Realization of Society 5.0 by Utilizing Precision Agriculture into Smart Agriculture in NARO, Japan

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ABSTRACT

Society 5.0 is the concept of a future industrial structure and the ideal of social system launched by Japan. The National Agriculture and Food Research Organization (NARO) challenges to realize Society 5.0 with Smart Food Value Chain of breeding, cultivation, harvest, storage, processing, distribution and consumption. Therefore, the Agricultural Information Technology Research Center (RCAIT/NARO), launched in October 2018, pursues application-oriented AI research using “WAGRI.” Precision agriculture is a data-based farming operation from cultivation to harvest, that can contribute to the realization of Society 5.0 by optimizing agricultural management. About 10 years ago, the data was mainly image information from satellites. At present, various data have been obtained from agricultural machineries, and the agricultural machineries themselves can perform optimum operations based on the data. Yield monitoring combine harvester for precision fertilization in paddy fields, typical development case, have become an environmentally friendly system in addition to lower N fertilizer use and improving productivity. In addition, a Farming Information Management System (FARMS) and a Planning and Management Support software for farm work (PMS) have been developed to manage multiple fields with farm work information. 2019 is an important year for applying the research and development results obtained so far to actual farming and realizing the Smart Agriculture (including the concept of precision agriculture) in Japan. Unmanned aerial vehicle (UAV), variable rate fertilizer applicator and robotic rice transplanter, etc. will be expected to contribute to unmanned precision management.

Keywords: WAGRI, Yield monitoring combine harvester, Paddy field, UAV, Robotic rice transplanter

Introduction

Japan’s “5th Science and Technology Basic Plan (2016-2020),” prepared by the Council for Science, Technology and Innovation, has the major goal of realizing a super-smart society (Society 5.0). Society 5.0 follows the hunting society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0), and information society (Society 4.0) (Cabinet Office 2015). Achieving Society 5.0 with smart attributes would enable not just Japan but also the world to realize economic development while solving key social problems. It would also contribute to meeting the Sustainable Development Goals (SDGs) established by the United Nations. Therefore, we have begun to move toward the realization of a "data-driven society", including the agricultural world.

In agricultural research, precision agriculture has been in development for a quarter century to map weather and soil and crop information and to refine the management of fertilization based on this
information. As an example of crop information use, imaging technology has been widely used to estimate the optimal harvest time of rice and wheat by converting image information from satellites to the normalized difference vegetation index (NDVI). Only satellite imagery obtained during clear weather can be used for analysis, and its practical use is limited to large-scale farming in Hokkaido in Japan, but by judging harvest order and improving the efficiency of post-harvest grain drying, it contributes to the reduction of drying preparation costs.

To acquire images, aircrafts have been used in addition to satellites. In recent years, the use of Unmanned Aerial Vehicles (UAVs) has attracted great attention, and high-resolution images can be obtained frequently at low cost. It is expected that the use of UAVs will expand in Japan in the future. However, the standardization of image acquisition technology is just beginning to be evaluated for agricultural use. In addition, cultivation management has problems using the acquired image information such as data accumulation, management, analysis. In Japan, the “WAGRI” "agricultural data collaboration platform" was launched to provide useful data and facilitate data sharing for everyone involved in agriculture, and the National Agriculture and Food Research Organization (NARO) has been operating it since 2019.

In Japan, manufacturers of information and communications technologies (ICTs) and agricultural machineries have developed several commercialized systems. The Farm Activity Record Management System (FARMS) and farm work Planning Management and Support System (PMS) developed by NARO, have influenced the specifications and basic ideas for agricultural information technology. Systems integration with smart farming machines is essential for applying information from the fields. NARO is developing precise management technology for use in smart farming. As agricultural management scale enlarges and the number of fields that must be managed greatly increases, a system is needed for enabling optimal field management.

To make the dream of a quarter century ago become a reality, we will introduce the process of research and development (R&D) from precision agriculture to smart agriculture, which is being implemented as part of the R&D strategy aiming for early realization of Society 5.0 by NARO.

