A Smart Water Management in a Paddy Field Using IOT Technology and Machine Learning

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Received : April 15, 2021
Revised : January 23, 2021
Accepted : January 27, 2021

Abstract

Alternative Wetting and Drying (AWD) is one of favorable rice growing methods since it lowers the costs for about 40% from less consumption of water, insecticide and fertilizer. This paper proposes a water management tool to help AWD rice farming. We design the tool with a combination of precision agriculture and smart farm from applying IoT and AI technology. Soil humidity and water level detection sensor are deployed to realize real-time and accurate essential environmental factors in a field while a pipe water-pump operated using electricity is designed to handle water in a field. The pump and sensors are connected with a network for an automatic operation using IoT. For decision-making, supervised learning technique is used to generate a model capable to consider when to operate a water pump from past data. This allows flexibility in generating decision-making rules for variation of locations and soil types with a requirement of having past data. From evaluations, experts satisfied with the proposed tool as the tool is well-designed for safety and proper performance. Regarding usefulness of the tool, experts and end-users rated high score for the ease of usage and its ability to reduce wasting of resource consumption comparing to the traditional method.

Keyword: Smart Farming, IoT, Alternative Wetting and Drying, Precision Agriculture.

1. Introduction

Information technology has been applied to assist agricultural activities called smart farming and precision agriculture for improving their productivity. Smart Farming and precision agriculture [1] are defined as the use of modern technology in farming management to increase the quantity and quality of agricultural products [2]. Farmers can obtain several benefits from smart farming including greatly optimizing the effectiveness of pesticides and fertilizers and monitoring the needs of nutrition for an individual farm unit correspondingly to prevent disease and enhance healthy products [1]. Smart Farming is proved to yield better productivity in both quality and quantity while requiring the capital in investment but should reduce the long-term cost.

In Thailand, smart farming projects have been deployed for many economic plants such as rice, durian and macadamia [3], [4], [5], [6]. Several techniques have been involved including GPS, IoT, data management, AI and Robotics. Since rice is the important product for domestic consumption and export [5], many existing smart farming researches were conducted to serve its maneuver. To achieve successful rice farming, controlling of environmental factors is the most important feat because these factors can affect quality and quantity of products and the risk of invasion from insects and diseases.

In this work, we aim to combine Internet of Things (IoT) with artificial intelligence (AI) to assist on decision making for rice farming. The focused process of this research is the management of a water level in a paddy field for the 'alternative wetting and drying' (AWD) method which is known for best productivity. The IoT handles on sensing environmental factors and controlling a water level while AI helps to adjust water flowing accordingly. This prototype is expected to consistently manage water usage for optimizing productivity and to lower burden of a rice farmer.

The rest of this paper is organized as follows. Section 2

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provides a brief background knowledge of our focused rice farming method which is the alternative wetting and drying method and a summary of related smart farming work in Thailand. For Section 3, a design of our proposed IoT and AI combined tool is explained. Section 4 gives an experiment setting and result with discussion. Section 5 presents a conclusion of this paper and finding remark.

2. Theoretical background and related researches

2.1 Alternative Wetting and Drying (AWD) Method in Rice Farming

Alternative wetting and drying (AWD) is one of favorable methods to grow rice used in many countries. This method has been researched and experimented, and the results indicated that it can reduce water usage amount for 30% from a usual method [3]. Moreover, it also affects on lowering costs of fertilizers and insecticides for about 40%. In addition, the research results [ref] also pointed out that yield amount and quality of the produced rice are slightly increased with the method.

The method focuses on keeping a field in alternative between wetting and drying based on growing periods of a rice. Since keeping a rice soaking with water for the whole time may result in weakened root and possibly affected with diseases. On the other hand, keeping a field dry may lead a rice to stop growing from malnutrition. With the method, soil in a field is not always wet or dry therefore humidity of the field is apparently lower than other methods. This can help to lower a chance of invasion from common insects prevalent in Thailand such as a brown plant hopper to not breed and attack the field. Thus, alternating between wetting and drying is the better option for rice to become healthier and easier to manage.

In details, the AWD method consists of 4 phases. The initial phase is when to keep a water level at 5 cm in a paddy filed. After rice reaches flowering phase, a water level is increased to 7 cm. Once rice age is around 35-45 day-olds, let a field dry out on a surface but keeping a soil under 10 cm of a surface moistened for 14 days, then pumping a water back to a field for 7 cm afterwards. At rice age 60-65 day-olds, a dry out phase is redone again for another 14 days. The overall time lapse of the method is illustrated in Figure 1.

