studies revealed that the persistence of viral contaminants, such as norovirus surrogates, in nutrient solutions is influenced by temperature, with slower inactivation at 15 °C compared to 30–37 °C. This highlights the importance of managing nutrient solution hygiene and environmental conditions to ensure safe production of leafy vegetables intended for direct consumption (Dhulappanavar & Gibson, 2024), (Yustina Suhandini, 2018). In addition to technical challenges, socio-economic capacity is crucial to sustaining innovation at the community level. The partner groups in this program, Poktan Karya Luhur II in Muneng Village, Sumberasih Subdistrict, and Poktan Gebangan Makmur in Gebangan

Village, Probolinggo Regency, reflect diverse conditions. Poktan Karya Luhur II has traditionally focused on conventional horticulture but faces limitations in farm management and financial record-keeping. Meanwhile, Poktan Gebangan Makmur demonstrates more advanced land use but lacks sufficient knowledge of modern agricultural technology and equipment maintenance. Both groups, however, show strong interest in adopting innovative methods to enhance productivity and competitiveness.

Therefore, the community engagement program was designed to (1) introduce and install hydroponic cultivation systems integrated with IoT-based monitoring, (2) develop standard operating procedures (SOPs) for crop production, system maintenance, and food safety, and (3) strengthen organizational and financial management capacity through tailored training sessions. By combining technological innovation with managerial capacity building, the program aims to improve production performance, product quality, and institutional independence of the farmer groups, thereby contributing to sustainable agricultural development in Probolinggo Regency.

B. METHODS

The implementation of this community engagement program was designed to address the production and managerial challenges of the partner groups, Poktan Karya Luhur II in Muneng Village, Sumberasih Subdistrict, and Poktan Gebangan Makmur in Gebangan Village, Probolinggo Regency. The activities were carried out in several stages, combining technical interventions in hydroponic farming with organizational and financial management training to ensure sustainability (Khairiyakh et al., 2022).

The IoT components used in this program consisted of a set of low-cost and widely available sensors and microcontroller modules. The pH and EC/TDS sensors were commercial hydroponic-grade modules sourced from local electronics distributors, while temperature and humidity monitoring utilized the DHT22 sensor purchased through national e-commerce platforms. A microcontroller unit (ESP32) served as the main data acquisition and wireless communication module due to its integrated Wi-Fi capability and compatibility with Blynk-based monitoring. Additional materials such as PVC pipes, pumps, net pots, and nutrient reservoirs for the DWC and NFT systems were obtained from agricultural supply stores in Probolinggo Regency. The selection of these tools was based on their affordability, field durability, and ease of maintenance to ensure suitability for community-level hydroponic implementation.

To provide a clearer overview of the implementation process, the stages of community engagement are illustrated in the following flowchart as shown in Figure 1.

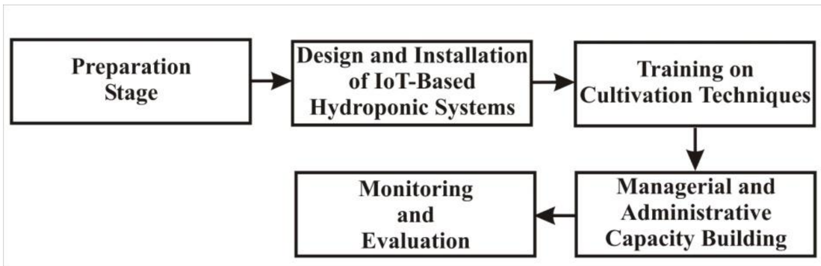

Figure 1. Flowchart of Community Engagement Methods

1. Preparation Stage

The team conducted preliminary surveys and coordination meetings with both partner groups to identify local conditions, available resources, and priority needs. Baseline assessments included observations of existing farming practices, farmer knowledge of hydroponics, and financial record-keeping capacity.

2. Design and Installation of IoT-Based Hydroponic Systems

A hydroponic greenhouse facility was designed and constructed at the partner sites. The system utilized deep water culture (DWC) and nutrient film technique (NFT) setups, equipped with IoT sensors for monitoring pH, EC/TDS, temperature, and humidity. The sensors were integrated with a microcontroller platform connected to a mobile application to enable real-time monitoring and data recording. This stage also included the development of operating manuals and maintenance schedules tailored to the partner's capacity.