OVERVIEW OF NARO

Organization

NARO is the core institute in Japan for conducting R&D on agriculture and food production. NARO was established in 1893 as a national agricultural research institute. NARO has 3,338 full-time employees, including 1,839 researchers, and a budget of 91.8 billion yen per year (as of January 2019).

As part of a structural reorganization of NARO, the Research Center for Agricultural Information Technology (RCAIT/NARO) was established in October 2018. With the aim of promoting the ‘smartization’ of the agriculture and food industry, external personnel with expertise in artificial intelligence (AI) will be appointed to train NARO staff who will be at the forefront of conducting extensive research towards the realization of smart agriculture using AI technology and big data. In addition, the NARO Development Strategy Center was established at NARO Headquarters in April 2019. The Center serves as NARO’s think tank to investigate and analyze policies, social expectations, and domestic and global trends to formulate R&D strategy.

A priority research center for agricultural machinery is the Institute of Agricultural Machinery (IAM/NARO), which concentrates on applying robotics and ICTs to the agricultural sector by focusing on collaborations between different research fields. IAM is the core center to achieve improved productivity, save labor, reduce environmental burdens, and develop basic technology for agricultural work safety by R&D in leading-edge agricultural machinery and technology.
Major research outcomes

To support future agricultural production sites, we are addressing the urgent issues facing the agriculture and food industry, such as ageing and decreasing number of farmers, to enhance the base of agricultural production; promote the development of farm management through innovative technologies; and achieve vigorous productivity in paddy-field farming, upland farming, and livestock production by taking advantage of regional conditions. In agricultural machinery R&D, unmanned robots that can perform agricultural work such as tillage, puddling, transplanting, and harvesting have been developed using global navigation system technology. Development of the Farm Oriented Enhancing Aquatic System (Figure 2), a new water control system with irrigation and drainage facilities for cultivation in paddy fields, has enhanced the growth and yield of many upland crops.

The most successful research result of NARO, in terms of impact on modern agriculture, is breeding of the “Norin 10” wheat, which contributed to the “green revolution. Fuji apples, the world’s largest production apple variety, and Shine Muscat grapes are just two examples of NARO products sold in the world market; these have given NARO’s breeding technology a high reputation. NARO is promoting the development of novel crops and new agricultural products through genomic and agrobiological research, an innovation that focuses on new elementary biological materials. By decoding the genome sequence of rice and analyzing the gene functions, we have developed DNA markers associated with important agronomic traits, which are expected to facilitate efficient improvement of rice cultivars. Other major biotechnology outcomes are development of silk fibers containing fluorescent proteins of different colors and silk materials with new functionality imparted by spider dragline protein.
NARO’s R&D policy

NARO’s overall mission is to contribute to the development of society through innovations in agriculture and food, by promoting pioneering and fundamental R&D. The agriculture and food industry sector in Society 5.0 creates high value by highly integrating physical (real) space and cyber (virtual) space and contributing to the realization of the future image and growth strategy of Japan (Figure 3).

In the physical space of the agriculture and food industry, it is important to establish a “smart” food value chain. The whole process, from smart breeding, smart agriculture, and smart distribution to consumption, must be connected. Data from each process in the food value chain are accumulated in ‘WAGRI’, which is’ located in cyber space. The term WAGRI is a coined word combining wa (a Japanese word meaning “harmony”) and agri (agriculture) (WAGRI 2017). The accumulated data are analyzed by AI for optimization of the entire process for productivity improvement, reduction of waste and total cost, and technology harmonization.

The future imagined by NARO includes promotion of industrial competitiveness, realization of a data-driven society, creation of new industry, and long healthy life. NARO is focusing on six research subjects to realize “the agriculture and food industry sector of Society 5.0” (Anonymous 2018a): (1) creation of a data-driven innovative smart agriculture, (2) development of a smart breeding system and cooperation with the private sector in breeding new cultivars, (3) construction of a smart food value chain that includes exports, (4) utilization of biological functions to create new industries and enhance health care through food, (5) development of essential agricultural knowledge and technologies, such as the NARO Genebank (Anonymous 2018b), and (6) advancement of fundamental technologies by RCAIT, such as robotics (Anonymous 2018c).