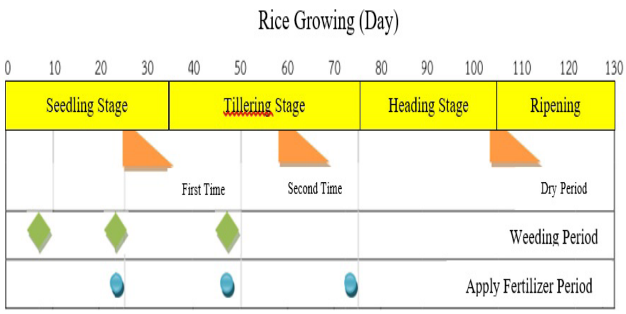

Figure 1. *States of a paddy field according to AWD.*

This method though is effective and is proved for many benefits; it has a specific requirement on water level and soil type. Farmers have to observe water level accordingly regarding phases of rice. Since soil in different locations has its own different absorption rates depended on soil types and soil layers, farmers need to be observative and calculative in handling water level. Furthermore, pumping water manually or semi-manually may lead to over-watering or under-watering in which may cause undesired outcomes such as lacking nutrition or flooding a field. With the method, farmers need to be experiencedly precise on water level and well-versed in finding solution once troubles occurred.

2.2 Smart Farm and Precision Agriculture in Thailand

Thailand is an agricultural country which most of successful exports are agriculture-based products. With the technological advances, Thailand has progressed to the era of Agriculture 4.0 where technologies lead subsistence agriculture to smart farm (with AI), precision agriculture (with IoT), agricultural robotics (with machinery), and biotechnology. This development greatly increases farm productivity and yields while possibly reduces the risk of loss from unexpected and undetected incidents. There are some researches and applications in Thailand involving smart farm and precision agriculture along with systematic rice-based information provider. We thus summarize them in Table 1.

Table1. *Show the Summary of theoretical background and related researches.*

Title	Purpose	Application Type	Technique	Work Type
Agri-Map [3]	**Agri-Map:** A geographic information system application about Thai geography for Agriculture management	Information provider	Geographic information system	Open service/ Mobile application
Rice-Time [4]	**RICE-TIME:** A recommendation system on rice cultivation planning by considering of geographic and climate information	Information provider	Geographic information system and rule inference	Open service / Mobile application
LDD Soil Guide [8]	**LDD Soil Guide:** A recommendation system for Thai farmer on fertilization and soil quality regarding farm location	Information provider	Information system and rule inference	Open service/ Mobile/ Web application
Rice Knowledge Bank : RKB [7]	**Rice Knowledge Bank (RKB)**: Web-based information provider in various aspects on rice cultivation	Information provider	Knowledge organization	Open service/ Web Portal
An Ontology for Integrated Farming towards the Sufficiency Economy [10]	A recommendation system for Thai farmer to support sufficiency economy	Individual-based recommender system	Knowledge representation and automated decision making	Research/ Method
A Framework of Ontology based Recommendation for Rice Production [5]	A personalization system to support management in rice farming	Individual-based recommender system	Knowledge representation and automated decision making	Research/ Method
Application with the Internet of Things for Smart Farms Mushroom [6]	Applying IoT to detect and manage in mushroom farm	Actual data collection for individual mushroom farm	Sensors for environment monitoring	Research/ Mobile application
IoT and agriculture data analysis for smart farm [9]	IoT to detect agriculture data for optimization analysis	Individual-based recommender system	Sensors for environment monitoring	Research/ Mobile application
Design and Application for a Smart Farm Based on IoT [14]	Using IoT to sense the change of environment in the farm for precision farming	Individual-based recommender system	Sensors for environment monitoring	Research/ Mobile application
Web-based for Management of Swine Breeding Herd Farm [15]	A recommender system for swine breeding farm focusing on breeding	Individual-based recommender system	data-driven model management	Research/ Web-based application
A Development of an Ontology-based Personalised Web from Rice Knowledge Website [16]	A personalized dynamic web for rice information based on personal interest	Dynamic information provider	Personalized Knowledge organization	Research/ Web-based Information System

