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Precision Agriculture in Taiwan: Examples and Experiences

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ABSTRACT

Since 1997, Taiwan has been planning for precision agriculture. In 1999, a pilot project was launched with rice as the target crop, entitled "Studies on Precision Farming System for Rice (1999-2002)." Although this four-year project cannot solve all rice production problems comprehensively and effectively, the concept of precision agriculture and the development of related technologies have progressively spread to various fields of agricultural research. Moreover, through various experimental studies conducted by different research institutions, a large number of experimental data has been accumulated, and it has gradually expanded to the production and application of various agricultural products. In the era of booming information and communication technology (ICT), as well as the fact that the proportion of aging farming population has increased year by year, the corresponding result is a shortage of labor in Taiwan. Therefore, precision agriculture at this stage has introduced elements of smart agriculture. With that, the Productivity 4.0 project and the Smart Agriculture Project were initiated in 2016 and 2017, respectively, by the Council of Agriculture (COA) of Taiwan (ROC). The development of precision agriculture systems has been listed as one of the three major areas of these two projects. This paper introduces Taiwan's research findings and industrial application examples of precision agriculture in the Smart Agriculture program, including crop quality production system, soil nutrition and irrigation management with geographic information system (GIS), crop disaster prevention and warning system, decision-supporting system for pest management, etc. These examples and experiences may apply to small holders for countries in the Asia-Pacific region.

Key words: Precision Agriculture, Smart agriculture, Crop quality production system, Pest management, Soil nutrient and irrigation management with GIS.

Introduction

Due to the global warming trend as well as rapid climate change, the occurrence of extreme weather events is becoming more frequent and more intense. The phenomena further intensify challenges facing global agricultural production. The concept of **Precision Agriculture** (PA) emerged in the 1980s, based on observing and responding to intra-field variations in a site-specific way. Such a farming management incorporates appropriate cultivation techniques combined with long-term accumulated farming information and derived decision-supporting systems, such as soil nutrition and meteorology, and equipment, such as variable-rate sprayers and yield monitor, offering farmers more effective cultivation management to achieve maximal benefits with minimal inputs in crop production (Reyns *et al.,* 2002).

Taiwan began planning for PA in 1997 and launched a pilot project called '**Studies on Precision Farming System for Rice** (1999-2003)' (Lin and Yang, 2000).This project included three research themes—Soil Fertility Status and Monitoring System, Decision-supporting System for Rice Cultivation and Environmental management, and Precision Agricultural Machinery and Operating Systems (Yang and Lin, 2003). Although this four-year project cannot solve all rice production problems comprehensively and effectively, the concept of precision agriculture and the development of related technologies have progressively spread to various fields of agricultural research.

Moreover, through various experimental studies conducted by different research institutions, a large number of experimental data has been accumulated to manage rice plants and soil. Moreover, site-specific techniques have been developed extensively. It has also gradually expanded to the production and application of various agricultural products. A preliminary system for image recognition and a prototype of grain yield monitoring equipment have been established. Some spectral models to assess growth status, pest infestations and yield production were developed based on ground truth from project studies. Results of simulation from satellite spectral data were compared with estimates from models of hyperspectral data. In recent years, measurements and model development from imagery taken from unmanned aerial vehicles (UAVs) or drones have been done and applied to the detection of plant nutritional status, monitoring and surveillance of natural disasters, and assessing the incidence and outbreak of pests and diseases.

As to the development of decision-supporting system, an algorithm to assist fertilization decision-making has been built. The dosage and distribution rate of nitrogen fertilizer can therefore be recommended to farmers in line with varieties, planting time and yield potential, etc. (Yang and Lin, 2003). More recently, an **Integration Information Platform for Crop Quality Production** has been developed for farmers to find effective and proper ways, through the Internet of Things (IoTs), to grow a crop.

