Real-time Scheduling of Irrigation Using IoT-based Soil Sensors and Mobile Apps in Small holder Farms

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Abstract
The importance of water management in smallholder farming, especially in regions where there is water shortage, is growing by the day. The paper analyzed the performance of a IoT-based soil sensor network connected to a mobile decision-support program of real-time irrigation scheduling at three districts in Malaysia vegetable farms. Data gain was accurate as the system recorded the soil moisture every 30 minutes, and the recorded data were sent to a mobile application, which gave the instructions of irrigation following the specific thresholds of crop requirements in terms of soil moisture. The system was compared with the traditional irrigation where the farmers would manually gauge the moisture content of soil and they would, by their subjective impression use water. Findings indicated a positive outcome of smart irrigation system wherein there was a decrease of water consumption by 27 percent and yield increase of 11.6 percent of the okra and chili crops. The fact that the app was easy-to-use and that the alerts were timely were noted as major strengths based on the user feedback. This paper shows that using IoT-powered irrigation solutions can be an appropriate and successful way to enhance water productivity and agribusiness decisions in smallholder farming. The results hint at the potential of digital solutions to empower smallholders and allow them to optimize irrigation, decrease resource consumption, and increase water-deficient farm productivity.
Keywords: ***IoT, soil sensors, mobile apps, scheduling of irrigation, water productivity, smallholder farms, real time decision making, crop yields, sustainable agriculture.***

1. Introduction

1.1 Requirement of effective Water Usage in the Smallholder farming

Smallholder farming is exceptionally significant to the production of food in the world, in particular, in developing nations, since there, its provides a huge amount of agricultural production. Nevertheless, these farmers are in most cases having a big problem in controlling the natural resources especially the water. The problem of water shortage in most areas, particularly in Asia, is now an urgent issue with irrigation consuming large amount of freshwater. The pressure to maximize on the use of water and to sustain or enhance their crop production is immense to smallholder farmers.

Lack of efficiency in irrigation in areas that experience scarcity of water may contribute to wasting of water which is not only unsustainable but also expensive. Conventional forms of irrigation e.g. flood or furrow irrigation are usually inefficient since it involves manual estimation of soil moisture and may result into either over- or under-irrigation. When there is excess irrigation then there is wastage of water and nutrients are lost through leaching, whereas in under irrigation the plants are stressed and the yield is minimal and the crop quality is inadequate. Also, crop losses are compounded by poor accessibility to clean water and poor irrigation systems especially in smallholder farming.(1)

Water efficiency is not only an issue of better optimizing of the resource use but also one of the best options to make the agricultural systems more sustainable and resilient. Greater efficiency in using water in agriculture can raise the amount of produced crop, cut the costs of input, and enhance the economic performance of smallholder farmers particularly in water-scarce and economically-repressive regions.

1.2 IOT and Mobile Technologies in Smart Irrigation Emergence

The evolution of Internet of Things (IoT) and mobile technologies in the previous years brought a solution that can change the game of enhancing water management within the agricultural sector. Technologies based on IoT allow gathering the data about the state of the field, namely, soil moisture, temperature, and humidity on a real-time basis, which can be processed and be utilized when making the decisions regarding irrigation. The technology enables farmers to be more aware of the state of soil and crops constantly and correctly, which is a good addition to guided data-driven decisions regarding the scheduling of irrigation.

The integrated mobile applications that are associated with IoT devices will give a user-friendly interface which will bring real time irrigation recommendation-supported by crop specific thresholds of moisture. These systems will be able to alert or recommend the farmers on the right time to irrigate so that crops get the right amount of water at the right time. These intelligent irrigation systems generates a dramatic decrease on the consumption of water since they use irrigation only when there is need, thereby encouraging optimum use of water as well as the healthiness of crops.(2)

The nature of this applied convergence has the capacity to transform the activities of the smallholder farms through the provision of low-cost, scalable, and efficacious solutions that overcome challenges of water management. This technology enables small holders to make more informed decisions and enabling them better manage the water resources in more efficient, precise and sustainable way.