2.3 Literature review

From the reviews, there can mainly be categorized into three application types of works as information (or knowledge) provider, information detection and individual farm recommender system (expert system). The information provider is a collection of information for users to browse through for obtaining information they want. Some provide a text with image and video clip such as 'Rice Knowledge Bank' (RKB) [7] for sharing knowledge while some display information based on a map such as 'Agri-map' [3] and 'LDD soil guide' [8]. These applications though are useful for obtaining beneficial information for users, but they have to manually search for their own needed information and comprehend it to make full use of it. For information detection, most works use sensors to detect factors in farm environment to precisely realize what happens in a farm. These works vary in several farm types including plant and animal raising farms. The detected factors then are used in farm management with either manual or automated handling. The detection with sensors is best known for its precision; hence, the obtained data are useful in farm management [6] and data analysis [9]. With IoT technology, devices can directly communicate to one another, and it thus results in automated activation of or handling farm tasks. The recommender system is designed to help in finding a solution for a specified farming issue. The optimized solutions are calculated with the given knowledge model for decision-making. There are two approaches on model generation including rule-based and machine-learning-based. The aim of these recommender systems is to mimic experts' expertise in their knowledge base and intelligently think of the best solution regarding individual specification. The knowledge bases are essentially designed to accord to human knowledge in specified domain such as sufficiency economy theory [10] and rice specie selection [5].

In overall, these applied technologies effectively help farmers to improve their quantity and quality of their products. Their results signify the promising outcome and show potential in practice. In this work, we also want to assist Thai rice farmer in managing rice cultivation with the AWD method which contains complex and detailed methodology. We thus combine the precise detection, network of devices and rational decision-making to our prototype to optimize the yield outcomes for Thai farmers.

3. Research Methodology

3.1 Methods

A purpose of this work is to facilitate water management in a rice paddy field regarding AWD farming method using IoT to communicate between devices and machine learning to create a decision-making model. An overview of the proposed prototype is drawn in Figure 2.

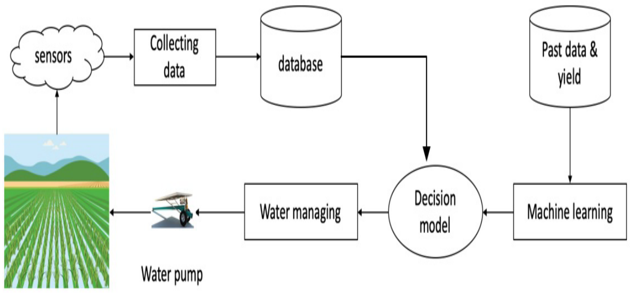

Figure 2. *Show an overview of the proposed prototype.*

3.2 Devices

With IoT, devices can communicate to one another; thus, it can automatically manage a water level in a paddy field. There are two main devices in this work as sensors and water pump. Sensors are required to measure environmental factors to use along with other factors in decision-making while a water pump is necessary to adjust a water level accordingly to the made-decision. An architecture of the designed devices in this work is illustrated in Figure 3.

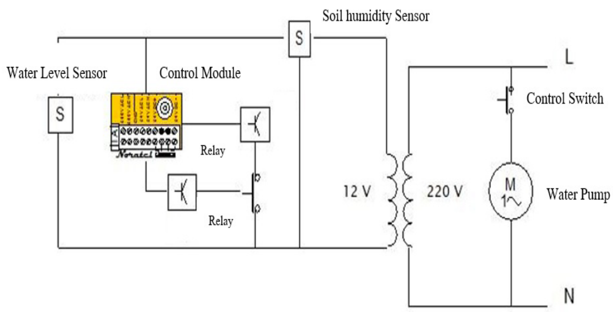

Figure 3. *Show an architecture of the designed.*

3.2.1 Sensors According to the AWD method, essential environmental factors for watering in a paddy field are humidity of a soil and current water level in a field. Hence, we design to apply two types of sensor as follows.