In the era of booming information and communication technology (ICT), as well as the fact that the proportion of aging farming population has increased year by year, it results in a shortage of labor in Taiwan. Therefore, PA at this stage has introduced elements of **Smart Agriculture** (SA). Through the combination of digitalization and intelligent technology and precision equipment, coupled with industrial processes and the use of Big Data and IoTs, the agriculture sector anticipated to achieve the goals of improving production efficiency, reducing labor costs and increasing product returns, thereby attracting and inspiring young people to pursue a career in agriculture/farming. With that, the Productivity 4.0 project and the Smart Agriculture Project were initiated in 2016 and 2017, respectively, by the Council of Agriculture (COA) of Taiwan (ROC). The development of PA systems has been listed as one of the three major areas of these two projects. This paper introduces Taiwan's research findings and industrial application examples of PA in the SA program, including quality crop production system, soil nutrition and irrigation management with geographic information system (GIS), decision-supporting system for pest management, crop disaster prevention and warning system, etc. These examples and experiences may apply to small holders for countries in the Asia-Pacific region.

CROP QUALITY PRODUCTION MANAGEMENT SYSTEM

Integration of information platform for crop quality production

Most of the farmland cultivated by farmers in Taiwan is less than 1 ha, and may be divided into several blocks for various crop species. The soil texture and structure are not even uniform in a piece of farmland, similar to soil fertility. Thus, cultivation management of a crop requires more elaborate planning for each of blocks. The **Integration Information Platform for Crop Quality Production** was developed to provide needed information for farming (Fig. 1). The databases include growth traits of crop varieties, farming practices and management, disease and pest control methods, epidemic and outbreak notification, and fertilizer use, etc. With this integration information platform, it will help farmers to create their own dynamic management operations during growing period, analyze and compile various growth data into useful cultivation information, generate traceable information for certified agricultural products, and produce statistical reports to meet the needs of operators/growers. It also provides farmers with practical application of field management through mobile application (APP) software.

Fig. 1. Homepage of the 'Integrated Information Platform for Crop Quality Production'. (https://kiscrop.tari.gov.tw/)

The prediction model for growth stages based on the daily effective accumulated temperature (growing degree days; GDD) during a growing season can also be yielded from the platform (Lin *et al.*, 2014). In addition to providing a reference for more precise cultivation management in the farmer's own field, this platform also provides information to the database for more effective analysis as well as extended information for different regions, seasons and cultivation practices.

Soil fertilization and plant nutritional status analysis

Fertilization with proper types and amounts in the appropriate period of crop growth are important tools to stabilize or increase yield and quality of a crop. **Rationalized fertilization** can not only improve quantity and quality of crop production but also reduce the waste of resources and enhance the protection of the ecological integrity. Research institutions under the Council of Agriculture (COA), including the Taiwan Agricultural Research Institute (TARI) and each District Agricultural Research and Extension Station (DARES), provide farmers with knowledge and correct information of fertilizer application through the rationalized fertilization workshop every year. They also provide the service of soil or plant nutritional status analysis for individual farmlands as a basis for farmers to apply fertilizers. There are at least 200 workshops held and 15,000 farmers participate in each year, and over 30,000 soil or plant samples are analyzed per year.

The Soil Geographic Information System (GIS search system) established at TARI can provide services at farm level for soil information (nutrient components and physical properties) through internet (Fig. 2). Government agencies may use the accumulated information in the center to estimate yield potential and locational distribution in various regions and design a cultivation plan.

Fig. 2. Homepage of the 'Soil GIS Search System'.(https://farmcloud.tari.gov.tw/SOA/index.aspx)

The service of diagnosis of plant nutritional status can give instructions to farmers to use fertilizer properly. On the other hand, non-destructive nutrition diagnosis provides effective technological support for PA. The technologies include remote sensing with hyperspectral imaging analysis and digital image processing analysis in nondestructive nutrient status diagnosis and drought (Fig. 3) (Lee *et al.*, 2007; Lee *et al.*, 2008; Shen *et al.*, 2000; Shen and Chang, 2003). The drone-based phenotyping is now actively being studied for developing various image systems and analyzing algorithms that can be used for nutritional status analysis, fertilization and pesticide application non-destructively.