3. Training on Cultivation Techniques

Training sessions were conducted to enhance farmers' technical skills in hydroponic farming. The topics covered seed selection, preparation of nutrient solutions, calibration of IoT sensors, daily monitoring procedures, and food safety practices. Demonstrations and hands-on practice were emphasized to ensure knowledge transfer.

4. Managerial and Administrative Capacity Building

In parallel with the technical training, workshops were held on financial literacy, farm bookkeeping, cost analysis, and simple business planning. The training modules were adapted from prior community empowerment programs that proved effective in improving knowledge and productivity .

5. Monitoring and Evaluation

Program outcomes were monitored using both qualitative and quantitative indicators. Technical performance was assessed through crop growth rates, yield per cycle, and system stability. Managerial outcomes were tracked through improvements in record-keeping practices and partner feedback. Regular evaluations and mentoring sessions were conducted to ensure that both Poktan groups could independently operate and maintain the hydroponic systems.

Overall, the methods combined technology transfer (hard system: hydroponics and IoT) and capacity building (soft skills: management and administration) to ensure that the community partners gained both technical proficiency and organizational resilience.

C. RESULTS AND DISCUSSION

Community Engagement Activities on Technology Implementation

The introduction of IoT-based hydroponic systems was successfully carried out in both partner groups, Poktan Karya Luhur II in Muneng Village, Sumberasih Subdistrict, and Poktan Gebangan Makmur in Gebangan Village, Probolinggo Regency. The installation of greenhouse units and hydroponic facilities (deep water culture and nutrient film technique) was completed with integrated IoT sensors for monitoring pH, EC/TDS, temperature, and humidity. The sensors were connected to mobile applications, enabling real-time monitoring and reducing the dependence on manual supervision. This technological transfer provided tangible improvements for the partners.

A comparative assessment between the two partner groups shows distinct outcome patterns. Poktan Karya Luhur II, which initially had limited experience in farm management and financial recording, demonstrated the most improvement in administrative capacity. Their adoption of bookkeeping tools and cost-tracking procedures increased consistently after the training sessions. Technological adaptation progressed more gradually due to lower digital literacy, and additional mentoring was required during sensor calibration and IoT system operation.

For Poktan Gebangan Makmur, participants showed strong interest in adopting IoT-based hydroponic technology and reported clear improvements in their understanding of sensor functions, nutrient monitoring, and system maintenance. However, the group has not yet implemented the hydroponic system on-site, as their current facilities are not fully prepared for installation. Consequently, further mentoring and follow-up assistance are needed to support the transition from knowledge acquisition to practical application. At this stage, hands-on practice and operational training were conducted primarily at Poktan Karya Luhur II, while Poktan Gebangan Makmur remains in the preparatory and capacity-building phase.

Figure 2. Impact on Productivity and Community Empowerment

Farmers reported increased confidence in maintaining consistent nutrient conditions, while the use of mobile notifications enhanced responsiveness to fluctuations. The system also reduced water and nutrient waste, aligning with prior studies that demonstrated the efficiency of IoT in optimizing hydroponic farming (Ciptadi & Hardyanto, 2018).

Training Outcomes in Cultivation and Management

Figure 2. Hands-on training session with farmer group members on hydroponic cultivation and IoT monitoring.

Hands-on training sessions on hydroponic practices improved the technical skills of farmers in seedling preparation, nutrient mixing, and calibration of IoT devices. Partner groups demonstrated the ability to independently operate and troubleshoot basic system issues, showing an encouraging level of technological adaptation. In addition, managerial training in bookkeeping, financial planning, and cost-benefit analysis equipped the groups with tools to record production expenses and evaluate economic feasibility (Mashudi et al., 2023). The combination of technical and managerial training had a synergistic effect. Improved technical performance was supported by better financial management, ensuring that increased yields could be translated into more sustainable group income. This mirrors earlier empowerment programs which confirmed that organizational strengthening is critical to sustaining technological adoption.