• Soil humidity detection sensor: automatic measurement of the moisture content of the soil. A soil humidity detection sensor composes of two components as shown in Figure 4. The first component is a two-legged lead with a pin which goes into the soil where humidity content has to be measured. The second component is an amplifier/ A-D circuit which links to the main connector to communicate with other devices. The pins of the lead and amplifier are connected so the measured content can be transferred as soon as it is read

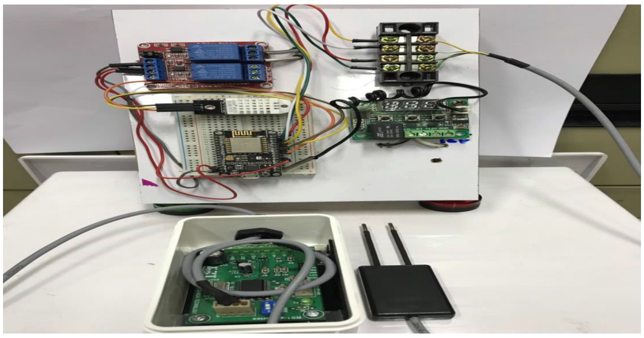

Figure 4. *Soil humidity detection sensor in this work.*

• Water level detection: automatic and real-time sensor of water level as shown in Figure 5. A water level detection system is to help in collecting water levels data in real-time. Ping sensor is used as a distance sensor for detecting water level by measuring distance between sensor and water surfaces. The system consists of two components as a transmitter and a receiver. A transmitter is to send a wave to locate a water surface and measures a water level by travelling time. Then, a receiver is to receive a transmitted data to collect. This can help to remotely realize water level in a paddy field.

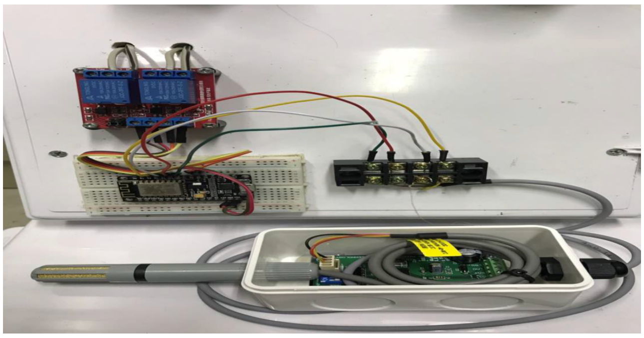

Figure 5. *The water level detection in this work.*

3.2.2 Water Pump A water pump in this work is a pipe-type water pump using electricity in activation as shown in Figure 6. Since we design to automatically manage a water level, a pump using fuel cannot be applied because of a complexity on engine starting and a refilling of fuel which needs to be done manually.

Since a water pump uses centrifugal force to send fluid to the outside while it spins causing fluid to be drawn from the center continuously, it is necessary for a pump input to be ready in a water source for the whole time to prevent damage of a device when it is activated. Moreover, a size of the pump should be select accordingly to a size of a designated paddy field.

Figure 6. *The water pump in this work.*

3.3 Water Management Decision-making Model

To develop a model that can decide in water management in a paddy field, a supervised machine learning technique is applied. Necessary features related to rice farming are collected to represent factors of rice farming and yield results. The features in this work are listed in Table 2.

Table 2. *Show a list of features for developing water management model.*

Feature	Definition/Reason	Example values
Rice specie	Different rice specie has its own preference water level, growing period and average yield	RD2, RD41, Hom Pathum, etc.
Farming season	There are 2 main farming timings for rice farming in Thailand as in-season and off-season. Since the day time is different in these seasons, yield rate and suggested growing method is thus different.	in-season, off-season
Rice age	There are different requirements in water for rice in different states	1-100 (days)
Soil humidity	A measured soil humidity in a paddy field (from sensor)	0-100 (percentage)
Water level	A measured water level in a paddy field (from sensor)	0-100 (cm)
yield	A measured rice yield in kilogram per rai	0-2000 (kg. per rai)

Remark : Rai is a unit of area equal to 1,600 square meters.

The past data are essential in this process since they can help to determine a specie with the proper factors to get the best yield accordingly. In this work, we however focus on RD41 rice specie since the testing sites grow this rice specie; therefore, our model is learnt and contains only RD41 data. For developing a model, we select a typical decision tree technique [11] to learn the features. An algorithm of the applied decision tree is as follows:

1. Assign all training instances to the root of the tree. Set current node as a root node.

2. For each attribute

   a. Partition all data instances at the node by the value of the attribute.

   b. Compute the information gain ratio from the partitioning.

3. Identify feature that results in the greatest information gain ratio. Set this feature to be the splitting criterion at the current node. If the best information gain ratio is 0, tag the current node as a leaf and return.