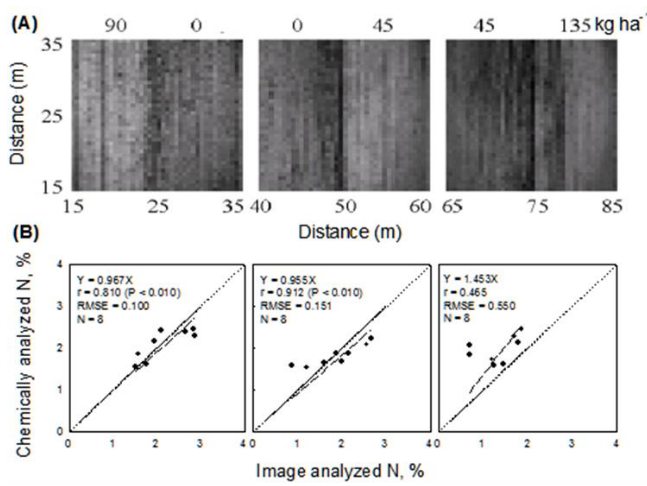

Fig. 3. (A) Maps of canopy N status of rice paddy obtained from three different regions of a rice field applied with different rates of N fertilizer, taken with a simplified imaging system unit mounted on a mobile lifter. (B) Validation of the relationships between the chemically analyzed and the image analyzed N (%) values from three different regions of a rice field applied with different rates of N fertilizer. (adapted from Lee et al., 2008)

Research and development on field intelligent management

In PA, the field management coupling with the application of intelligent sensors is one of the important trends in the SA. Through wireless network transmission and IoTs technology, the efficiency of field operations can be greatly improved. For instance, in the case of rice irrigation, the usage of intelligent sensors for water management of alternate wetting and drying (AWD) irrigation can promote water consumption more effective than conventional irrigation management. It saves water consumption for

30.9% and 49.8% in the first crop and second crop seasons, respectively, but the yield and physiological characteristics are not affected under AWD management condition (Wu *et al.* 2019).

The light integral control logic algorithm and the local automatic fertigation system were developed by light integral irrigation technology based on the principle of crop evapotranspiration (ET; ET = soil evaporation + crop transpiration). According to weather changes, the timing and frequency of irrigation can be adjusted intelligently (Chen and Chen, 2014). The irrigation interval is automatically shortened on sunny days, but the number of irrigation practice is increased to 8 to 13 times, especially the irrigation interval before and after noon when ET is the strongest shortened to 0.5 hr. In contrast, the irrigation interval is automatically extended on rainy days, irrigated 2-5 times and irrigated once every 2-3 h. The application of light integral irrigation technology can effectively reduce the amount of irrigation water and nutrient solution in rainy days by 58-61%. This simple, low-cost and stable irrigation technology can improve the shortage of high cost of complete and accurate ET sensing and rainfall sensing equipment, and need to be maintained regularly (Chen and Chen, 2014).

PESTS AND DISEASES MONITORING SYSTEM AND MANAGEMENT

The monitoring and management of pests and diseases is also an important strategy in the crop production process. Farmers always use comprehensive control by spraying chemicals. In addition to the high labor cost, it also has an influential impact on the environment. It is a key point of PA with proper control of pests and diseases by practicing in suitable time, dosage and plant parts. The **Crop Pests and Diseases Information System** is one of the services of Integration Information Platform for Crop Quality Production. The system provides instant online diagnostic services, which can be based on the crop growth period, plant parts, and damage symptoms (e.g., texture, color and other conditions). The outputs of appropriate diagnostic results and pesticide control information are valuable for users in planning farming practices.

The **Intelligent Management Decision System for Agricultural Pests** integrates the results and findings from research at TARI for many years in facilities, includes Phalaenopsis, vegetables, fruit trees and stored products (Fig. 4). It is a practical and feasible example based on the monitoring and effective management of key pests. The query system has an interactive search function. The users can identify common pest types, risks and related consultations in the shortest time. For example, pest search can quickly find relevant pest ecological and hazard information, including text, audio video output, and integrated prevention instruction. Integrated pest management (IPM) knowledge-based inquiries focus on the integrated management of application examples or important crop pests. The report also provides a complete information of the workshop. Image consultation can upload pest photos or crop hazards according to farmers, assist in the study of pest species and provide prevention information. It outputs practical methods for pest management to reduce the improper use of pesticides and improve safety and quality of agricultural products.