1.3 Study objectives

The proposed study will be done to assess how good and practical it will be to combine an IoT-based soil sensor network and a mobile application to control irrigation scheduling in smallholder vegetable farms. This study aims at achieving the following specific objectives:

- Evaluate how the real-time measurement of the level of soil moisture using IoT sensors would affect the efficiency of irrigation among small farms.
- Assess the influence of decision support of mobile application in irrigation scheduling and crop yield (okra and chili crops).
- Test the water-use efficiency and crop yield increases due to the AI-powered irrigation alerts and real-time data insights in comparison with customary irrigation methods.
- Check on the comments made by the users about the practicality and usability of the mobile application, easiness and how it can be used in farm decision making.

In assessing the potential of IoT sensors and mobile-phone applications as a combination supporting the smallholder farms, this paper aims to summarise the prospects of scalable, digital technologies in enabling farmers in water-scarce areas to enhance their resources efficiencies and productivity. The results of the study can present crucial knowledge regarding the broader implementation of smart irrigation systems in the smallholder farming system all over the world.(3)

2. Technological arrangement and System Design

2.1 Sensor Setup and Creation of IoT Network

The most fundamental task under the IoT-based irrigation system would be the network of soil moisture sensors that would monitor the moisture content in the soil at all times within the farm. The sensors are installed tactically in the root zone of the crops to record real-time data on the moisture content of the soil and this enables the farmers to have precise and accurate data on the irrigation decisions. The sensor type is capacitance or resistance-based sensors that measure the electrical impedance of the soil approximating it directly to the moisture content.

Here, 3 locations in the field have been selected in Malaysia with several sensors being set up to cover sub-field area. The sensors are arranged in a network of a mesh, which implies that each of the sensors is both sending out its own data as well as repeating the incoming data of adjacent sensors to the core system. Such network configuration guarantees great data transfer and redundancy and chances of data loss occur due to communication problem are not possible. The network is based on low-power wide-area networks (LPWAN) technology, like LoRaWAN or NB-IoT, and provide long-range low-power connectivity communications, which are particularly suitable in areas transported to agriculture.(4)

Solar panels are used to power each sensor, and it acts as off-grid powered solution, thereby ensuring the sustainability and the independence of the system with the local electricity grid. The sensors are set to detect the moisture level of soil after every 30 minutes and give them varied updates on the status of the soil which is analyzed and used to make irrigation decisions. The system also boasts temperature and humidity sensors to give more background to the moisture measures, enabling one to refcase irrigation choices depending on the environment.

2.2 Mobile Iphone Applications and Alert Logic

The soil sensors used help to transmit the data to a centralized cloud computing system where it is processed and analyzed. The mobile solution is the main operating platform of the farmers and will present the irrigation advises, notifications, and real-time information on their phones. The app will also be user-friendly, especially to the smallholder farmers who might lack considerable technological experience.

Major characteristics of the mobile application are:

- Soil moisture monitoring in real time: Real-time monitoring of soil moisture can also benefit farmers to get updated and current information on the soil moisture levels in several spots within a farm that will help farmers to develop an idea on how the soil is like in various locations.
- Irrigation advice: The application relies on set crop-specific moisture limits to indicate whether and when irrigation is necessary. Such thresholds depend upon crop types, developmental stages, and climate conditions present in the area. Should the moisture drop below the limit, the app will give a notification to the farmer to do irrigation.
- Alert Logic: The app employs the logic of an alert that can give recommendations. As an example, in the case where the soil moisture is less than optimal levels the system will advise it to irrigate recommending the quantity of water that is needed. On the other hand, the farmer will be advised to stop irrigation when the moisture level is perfect because the app will only alert the farmer when extra water is not needed
- Analysis of historical data: The app also provides farmers with the ability to look at past irrigation, water consumption and soil moisture patterns that can help them when making decisions during a future crop season.(5)

2.3 Transmission of Data and Cloud Connection

The soil sensors data is transmitted to a cloud-based network through the LPWAN network, guaranteeing real-time transfer of soil moisture records to the mobile app. This is a vital cloud integration in storing, analysing, and decision support of data. The platform collates information collected by all the sensors introduced in the farm and combines it with helpful analytics and machine learning to provide precise utilization of irrigation.