4. Partition all instances according to attribute value of the best feature.

5. Denote each partition as a child node of the current node.

6. For each child node:

   a. If the child node has instances from only one class, tag it as a leaf and return.

   b. If not set the child node as the current node and redo step 2.

The generated decision tree model then is cooperated to the designed water pump and measured data from sensors. With prior knowledge, we set the decision criteria accordingly such as a group of rice age as under 12, 12–29, 31–39, 40–49, 50–59 and so on. Moreover, a numerical measurement such as a water level requires to be calculated in defined uniformed measurement as centimeter (cm) to prevent confusion of different measurement units such as inches and meter. Farmer actions towards water pump are also collected for result actions of the model. The generated decision tree is exemplified in Figure 7. With the generated model, we gain water pump activation rules thus as shown in Table 3.

Table 3. *Show a list rules to activate water pump for watering a paddy field of RD41 rice specie.*

Rice age	Water level (cm)	Soil humidity	Pump action
<12	0	-	off
<12	>0	-	Drawing all water out
≥12, <30	<15	-	Drawing water in until a water level reaches 15 cm.
≥12, <30	≥15, <16	-	Off
≥12, <30	≥16	-	Drawing water out until a water level reaches 15 cm.
≥31, <40	>0	-	Drawing all water out
≥31, <40	0	≥20, <40	Off
≥31, <40	0	<20	Drawing water in until a soil humidity reaches 20%
≥41, <50	<15	-	Drawing water in until a water level reaches 15 cm.
≥41, <50	≥15, <16	-	Off
≥51, <60	>0	-	Drawing all water out
≥51, <60	0	≥20, <40	Off
≥51, <60	0	<20	Drawing water in until a soil humidity reaches 20%
≥60	<15	-	Drawing water in until a water level reaches 15 cm.
≥75	≥15, <16	-	Off
≥75	≥16	-	Drawing water out until a water level reaches 15 cm.
≥90	>0	-	Drawing all water out

With the decision rules, water management according to AWD method can be performed automatically. This will lower a burden of farmers to personally check on a water level. Moreover, the past yield result should guarantee a farmer to be convinced on using the prototype. We expect that this prototype will facilitate an AWD farming method and convince Thai rice farmers to more participate in this method since it is best method in terms of optimizing water usage and productivity in rice farming with less risk in disease and insect invasion.