Figure 3. Agriculture and food industry sector in Society 5.0
PROGRESS FROM PRECISION AGRICULTURE TO DATA-DRIVEN INNOVATIVE SMART AGRICULTURE

Precision agriculture driven by image information from satellites

The Japanese model of precision agriculture has been accompanied by well-organized farmer wisdom and a technology platform. The farmer wisdom groups improve upon the conventional farming system through the management of hierarchical variability. The technology platform organized by innovative companies develops and provides three key technologies: mapping techniques, variable-rate techniques, and decision support systems (Shibusawa, 2003).

NARO started to apply mapping techniques in Hokkaido in 2004 to develop a decision support system for determining wheat harvest order by showing growth information from satellite images on a map. In the early 21st century, wheat harvesting and drying operations in large-scale field farming areas in Hokkaido were promoting shared use of harvesting machinery and drying facilities. However, an oligopoly of cultivars and increase of wheat acreage made it difficult to organize the harvest sequence due to usage conflicts between facilities and machines. A “wheat harvest support system to optimize harvest timing with satellite remote sensing” was developed in cooperation with the Hokkaido Prefectural Agricultural Experiment Station, JA Memuro and Zukosha Co., Ltd. This system consists of four methods: “wheat growth early and late map creation method by satellite remote sensing,” “250-m meshing method of meteorological data,” “maturity prediction method,” and “low amylose wheat occurrence prediction method” (Okuno 2005).

To create a map of early and late wheat growth, we use satellite images equipped with optical sensors that can capture red (R, near 640 nm) and near infrared (IR, near 800 nm) wavelengths necessary for calculating the NDVI defined as (IR-R)/(IR+R). The NDVI of the wheat field obtained from the satellite image in mid-July corresponding to 1-2 weeks before harvest start can properly express the change of leaf color from green to yellow as the wheat ripens. The map was provided to JA Memuro prior to harvest, and its data are used for determining the harvest order for about 4,000 ha. Therefore, the cost of drying has been reduced because the harvest is not performed when moisture is excessive, the wheat moisture content at drying facilities were reduced and homogenized (Figure 4).

![Image of satellite remote-sensing map of wheat growth early and late and effect of wheat harvest support system to optimize harvest timing with satellite remote sensing](image)

Decision support by Farm Management Information System (FMIS)

Here we introduce PMS and FARMS as components of the Farm Management Information System (FMIS) developed by NARO.

PMS software for farm work was developed in 2007. It visualizes agricultural data with a geographic
information system (GIS), which makes it easy to understand the status of crop production and farm work, and helps farmers make decisions for various work. PMS uses GIS-compatible components for map display, and it includes several tools to make maps, reports, and user-customized data queries and backup data. The program is an aggregation of programs accessing a common database on a Microsoft SQL server, and most data are stored in a “Field DB” format (Figure 5). The data structure is designed for practical data uniquely derived for farming in Japan. More than 100 farmers, including farming companies, are proving the effectiveness of PMS.

FARMS was developed as a prototype in 2008 to register more advanced information, such as workers, names of operations, fertilizers, pesticides, and agricultural machines, that is also managed based on GIS. The development has focused on establishing methods to obtain information from individual agricultural machines. It was possible to display a tractor working and its state of fuel consumption by recording the operating condition of the tractor together with the output of a Global Positioning System (GPS) receiver. Furthermore, a harvest size map can be created from the harvest information by using a yield-monitoring combine harvester equipped with GPS receiver and yield sensor capable of continuously measuring the amount of grain entering the grain tank.

In an agricultural production corporation, it is necessary for one corporation to manage farm work information for hundreds of fields. At the same time, it is important to utilize farm management information systems as the core technology of data-driven smart agriculture to achieve low-cost and labor-saving production. In addition to NARO developments, several commercialized systems developed by manufacturers of ICTs and agricultural machineries will be able to exchange information under WAGRI within a few years.
Electronic control unit certified by ISOBUS

As described above, to exchange information between FMIS and agricultural machinery and to control the attached implements, it is necessary to standardize the controller area network (CAN) interface of agricultural machines.