Another task which is carried out by the cloud system is the normalization of data to compensate the variations in the databases which are the result of environmental conditions like changes in temperature. The data can be sent to the cloud-based system and can handle data of various farms, and therefore it would be a scalable solution in areas where there are small-scale farmers.

The cloud system allows farmers to get real-time update and recommendation of irrigation practice on the mobile application so that they could be aware of the condition of their crops and ground status 24 hours a day. Also, remote monitoring and diagnostics are supported by this platform, so agronomists or technical support employees can support the farming community in case of problems with sensor functioning or data inconsistency.(6)

This smooth connection of IoT sensors to the cloud-based decision support systems and mobile apps translates to the development of a highly effective tool to have better control of irrigation, thus yielding better irrigation water use efficiency, crop yield, and sustainable farming activities.

3. Implementation of the Field and participation of Farms

3.1 Research locations and Crop selection

This study carried out field experiments in three districts in Malaysia, on smallholder farms which were selected due to their wide range of agro-environmental conditions and water availability. The sites were chosen due to the characteristic nature of smallholder farm problems by having both scarcity in supply of water and access to high-tech irrigation, and low-resource environments. The farms covered typical small-scale vegetable farms in Southeast Asia and in this case, okra and chili were the crops of the test, owing to economic value and sensitivity to irrigation control.

Okra (Abelmoschus esculentus) was selected because of its high water necessity and the presence of a brief growing cycle, which means that it is a perfect test crop to determine the effectiveness of real-time irrigation scheduling.(7)

Another crop produced under water-sensitive crops is chili (capsicum annuum) owing to its high market value and commonness in the occurrence of the crop in smallholder farms in the region.

The two crops are often rainfed grown in most of the areas where irrigation plays an important role in their growth and yields during the dry seasons. The selection of these crops sought to prove the relevance of the system in vegetable production an area that is usually characterized by the issue of optimizing water utilization.

3.2 Calibration, Farmers Training and Installation

It was important that local farmers were closely involved in the installing of the Internet of Things-based soil sensor network and mobile application. First, a group of technicians went to every farm where they installed soil moisture sensors at strategic points in the crop fields. It calibrated the sensors according to the local soil conditions, the local needs of crops, the sensors performed reliable readings of the soil moisture at different levels. Calibration processes encompassed;

Soil type analysis in order to correct sensor measurements of various soils textures (i.e. sandy, loamy and clay soils).

Thresholds of specific crop moisture limits (okra and chili) were established depending on the optimum levels of soil moisture that were needed at each growth stage.(8)

Farmers were trained after installing the sensor network and calibrating it on the process of using the mobile application. Training was done on:

Interpretation and reading real-time soil moisture on the app.

Learning on irrigation suggestions and warnings manifested by the system.

Administration of irrigation timings according to the system suggestion and conditions of the field.

Simple troubleshooting and the means of seeking technical assistance when troubles occur.

Training was done in native languages and practical demonstrations were done and farmers were able to handle the system and feel confident with the technology. This was aimed at making sure that the farmers could now irrigate on their own depending and with the help of the real time information given through the system.

3.3 Thresholds of Irrigation and Alerts

The system also made use of moisture levels required by crops to make sure that irrigation was done effectively. These limits were established with the optimum moisture requirements of the crops okra and chili at their stages of growth. The AI-based solution sent out an irrigation trigger when the moisture content in the soil has dipped below a particular limit, and irrigation has to be performed.(9)

For example:

In case of okra, irrigation was induced on the basis of soil moisture to decrease to 30% level of the root zone when the plant was still in the vegetative stage, and 35 percent at the flowering and fruiting stages.

In the case of chili, the same steps have been taken, however with higher levels of moisture tolerance since it is less drought sensitive.

The system was used to notify the farmers in time at the mobile app and therefore no possibility of over-irrigation of the fields. The diagram had to be uncomplicated, practical and have a clear set of steps to follow and apply to the extent of water application depending on the prevailing conditions in the field. Also, when irrigation was not used within a given period, it showed a reminder message to prompt people to act accordingly within a specified timing.