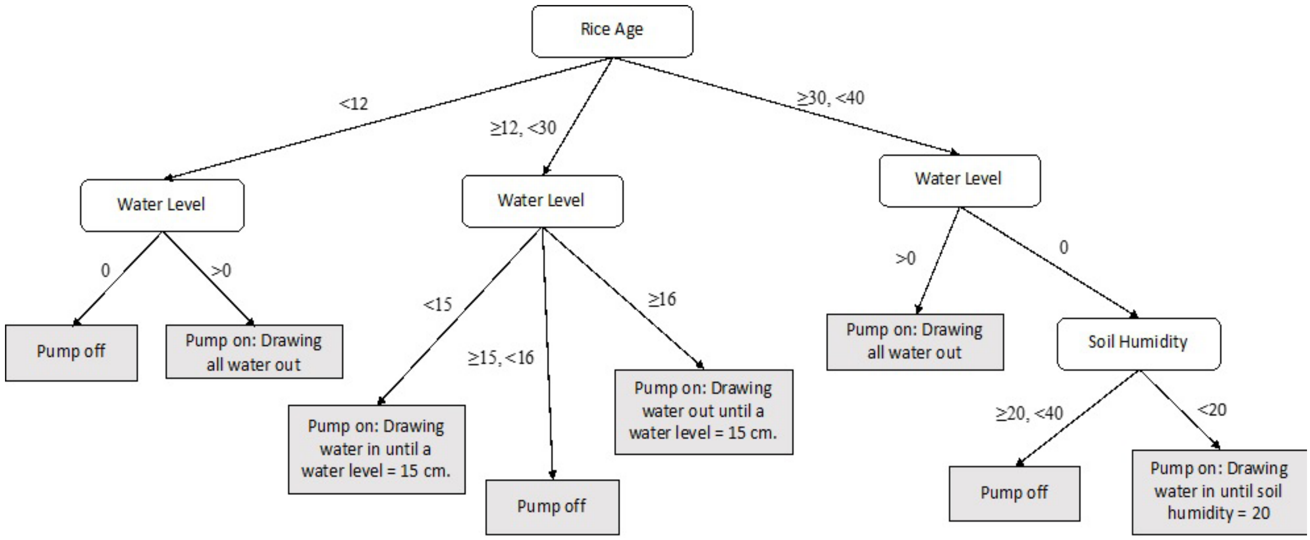

Figure 7. *Some parts of generated decision tree model.*

4. Result and Discussion

This research was determined the experimental area and data collection in Lad Nga Sub-district, Sena District, Phra Nakhon Si Ayutthaya Province. Set up experimented in the paddy field of farmer who are volunteer, On an area of 2 rai, divided into : 1 rai for conventional farming and 1 rai for AWD using smart water management in a paddy field by IOT technology and machine learning. The trial period from planting to harvesting is 105 days. To evaluate the prototype, we set up three evaluations as expert evaluation, user evaluation and cost-efficacy evaluation. For expert and fa evaluation, a questionnaire in Linkert scale between 1-5 where 5 refers to 'highest rating' and 1 stands for 'lowest rating' respectively is used. The score is calculated for average and standard deviation (SD) for rating the given topic. For cost-efficacy evaluation, we compare cost-benefit of the use of the proposed prototype with the common rice farming in the same setting.

4.1 Expert evaluation

We asked 5 experts in rice farming to evaluate the prototype and its performance. The experts were asked to observe the activation of the prototype for 2 weeks, and they were asked for evaluation on the last day of observation.

Table 4. *Evaluation results from experts regarding performance of the proposed prototype.*

Topic on Performance	Average	SD	Rating Interpretation
Safety of the prototype	4.21	0.75	High Level
Accuracy on measuring soil humidity	4.21	0.84	High Level
Accuracy on measuring water level	4.43	0.79	High Level
Accuracy on adjusting water accordingly to AWD method	4.45	0.93	High Level
Overall average	**4.32**	**0.82**	**High Level**

We split the topics into 2 topics as performance and worthiness/usefulness. The results are given in Table 4 and 5, respectively.

The results indicate that experts agree on good ratings for performance and usefulness of the prototype. This pointed out that the proposed tool has an acceptable accuracy on realizing necessary factors in water management for AWD methods. Furthermore, the used model could provide a set of good decision-making rules that experts gave a rating of 4.45 in average. Thus, in terms of performance, the prototype obtained a high rating feedback from expert evaluation. Regarding worthiness and usefulness, experts

Table 5. *Evaluation results from experts regarding worthiness and usefulness of the proposed prototype.*

Topic on Worthiness and Usefulness	Average	SD	Rating Interpretation
Able to reduce times in a rice paddy field management	4.47	0.84	High Level
Able to reduce wasting water used in a rice paddy field	4.33	0.92	High Level
Able to reduce a risk of unintentional flooding a rice paddy field	4.42	0.94	High Level
Easy to use by farmers	4.55	0.91	Highest Level
Overall average	**4.44**	**0.90**	**High Level**

evaluated in high rating for overall. The highest rating was obtained for 'easy to use by farmer' for 4.55 rating in average. Moreover, the experts also agreed upon the worthiness of the tool in their observation in which they consider its ability to help in reducing risk of unintentional flooding the field and wasting water usage, for example.

4.2 Farmer Evaluation

In this evaluation, we asked 30 farmers who involved in a paddy filed deployed with the prototype for their ratings. After 2 months of deployment, a questionnaire regarding the prototype was conducted. The rating results from farmers are given in Table 6.

The end-users evaluated the tool for highest rating in average. They were satisfied in many aspects including ease of use for the tool and its application, durability and components that can easily be repaired and found in a market. In fact, they also appreciated in consistency of the prototype since it works properly and low noise and vibration comparing to existing similar products. Some of them gave a remark that this tool could lead them to easily manage their paddy field and let them have a spare time for handling other issues such preparing sale plan and taking care of storage.