Impact on Productivity and Community Empowerment

The short-term impact of the program can be observed in improved productivity and efficiency. Partners reported that the hydroponic system allowed for more stable production cycles compared to traditional soil-based cultivation. The integration of IoT monitoring provided not only higher efficiency but also enhanced transparency of operational data, which may serve as a basis for future scaling. From a socio-organizational perspective, the program enhanced farmer self-confidence and fostered collaborative decision-making within the farmer groups. The structured financial records also provided opportunities for better access to funding and external collaboration. These results align with previous findings that technology-based community empowerment must be accompanied by management strengthening to achieve long-term sustainability (Awal et al., 2025).

Reflection and Challenges

Although the program demonstrated positive outcomes, several challenges were identified. First, limited digital literacy among some group members slowed down the adaptation to mobile-based IoT systems. Second, technical maintenance, such as sensor recalibration and nutrient solution adjustments, still required continuous mentoring to ensure sustainability. Third, market access for hydroponic products remained a concern, highlighting the need for future activities that connect farmer groups with local businesses, schools, or cooperatives to secure stable demand.

Table 1. Before–After Comparison of Community Engagement Outcomes

No	Before Program	After Program
1.	Conventional holticulture, dependent on soil and season	Hydroponic farming using DWC and NFT with greenhouse facilities.
2.	No. systematic monitoring of PH, EC, or water quality	IoT-based monitoring of PH, EC/TDS, temperature, and humidity.
3.	Limited book keeping and finansial records	Improved bookeeping and finansial literacy through training
4.	Low confidence in adopting modern farming technology	Higher confidence and ability to operate IoT hydroponic systems

As shown in Table 1, the transition from conventional horticulture to IoT-based hydroponic farming marked a significant shift in farming practices among the partner groups. Prior to the program, cultivation heavily depended on soil conditions and seasonal variations, while financial management and record-keeping were minimal. After the program, both farmer groups successfully adopted hydroponic techniques using DWC and NFT systems equipped with IoT monitoring, which allowed more precise control of nutrient and environmental parameters. Moreover, the managerial training enhanced bookkeeping capacity and financial literacy, enabling farmer groups to track costs and evaluate profitability more systematically. Importantly, the program also strengthened farmers' confidence in operating modern farming technologies, fostering a sense of independence and readiness for scaling the practices in the future. These outcomes confirm that combining technology transfer with organizational strengthening is an effective strategy for sustainable community empowerment.

D. CONCLUSION

The implementation of IoT-based hydroponic farming in Probolinggo Regency has demonstrated positive outcomes for both partner groups, Poktan Karya Luhur II in Muneng Village, Sumberasih Subdistrict, and Poktan Gebangan Makmur in Gebangan Village. The program successfully introduced hydroponic systems equipped with IoT monitoring, enabling farmers to maintain optimal nutrient and environmental conditions more effectively than in conventional soil-based farming. In addition to the technological transfer, the managerial and administrative training provided significant improvements in financial literacy, record-keeping, and organizational capacity. These skills supported the sustainability of the technological innovations by ensuring that production gains could be translated into long-term economic benefits for the farmer groups. Overall, the program enhanced productivity, efficiency, and farmers' confidence in adopting modern farming technology. Furthermore, the integration of technical and managerial interventions fostered greater self-reliance and organizational resilience. Nevertheless, challenges remain, particularly in ensuring continuous digital literacy improvement and securing broader market access for hydroponic products. Future community engagement activities are recommended to focus on strengthening marketing channels and providing ongoing mentoring to sustain and scale the achievements of this initiative.

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F. AUTHOR CONTRIBUTIONS

Yustina Suhandini Tjahjaningsih and Mimik Umi Zuhroh were responsible for implementing the community engagement activities, while Yustina Suhandini Tjahjaningsih and Ira Aprilia prepared the manuscript. The impact analysis was carried out by Andrik Sunyoto and Mimik Umi Zuhroh. Yustina Suhandini Tjahjaningsih presented the results, and Ira Aprilia revised the article. Only authors who directly contributed to the activities and manuscript preparation are included, and each author participated according to their respective roles and responsibilities in both the community engagement program and the writing of this article.

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