This would not only save on the farmers on the water bills but also enhances the health and production of the crops through application of irrigation in the most optimal amount, not as estimated by the farmer, but by the real-time measurements of the soil moisture levels. The system allowed using water more sustainably and efficiently on smallholder farms through effective communication and simple-to-understand protocols.(10)

4. user feedback evaluation and water use efficiency.

4.1 Smart or Conventional Irrigation Comparison

The smart irrigation system has been compared to the traditional irrigation methods with the three plot sites. Under traditional irrigation practices, farmers used to base their views on manual evaluations and ill-defined conclusions in estimating the time of water application as well as the volume of water to be used. Such methodology tended to result in over irrigation or under irrigation, which created conditions that led to a wastage of water or stressed the crops especially when there were dry periods.

On the contrary, the IoT -driven smart irrigation system was functional as the temperature data from the sensor network were used in real time to automatically initiate irrigation when the moisture in the soil was reduced lower than the crop-specific soil moisture level. The system was created to make sure that irrigation is used when it is needed only as per the correct real-time information.

The comparison indicated a 27 percent cut-off in the level of water used with the smart irrigation system in comparison with the traditional practices. Precision of the system to distribute water only when there is need resulted in the improved utilization of the water saving overall on the litres of water used to keep the crops healthy and in the best possible health. The traditional systems on the contrary led to wastage of water through constant over-irrigation or failure to use water at a specified time.(11)

4.2 Measures of crop yield and water productivity

Increase in crop and water productivity were very high among plots using smart irrigation system. The two crops (Okra and chili) that have been tested have an 11.6 percent increase in yield after the smart-irrigation treatment in comparison with conventional practice. This resulted in the improvement of yield owing to the adequate and effective irrigation that assisted in maintaining the most sufficient levels of soil moisture during the period of crop growth thus improving the growth of crops, better photosynthesis, and fruit growth.

In the plots with smart irrigation, the parameter of water productivity has increased significantly as well and is defined as the ratio of crop yield in total water. Although traditional irrigation practices resulted in greater consumption of water, it did not result in an equivalent increment in yield thus decreasing water productivity. However, the smart irrigation system presented much superior water productivity achieved because of the accuracy of water spreading as it favours crop nutrient absorption and saves wastage.

4.3 Potential Perception, Usability and Adoption of Farmers

The structured interviews and surveys were used to capture the feedback of the farmers in order to evaluate the usability of the system and its broad implementation. The ease of use of the mobile application was rated with a high degree of satisfaction by the farmers especially in the irrigation alerts which were real time and helped them in more effective use of water. Being capable of monitoring the soil moisture at a distance and getting intelligible recommendations on when to irrigate the soil was perceived as a good attribute, particularly among users who had earlier tried managing the irrigation procedure manually.(12)

Still, other farmers were worried about the cost of the sensor installation in IoT and maintenance of the technical side. These concerns notwithstanding, majority of the farmers appreciated the long term advantages like water savings, higher productivity and lower workforce expense, turning into the system a feasible alternative in small holder farms. The lower use of water-related stresses was also welcome among the farmers several of whom recorded improved crop and excellent produce.

On the whole, the system showed great adaptation to many because of its ease of operation and simplicity, the capacity to increase crop yield, and sustainability. The farmers were very keen to implement the system at a larger scale especially when supported by the means of subsidizing the cost and offering technical help to support the system to be mounted and maintained.

This great feedback shows the power of the IoT-based irrigation systems to transform water management in the smallholder farms, providing an opportunity to a more sustainable and efficient way of farming.