Table 6. *Evaluation results from farmers (end-users) of the proposed prototype.*

Topic	Average	SD	Rating Interpretation
The tool works properly	4.47	0.72	High Level
The tool can work continuously	4.29	0.97	High Level
The tool and its application are easy to use	4.58	0.79	Highest Level
Components of the tool work efficiently	4.42	0.94	High Level
Component of the tool can be repair easily	4.54	0.88	Highest Level
Component of the tool can be bought easily	4.65	0.68	Highest Level
The water pump produces lower noise and vibration	4.69	0.73	Highest Level
Components are durable to weather	4.88	0.73	Highest Level
Overall average	**4.56**	**0.80**	**Highest Level**

4.3 Cost-efficacy evaluation

In this section, we compare the cost and benefit from applying the prototype in terms of cost and return. This can indicate the cost-efficacy from using the tool in practical. For this experiment, costs in managing a usual rice field with AWD method and with the prototype are compared to calculate for different in total profit. The costs were calculated per crop cycle (about 90 days). There were 3 fields in this experiment; thus, the water and pump power usage were given in average. The price and cost in a calculation were referred to the experiment date. The results are detailed in Table 7.

The experiment results show that the proposed tool could help the farmers to yield a better profit for about 4,210 baht per rai. The result also indicated that an electricity water pump required less cost than a fuel type; thus, to be

Table 7. *A comparison of cost, product yield and profit from usual method and applying our propose tool.*

Cost	Usual method	Proposed tool
Daily wage for a farmer who need to manage for water	31,500 bath per crop cycle (1 farmer (350 baht) * 90 days) *remark – not calculated in a total cost	0 for managing water but still need 1 farmer to take care of a farm in other regards
Water usage	1,200 cubic meters per rai	900 cubic meters per rai
Pump activation (~1.5 hour per day) • Fuel • Electricity	 20 baht per hour 3.67 baht per hour	 - 3.67 baht per hour
Maintenance Cost per rai	2,00 bath per crop cycle	300 bath per crop cycle
Cost per rai	5,000 bath per rai (diesel fuel pump) 4,800 bath per rai (electricity pump)	4,590 baht per rai

Productivity	Usual method	Proposed tool
RD41 unprocessed rice (8 baht per kg.)	7,200 baht (900 kg. per rai)	8,800 baht (1,100 kg. per rai)

Profit	Usual method	Proposed tool
Total Profit	2,200 baht per rai (diesel fuel pump) 2,400 baht per rai (electricity pump)	4,210 baht per rai

fair, we discussed only on an electricity pump onwards. Since the cost was reduced by preventing waste on water and pump operation usage, the difference in costs were different for about 210 baht per rai in case of using electric pump on a rice field. In addition, the tool also controlled better environment factor to maximize a product yield which was greater than the usual method for about 300 kg. per rai. This led to better income for farmers for about 2,400 baht per rai. From the overall calculation of profit, the prototype was proved to be superior in every aspect.

In fact, the cost of investing the tool though was about 21,500 baht per unit. In details, the pump part including a motor and pipe took about 40% of the cost in which also requires in a usual method; hence, we can subtract to only around 13,000 baht for additional sensors, connecting and controlling components. Therefore, the farmer should gain back the investment on developing this tool within 4-5 cycle crops. However, to scale up for using with a larger rice field, the invested cost would be higher depending on the size of a water pump and a motor in which leading to higher consumption in operation. There still needs a further study on scaling up the tool to serve for larger field for practical usage or to use with other types of plant.

5. Conclusions

This work proposes a water management tool to help rice farming with alternative wetting and drying method. We design the tool with a combination of precision agriculture and smart farm from applying IoT and AI technology. To obtain real-time and accurate essential environmental factors in a rice paddy field, soil humidity sensor and water level detection sensor are deployed. A pipe water pump operated using electricity is designed to handle water in a field. The pump and sensors are connected with a network for automatic operation using IoT. For decision-making, supervised machine learning technique is exploited to develop a model capable to consider when to operate a water pump from past data. This hence allows flexibility in generating decision-making rules for variation of locations and soil types in a trade of large past data requirement.

From evaluations, opinions from experts were in favor of the proposed tool with the indication that the tool is well-designed for safety and proper performance. Furthermore, regarding usefulness of the tool, experts and end-users rated for high score to ease of usage and its ability to reduce wasting of resource consumption comparing to the traditional method. Based on cost and profit from using the tool, experiment results signify that applying the tool could help in reducing the costs for about 210 baht per crop cycle per rai while increasing the yield for about 2,400 baht per crop cycle per rai in average. This could be summed up to an additional profit of 1,810 baht comparing to the traditional method.

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