Fig. 4. Homepage of the 'Intelligent Management Decision System for Agricultural Pests'. (http://azai.tari.gov.tw/aisearch/index.html)

Pest management platform for stored products

During rice production process, in addition to the losses caused by pests and diseases in the field, grain storage period is often affected by stored product pests. It may result in about 2-5% grain loss, with an estimated annual loss of more than US$6.6 million. The main stored product pests of rice are *Sitophilus oryzae* (L.), *Rhyzopertha dominica* (Fabricius) and *Sitotroga cerealella* (Olivier). The comprehensive prevention and management of major stored product pests has been developed, including light emitting diode (LED)-based pest traps, wireless sensor network (WSN) pest monitoring technology and anti-insect netting. From the perspective of prevention, this is considered as better than chemical treatments. The construction of a complete grain pest management model should include information of the government-owned grain barns, imported grains and small packaged rice together. It is implemented by four prevention stages of pest control, from source cleaning, anti-blocking, monitoring to control practice, to enable barn managers to obtain maximum benefits. The build of **Pest Management Platform and Monitoring System for Stored Products** (Fig. 5) (http://spir.tari.gov.tw/) provides a networking for users to learn, consult and communication (Yao and Lee, 2017).

Fig. 5. Homepage of the 'Pest Management and Monitoring System for Stored Products'. (http://spir.tari.gov.tw/)

The equipment of LED-based insect traps for stored product pests is developed to trap the grain pests. In particular, it has excellent trapping effect on the major pests in rice storage. The maximum number of traps per 10 minutes is 2,500, and the estimated grain loss is about 2%. It is not only low energy cost and high environmental protection, it also reduces the use of pesticides and improves the safety of barn pest control and consumers' food intake. In addition to the use in rice storage silos, it can also be used in imported grain storage silos such as corn and sorghum, which is more suitable for promotion and application in safe agriculture.

Image recognition system for insect pests

The technology to intelligently identify the types and quantities of insect pests through mechanical learning is now under development to provide farmers with more accurate management when the occurrence of pests population. Taking rice brown planthopper (BPH) as an example, an image recognition system for recognizing BPH is being developed at TARI in cooperation with the Industrial Technology Research Institute in order to assist controlling BPH migrated to Taiwan from neighboring countries or regions with airflow. This insect may cause more than 30% of production losses in severe cases. Moreover, the damage of BPH often occurs in the late growth stage of rice development making it difficult to control. Therefore, it is suggested to initiate pest management program when 2-3 larvae of BPH are found in a single rice plant. Unfortunately, BPH is small in size and generally difficult for farmers to identify, so that an automatic identification system is necessary to improve the efficiency and accuracy of BPH image judgment for a timely control. At present, the recognition rate can reach 90% through the deep leaning method, and can be used for the long-term dynamic monitoring. An image capturing device that to facilitate farmers' use and data uploading and an automatic identification system are now in development.

CONSTRUCTING THE EARLY WARNING AND NOTIFICTATION SYSTEM TO COPE WITH NATURAL DISASTERS

Agricultural production in Taiwan is vulnerable to meteorological disasters, such as typhoons, heavy rainfall, drought, etc. Annual crop losses due to disasters caused about 50 million NT dollar (approximately USD$1.7 million), even as high as $NT27.2 billion (USD$3 billion). Therefore, the applications of disaster prevention information and technology to reduce losses are important issues to stabilize food production. And the early warning systems are considered to have greater benefits for disaster prevention (Rogers and Tsirkunov, 2010). In 2016, the COA has implemented a four-year project, entitled "Study on the Construction of Risk Indicators for Agricultural and Forestry Meteorological Disasters and the Strategy for Disaster Adaptation." This project puts together the efforts of research and development to reduce damages from meteorological disasters, including integrating the database, developing disaster prevention technologies and preventing disasters in major crop production areas. It is hoped to change from the passive disaster relief to turn into active prevention measures. The experimental results and outputs from the project were promoted through sixty extension activities, with a total of more than 3,000 participants.