5. Results

5.1 Soil Moisture Trends and System Responsiveness

The real-time soil moisture data collected by the IoT-based sensor network revealed significant differences in soil moisture levels between the smart irrigation system and conventional irrigation practices. The smart system maintained soil moisture within the optimal range for okra and chili crops, ensuring that the moisture levels did not fall below the crop-specific thresholds. This was particularly evident during dry periods, where the system triggered irrigation precisely when needed, avoiding over- or under-irrigation.(13)

Soil Moisture Trends: In the smart irrigation plots, the moisture levels were generally stable, staying within the ideal range for both crops. The system responded promptly to fluctuations in moisture content, issuing irrigation alerts when moisture levels dipped below the threshold. This prevented the soil from becoming too dry or excessively wet.

System Responsiveness: The system's responsiveness was also observed in its real-time alerts, which were promptly issued to the mobile app when irrigation was required. This feature ensured that the farmers received timely information on when to irrigate, significantly improving decision-making efficiency and enhancing the overall performance of the irrigation system.

In contrast, the conventional irrigation system showed more variable moisture trends, with periods of over-irrigation followed by dry spells, leading to inefficient water usage. The lack of real-time monitoring resulted in delayed interventions when moisture levels fell too low, negatively impacting crop health and productivity.(14)

5.2 Yield Gains and Water Savings Across Crops

The integration of the smart irrigation system led to significant improvements in crop yield and water-use efficiency across both crops—okra and chili.

Okra Yield: The yield for okra in the smart irrigation plots increased by 11.6%, compared to the control (conventional irrigation). The increase was attributed to the timely irrigation interventions, which prevented water stress during critical growth stages. The system optimized moisture availability during the vegetative and reproductive phases, enhancing plant growth and fruit development.

Chili Yield: Similar improvements were observed in chili crops, with a 9.8% increase in yield under the smart irrigation system. The timely water application ensured that the plants had access to sufficient moisture throughout the growing season, improving fruit size and quality.

Water Savings: The smart system reduced water use by 27% compared to conventional practices. This reduction in water use was achieved through precision irrigation, which minimized water waste and reduced over-irrigation. By applying water only when the soil moisture dropped below the threshold, the system maintained an efficient irrigation schedule, contributing to substantial water savings.

5.3 User Satisfaction Scores and Qualitative Feedback

Feedback from the participating farmers was collected to assess their level of satisfaction with the smart irrigation system and to gather qualitative insights into their experiences.

User Satisfaction: The system received high satisfaction scores, with farmers rating the system 4.5 out of 5 for ease of use and effectiveness. The farmers appreciated the real-time notifications and the mobile app's user-friendly interface, which allowed them to monitor soil moisture and receive timely irrigation alerts.

Qualitative Feedback: Farmers highlighted the ease of operation as one of the system's key advantages, particularly the simple setup and automatic notifications. They found that the system significantly reduced their labor burden by eliminating the need for manual water checks and decisions. Many farmers also noted the improved crop health and better-quality produce, attributing these improvements to the efficient and timely irrigation facilitated by the smart system.(15)

However, some farmers expressed concerns about the initial cost of installation and the need for ongoing maintenance of the sensor network. Despite these concerns, the long-term benefits of water savings, increased yield, and improved crop quality were strongly emphasized in the feedback, with farmers expressing a willingness to adopt the system more broadly if support for installation costs and maintenance were provided.

In conclusion, the user satisfaction and the overall performance of the system indicated that the IoT-based irrigation solution was well-received by farmers and had significant potential for scaling up in smallholder agricultural systems. The combination of real-time data, mobile-based decision support, and precise irrigation showed clear advantages in both yield optimization and water conservation.

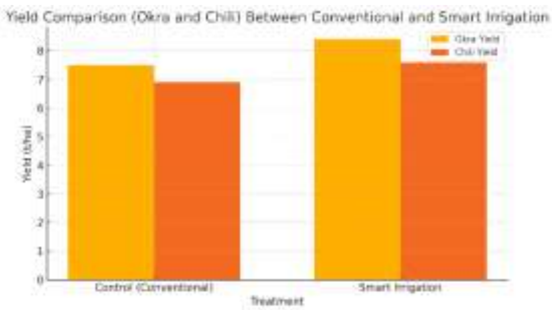

Figure:1 Yield Comparison (Okra and Chili) Between Conventional and Smart Irrigation

