Appropriate adaptation of precision agriculture technology in open field cultivation in tropics

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Abstract. Tropical agriculture production is profoundly affected by the uncontrollable environmental condition. To obtain good agricultural products, farmers manage their farm to fit with the variation of weather and season. The farming managements are generally determined according to farmers personal knowledge, gained from the long-term experience from preceding years. Nowadays, climate change intensifies unpredictable weather and its unstable distribution. Consequently, conventional farming management considering the climate change factor should be considered. The farming management should face the dynamic change of weather condition as well as improve the farmer’s knowledge towards the implementation of precision agriculture approach. The objective of this study was to introduce an appropriate adaptation of precision agriculture technology by the utilization of information and communication technology (ICT) to improve conventional farming management in tropical agriculture production. The framework is implementing cloud technology as a backbone, which can be extended with various knowledge such as data science, plant biology, plant physiology, biophysical, and biomechanical. The appropriate adaptation of precision agriculture represented by the improvement of the conventional farming method using the technological aspect by fostering their knowledge to adopt modern agriculture empowered with Information and Communication Technology (ICT). Learning process from data-information-knowledge on the application of precision agriculture will be documented at the PA Knowledge Management System.

1. Introduction

Indonesia is a country with the largest area with a land area of 1.9 million km$^2$, highest population, and the most precious natural resources in Southeast Asia. It has 200 million ha of the land territory, which 25% is allocated for agricultural activities, which play an essential role in the national economy, accounting for 15.4% of the total gross domestic product [1]. Agriculture in Indonesia is strongly affected by ENSO (El Nino Southern Oscillation), which intensifies the extreme meteorological conditions. Impacts of climate change have been intensifying with an increasing number of extreme weather patterns occurrences, climate anomalies, and interannual variations in precipitation. Accordingly, the agricultural production system should consider global climate change as well as maintain productivity.

Precision agriculture (PA) comprises a set of technologies that combines sensors, information systems, enhanced machinery, and informed management to optimize production by accounting for variability and uncertainties within agricultural systems [2]. PA is one of the approaches that can be
adapted to increase the agricultural productivity as well as reduce the cost and environmental impact by optimizing the resource usages through the utilization of appropriate technology [3,4]. PA optimizes the field-level management concerning crop science aspect (matching the farming practices with crop needs), environmental protection aspect (restrict the use of a chemical product as needed), and economics aspect (more efficient in resource utilization). By its implementation, the farmer can build up a record of their farm (on-farm data collection), improve the decision-making process, and enhance the quality of the product [5]. However, some problems on the implementation of PA in Indonesia are related to the agricultural management; the farmer still using a conventional farming system, low capital and limited knowledge of technology in farmer level [6]. Also, PA technology is often defined as expensive and unreachable technology. On the other hand, the unique characteristics of tropical agriculture and existing knowledge on efficient agriculture production might bring new concept on the appropriate adaptation of PA. Especially in the open field tropical agriculture cultivation, best practices and existing local knowledge have already established in conventional farming. Therefore, to encourage progress, we propose an appropriate adaptation of precision agriculture to enhance conventional farming management.

The objective of this study was to introduce an appropriate adaptation of precision agriculture technology by the utilization of information and communication technology (ICT) to improve conventional farming management in tropical agriculture production. The framework was implementing cloud technology as a backbone, which can be extended with various knowledge such as data science, plant biology, plant physiology, biophysical, and biomechanical. The application covers the aspect of environment, plant, and human knowledge.

2. Material and Method

2.1. Conceptual framework

Precision agriculture is a concept for optimizing the process of agricultural production by the implementation of ICT, including sensor technology and robotics [7]. Precision agriculture is “information-intense,” as illustrated in the information flow diagram visualized in Figure. 1. The input (1) of the system is the raw data, obtained by the utilization of sensing or positioning system, that is processed by the knowledge on agriculture production, such as Agronomy, Crop management, Plant Science, Soil science, etc. The process (2) could be improved by the utilization of decision support and expert representing the addition of knowledge from outside. The output (3) is the process control data which connected to the activities related to the actuator and machine.

Figure 1. Conceptual framework of appropriate adaptation of precision agriculture, improved from Stafford [7] by introducing the knowledge management as support system for each stage.
Appropriate adaptation of PA is realized by enhancing the input-process-output flow in existing local knowledge with introducing new technology as a complement of the conventional method. Hence, it could provide the linkage of the farmer local wisdom and the technology platform. The divers and uniqueness of local knowledge for each farmer and field might bring various case study that can be captured and facilitated by the knowledge management (4). Learning process from data-information-knowledge on the application of precision agriculture will be documented at the PA Knowledge Management System (KMS).