According to the real-time meteorological information and disaster forecast provided by the Central Weather Bureau (CWB), the databases of meteorological critical conditions of crop disasters were built by the district agricultural research and extension stations and research institutions in each area and have been linked to establish the **Crop Disaster Early Warning Information Platform** (Fig. 6) (http://disaster.tari.gov.tw). Disaster prevention measures and cultivation calendars have been established for various important economic crops, including information of disaster critical conditions, damage patterns and corresponding disaster prevention technologies. With that, it can be extended to use as a basis for crop disaster warning, damage assessment and agricultural insurance. At the same time, it also provides the basic knowledge for impact assessment of climate change. In the future, crop cultivation information and farming systems will be integrated with the databases of agricultural production and meteorological resources, so that climate information can be downloaded upon request to carry out high efficiency agricultural management and to reduce the negative impact of meteorological disasters on agricultural production.

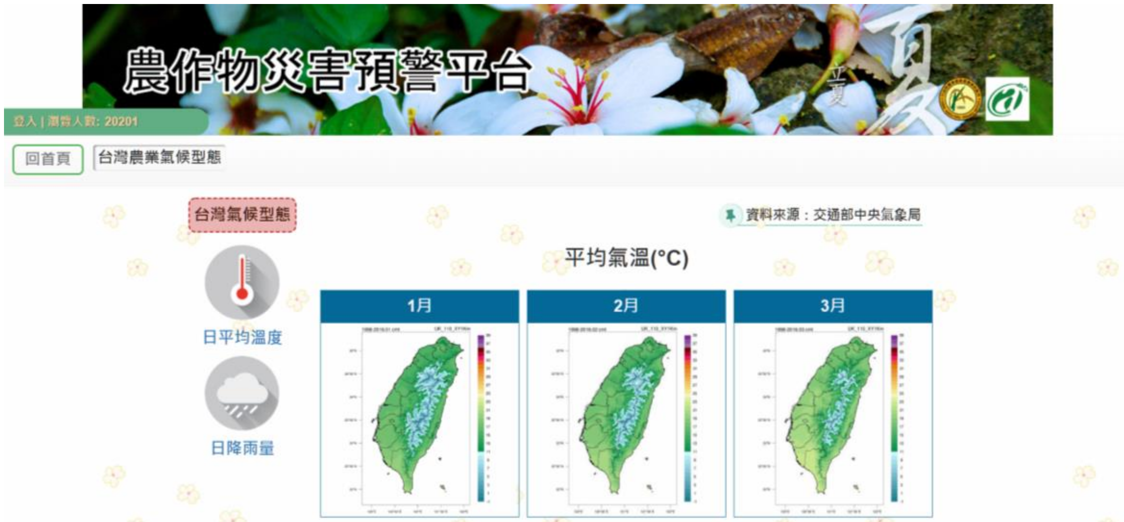

Fig. 6. Home page of the ‘Crop Disaster Early Warning Information Platform ’. (http://disaster.tari.gov.tw).

In addition, the development of disaster prevention standard operation procedures and technologies, when the probability of disasters reaches a certain level, is to promote farmers to take corresponding preventive measures, such as the use of internet, newsletters, APP and other media to deliver information. The APP of Crop Disaster Early Warning Information System could provide real-time disaster information of various crops and help automatically determine the severity of agrometeorological disasters.

The use of UAVs or drones has the advantages of quickly recording high mobility and high spatial resolution images and generating maps in short time to assist the monitoring and surveillance of natural disasters and post-disaster investigations, and therefore to accelerate post-disaster rehabilitation and recovery. As such, the geographic information system, image unsupervised classification, image segmentation, and digital surface model (DSM) are applied altogether in line with UAV high spatial resolution images. So far, the developed systems have been used in some crop disaster evaluation processes such as the lodge of rice and banana (Chou *et al.* 2018).

CONCLUSION

Precision agriculture is no longer just a basic data collection and analysis of field operations. In the era of ICT, it provides farmers an excellent management tool, including crop quality cultivation, pest management, field or greenhouse irrigation decision-making, and applications for disaster prevention and mitigation. It also plays an important role in a new wave of SA through intelligent machine learning or identification system development, combined with the decision-making system generated by big data analysis and intelligent auxiliary equipment operation. In the long run, as to the various environments of agricultural production and the specific targets set by various limiting factors are different, real-time and high efficiency information of plant physiology, nutrition, and environment must be optimized and incorporated for various management systems. The integration of various decision-making and management systems is also the goal of continued efforts in the future.

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