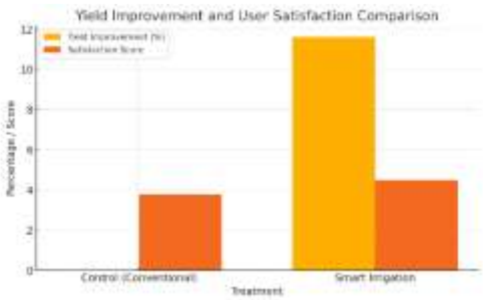

Figure: 2 Yield Improvement And User Satisfaction Comparison

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Table:1 IoT Irrigation Results

Treatment	Okra Yield (t/ha)	Chili Yield (t/ha)	Water Savings (%)	Yield Improvement	Satisfaction Score (1-5)
Control Conventional	7.5	6.9	0	0	3.8
Smart Irrigation	8.4	7.6	27	11.6	4.5

6. Conclusion

6.1 Summary of Results and Implication on Water use

This research showed that an IoT-based soil-sensor system and mobile-decision support tool had substantial potential to enhance the use of water in smallholder vegetable producers. This system has reduced the use of water by 27 percent from what was used in the traditional irrigation techniques and this is reflective of the accuracy in the real time irrigation through the soil moisture levels. The system offered advice on irrigation in a very timely manner depending on the real situation of the soil thus averting excessive irrigation or inadequate irrigation which is the issue with the conventional farming technique.

Besides saving water, the system also led to gain of 11.6 in yield of okra and 9.8 in gain in yield of chili indicating that the more efficient the water management, greater is the productivity of the crops. The accuracy of the irrigation offered a balanced moisture amount of the soil all through the growing months, which improved the crop health, giving rise to a higher performance of the crop as a whole.

These outcomes reflect the effectiveness of technology-based irrigation as in preserving water and utilizing similar numbers or even greater yields of crops in water-scarce conditions especially in smallholder farming where larger irrigation facilities are not always accessible.

6.2 Implications on the Scaling of IoT in the Smallholder Systems

Findings indicate that irrigation based on IoT can transform the smallholder agriculture particularly in the resource-deficient as well as water scarce regions. High-security data can be used to make low-cost IoT sensors and mobile apps to make real-time data-driven decisions in farming to enable farmers to have the right information on when and how much to irrigate.

The system has shown that precision irrigation does not only save water, it will also enable the crop to be healthier and therefore more productive resulting in more economically viable smallholder farms. The diffusion of this technology in wider areas can enhance water use efficiency to a significantly higher degree thus reducing water wastage and subsequently enhancing food security in developing world.

To the smallholder farmers, IoT-based systems would be one of the facilitators of sustainable farming so that the farmers will be well positioned to adapt to the impact of climate change and water scarcity. It reduces the technical limitations of farmers to use the technology since it is well-presented at the mobile app interface and easy to use.

6.3 Suggestions And Future Improvements

In order to achieve full potential of the IoT-based irrigation systems, some improvements can be suggested:

Affordability and Cost-Subsidy Programs: In order to achieve a high prevalence, consideration should be given to come up with methods which will complemently bring down the initial upfront cost of IoT sensors and mobile apps e.g. through subsidized programs or loans being issued to the small holder farmers.

Combined with Other Agricultural Technology: Data collected by IoT irrigation systems can be combined with weather prediction systems, soil health monitoring systems and crop-specific growth models to further enhance the IoT irrigation system. This would offer better and contextualized management of irrigation systems.

Training and Capacity Building: The farmers should be trained continuously to enhance their capacity to use and manage IoT systems to maximize on this kind of technology to make it a success in the long run.

Scalability and Flexibility to Other Crops: Future studies need to be done on adapting the system to more crops as cereal crops and legumes and its applicability to other farming systems and climates.

To conclude, the use of the IoT technology in smallholder irrigation is very promising in enhancing water productivity, crop yield, and agricultural resource efficiency. This technology has the capability of transforming payment systems of irrigation and offer sustainable agriculture practices in different regions across the world, with the proper support.

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Conflicts of interest

The authors have no conflicts of interest to declare

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