2.2. Research method
Research on the application of PA was carried out at the Home Farming Farm, located at Candi Mendiro, Sardonoharjo, Ngaglik, Sleman, Yogyakarta since December 2013 – April 2016. The concept of PA adopted the cloud technology to optimize agricultural production by applying monitoring equipment and controlling environmental conditions to support wisdom local horticulture farming system with the framework shown in Figure 2. This cloud-based framework facilitates the function of observing and controlling the conditions of remote environments with integrated data storage in online databases that can be accessed flexibly through Internet networks [8,9].

Figure 2. Remote environmental monitoring and control framework based on cloud technology and its implementation in tropics [7].

The concept of appropriate PA includes: (a) Observation of real-time environment, (b) Assessment of environmental conditions with estimates of surface water loss represented by reference evapotranspiration values estimated from climatological data using the FAO model -56 Penman-Monteith, (c) Control of micro irrigation with various control methods (setpoint, fuzzy, and hybrid sensors) [10], and (d) observations of plant responses to the treatment of environmental conditions [11].

3. Result and Discussion
3.1. Environmental monitoring and control
Observation of environmental conditions is carried through a web browser on smartphones to determine microclimate conditions. Furthermore, factual data readings of soil moisture content sensors are used for automatic irrigation control based on user-specified setpoints. Figure 3. shows the results of observations of environmental conditions (top) and soil moisture levels (bottom) following by recording the actuation of irrigation water using a setpoint control. The amount of water, the time of administration is automatically determined based on real conditions in the field.
Figure 3. Environmental monitoring (top) visualizes the temperature and solar radiation, and micro-irrigation control result according to decided setpoint control and actuation history.

3.2. Environmental assessment

Observation of real-time reference evapotranspiration presented in the distribution map can be seen in Figure 4. The reference evapotranspiration rate ($ETo$) on land with vegetable crops can be estimated automatically with a range that reads between 0 - 0.7 mm / h. The $ETo$ rate is recorded high at midday between 9:00 a.m. 2:00 p.m. with varied days shown in B1, B2, and B3. By understanding the conditions and patterns of distribution of evapotranspiration, the farmer will find it easier to determine water supply management and facilities to protect plants more precisely.

Figure 4. Distribution of reference evapotranspiration ($ETo$) during the 30 days observation visualized in heatmap, the high $ETo$ denoted with B1- B3.
3.3. **Plant monitoring and assessment**

Plant responses to environmental conditions are correlated with observations of environmental conditions, and \( ETo \) can be seen in Figure 5. The temperature and radiation of sunlight in the top image, the condition of plants in the middle, and real-time \( ETo \) and daily \( ETo \) accumulation on the bottom graph. The learning and practicing process using monitoring equipment for environmental conditions to increase user knowledge can be seen from the start of installation (A), the occurrence of extreme conditions where temperature, radiation, and evapotranspiration are high. Found wilted plants (B) and after being compared with daily recordings obtained \( ETo \) values of more than 4 mm/day, relatively high evapotranspiration values, and when compared to previous days, there were significant leaps. Therefore, the farmer can carry out initiatives for prevention the next day, for example, by installing a shading net to reduce the rate of water loss. Another thing that can be done is the provision of more intensive irrigation water.

![Figure 5](image)

**Figure 5.** Observation of environmental condition and reference evapotranspiration in relation with plant condition recording system during cultivation.

3.4. **Knowledge Management**

Knowledge management system provided as a web application and forum for facilitating the sharing of daily activity related to agricultural practices. The system input might come from the farmer’s social media, group messenger, and discussion [12]. As a necessary foundation, data collection is provided using an environmental field monitoring system, supported by evidence and best practice by each farmer activity. Information is displayed on the website as can be seen in Figure 6. The portal website, Figure 6 (a), facilitates the sharing of success and failed story. The specific discussion will be in the forum, Figure 6 (b), and the knowledge will be stored explicitly in the knowledge management system as displayed in Figure 6 (c). The conversion from Information to knowledge requires an expert to map and assign the obtained knowledge into knowledge taxonomy that might help other members to find and search valuable knowledge for agricultural practices.

Data-Information-Knowledge dissemination using the KMS requires a process on the adjustment the knowledge needs and sharing culture in order to sustain and bring benefit. Some process that needs to be practiced following the Nonaka-Takeuchi (2006) SECI model are Socialization, Externalization, Combination, and Internalization.

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4. Current Conclusion and Future Works

The appropriate adaptation of precision agriculture in Indonesia represented by the improvement of the conventional farming method using the technological aspect. The farmer should be encouraged by fostering their knowledge to adopt modern agriculture empowered with Information and Communication Technology (ICT). Learning process from data-information-knowledge on the application of precision agriculture will be documented at the PA Knowledge Management System (KMS). The use of monitoring equipment to assist the implementation of Precision Agriculture in the tropics leads to an increase in knowledge on conventional agriculture which more generally uses intuition (feeling) or estimates in daily tactical decision making. With the basic knowledge of farming that is already owned (either starting learning or derived from ancestors), combined with the use of information technology to support the supply of location-specific information, the improvement in the quality and quantity of agricultural production is expected to be realized.

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