To control tractors and fertilizer machines using variable information, such as fertilization maps, it is important to standardize the communication control common technology in agricultural machinery. NARO collaborated with the Agricultural Information Design Co., Ltd., to develop an electronic control unit (ECU) for agricultural machineries. We have developed the ECU by applying the ISO 11783 standard to domestic agricultural machines since 2008. Subsequently, the ECU received formal certification under ISOBUS, an international protocol (described below), the first time for a domestic technology (IAM/NARO 2018, Figure 7). With this conformance to international standards, connection compatibility across barriers is guaranteed when interconnecting equipment (including vehicles and attached implements) from different manufacturers.

ISO 11783 is a standard for an international communication protocol for agricultural electronics, commonly called ISOBUS, and equipment can be certified according to the guidelines defined by the Agricultural Industry Electronics Foundation. In the USA and Europe, ISOBUS is widely used for large agricultural machinery as a global standard of connection compatibility for tractors and attached implements.

![External Appearance of ECU for Granular Fertilizer Applicator](image)

**Figure 7. Positioning of ECU for granular fertilizer applicator in the network**

The ECU bridges the manufacturer’s proprietary control unit and the ISOBUS network.

Nationwide on-farm demonstration trials of smart agriculture

The “On-farm Demonstration Trials of Smart Agriculture” started in March 2019. The trials started with 69 farm trials in 6 fields (paddy rice production, field and greenhouse cultivation, fruit, tea, and livestock) and are planned for the next 2 years. The technologies for smart agriculture have been developed by the cross-ministerial Strategic Innovation Promotion Program (SIP). NARO will promote trials of data accumulation by WAGRI, productivity improvement, cost reduction, achievement of farmer income improvement, and improvement of agri-robots (performance, reliability improvement, and cost reduction). In addition, we will propose standardization of agri-robots and revision of laws and regulations that affect smart agriculture.

The SIP, started in 2013, is a program that cuts across government agencies and fields. Phase 1 of the SIP (2013-2018) produced uniquely Japanese smart, ultra-labor-saving, and highly productive agriculture models (Cabinet Office 2017). However, implementation to actual farms varies according to field
conditions, such as location, land shape, and soil, resulting in the problem that machineries and facilities become too expensive. Phase 2 of the SIP (2019-2023) is in progress to implement R&D at farms, especially smaller farms, which constitute most farms in Japan.

On April 24, 2019, a field tour was held prior to the Eighth Annual Meeting of Agricultural Chief Scientists of G20 States (G20-MACS). The tour demonstrated the operation of multiple robot tractors. NARO promoted the research outcomes of smart agriculture utilizing ICT at the G20 Niigata Agriculture Ministers’ Meeting on May 11-12, 2019.

**CONCLUSION**

The SIP goal of “Technologies for Creating Next-generation Agriculture, Forestry and Fisheries” is meant to establish a uniquely Japanese system of production, creating a smart, eco-friendly, ultra-labor-saving, and highly productive agriculture model. By aligning individual research efforts and leveraging synergies to achieve Society 5.0 for agriculture, we will build a next-generation agriculture, forestry, and fisheries industry robust enough to grow and compete on the global stage (Noguchi 2018). The results of the SIP have been used for nationwide on-farm demonstration trials of smart agriculture since 2019. From April 2021, NARO will embark on the 5th mid-term plan for 2021-2025. NARO will create innovations in science and technology during the 5th mid-term plan that will eventually transform agriculture into a robust industry by using the results of on-farm smart agriculture demonstration as feedback. We are convinced that Society 5.0 can be realized in the field of agriculture and food, and then it will contribute to promoting R&D in other agricultural research institutes in Asia.

**REFERENCES**

(http://www.naro.affrc.go.jp/english/society5-1-rdgs/index.html; Accessed 7 July 2019)


IAM/NARO. 2018. Electronic control unit certified by ISOBUS.