Invited Speakers

Needs of Quality Information in Sustainable Agro-ecosystem Services

Seishi Ninomiya
Institute of Sustainable Agro-eco Services
The University of Tokyo
Nishi-tokyo, Tokyo, Japan
e-mail: snino@isas.a.u-tokyo.ac.jp

ABSTRACT

The sustainability of agriculture is one of the most important and common issue of the human kinds. The high productivity of agriculture achieved in the 20th century succeeded in dramatically decreasing hunger but we are now realizing such productivity is not a necessary and sufficient condition. In addition to the high productivity, stable and robust productivity under climatic change and frequently occurring extreme weather conditions, low environmental impact, low emission, food safety and farmers' welfare must be also achieved simultaneously. They are all related to sustainability of production either directly or indirectly. In general, to fulfill such multiple conditions is a complicated problem to solve. In this paper, how we should approach such a problem utilizing ICT is discussed.

Keywords-*benefit; agriculture;quality; low input; robastness; productivity; stability; safety; sustainabilility; welfare*

I. INTRODUCTION

Agriculture in the 20th century was very successful in terms of supporting the rapid growth of the world population that became 10 times as many in just a century from 0.6 billion to 6.3 billion. For example, the wheat productivity rose up from 1.1 t/ha to 2.9 t/ha between 1961 and 2003 [1]. The success was achieved by the discovery of the Habor process to efficiently produce nitrogen fertilizer, agro-chemicals such as DDT, parathion and 2-4D, machineries, irrigation systems and new high-yield varieties that effectively respond to such high input of chemicals. In other words, the agriculture was based on chemistry and engineering.

Such success in agriculture, however, brought serious drawbacks as well by the end of the century, i.e. serious impacts on environments with agricultural chemicals such as water pollution, damages on ecosystem, soil erosion by cultivation of slope land with machinery, exhaustion of soil by high input and high water demand by new verities. As a result, agriculture which was originally a green industry of fixing CO2 by photosynthesis became a highly recourse consumptive and non-sustainable. The issue of food safety is also a part of it [2].

In the 21st century, the population is still increasing while food is transiting from grain to meat particularly in developing countries and the use of crops for bio-fuel is growing, still causing the high demand on food. In addition, we have to consider that the shortage of land for cultivation, water supply and frequently occurring extreme weather conditions under global warming are terrifying stable productivity of food. Namely, we need to realize both high productivity and sustainability simultaneously. Here, sustainability does not mean only environmentally low impact nor low emission but mean also sustainable and robust productivity, and beneficial farming for farmers.

Simply to say, agriculture pursued the maximization of the productivity in the 20th century but now we have to think of solving several issues simultaneously. There have been several approaches to solve those issues. For example, non-tilling cropping may solve many of the above issues in paddy rice [3] but cannot be a general solution. What is clear is that we have to seek for the way to optimize several conditions to fulfill the requirements to achieve real sustainable agriculture of the 21st century; a paradigm shift of agriculture for sustainable agriculture maximally harmonizing with ecosystem services [4]. In recent years, information science has often given us a good solution for complicated problems, having powerful computers. In this paper, how we should approach such a problem in agriculture, utilizing ICT is discussed.

II. OPTIMIZATION?

How shall we optimize agriculture? There must be several approaches but one of the simple answers is to realize an emission free farm while keeping its productivity, conducting its LCA (Life Cycle Assessment). The first step is to identify all the inputs and the outputs in a farm level considering the linkage of them as models. Then, we need to calibrate the models using the observations practically monitored in the farm. If the models are ready, then we can start the process of the optimization. The most typical way of optimization is to combine the models with linear programming in order to find out the most optimal combination of the inputs to achieve the zero (lowest) emission in net while securing targeted productivity and benefits. In such an approach, ICT will take an important role;

- The process is expected to be very complicated and requires high computational power and efficient algorithms.
- The process needs to be handled with huge scale data sets and an efficient database and data-mining technologies are inevitable.
- Efficient and continuous monitoring is absolutely important to watch the present status of the farm and

to keep the optimized condition, which is also achieved by ICT such as sensor network and sensing technologies.

One simple example of such optimization is prediction of pest occurrence. Once we can predict pest, then a pinpoint and timely application of pesticide becomes possible, which results in reduction of pesticide use, labor and time cost for spray. It also reduces fuel use for machinery for spray and, transportation and production of pesticide itself. Therefore, such pest prediction achieves lower output of CO_2 in several ways additionally to decreasing direct impact on ecosystem by pesticide application. In this case, accurate and reliable prediction is extremely important. Such prediction should be based on a prediction model which has been calibrated and evaluated by a plenty of observations widely acquired by automated sensors. Then, based on the targeted emission, productivity, farm benefits etc., farming is to be optimized.

III. ICT for Optimization

To realize such optimizing process, we have to provide several models and to integrate them. Unfortunately, both are rather delayed and we still need to wait before we can conduct a rather simple optimizing process. However, ICT is doubtlessly helpful in many aspects of optimizing agriculture to solve the issues. Going back to the above example, the pest prediction model (early warning system) needs observed and forecast weather data. The former data can be efficiently acquired by ICT based monitoring systems [5] and the latter can be obtained by huge amount of computation with super computers. For example, emergence of rice blast can be well predicted by temperature, humidity (leaf wetness) and wind speed. Disease symptom and emergence of insect pest can be detected by image analysis or automated insect counting traps.

After predicting or detecting emergence of pest, a navigation system for propriety pesticide use [6, 7] prevents violating regulations for pesticide use and supports to record pesticide application. The record is used to know amount of chemical input, labor cost and material cost as well as data for traceability systems and GAP (Good Agricultural Practice) that are used to certify right use. Finally, the collected data are used as a part of data to realize farm level optimization regarding sustainability.

In general, ICT can be used for [8];

- Cost reduction by optimal farm planning and management based on farm records and market information.
- Optimal input of chemicals against environmental impacts by monitoring environmental and crop conditions.
- Robust and stable production by finding optimal crop, cropping timing and early warning.
- Food safety and reliability by right use of chemicals, GAP compliance and traceability system.
- High quality products by monitoring crop and proper guidance.

To use ICT for those applications, we need several technologies [8];

- Efficient and low cost data collection tools to know environmental condition, crop condition and farm records.
- Efficient knowledge transfer tools to quantify invisible empirical knowledge and to utilize case data.
- Optimization and risk management tools to support decision making based on acquired data and knowledge.
- Framework to support decision making to integrate data and applications.

In the following sections, some examples of existing applications that can contribute to optimization process are introduced.

IV. Data Collection

Agriculture is typically site-specific, depending on weather, soil, cropping style, market requirements etc. This makes it difficult for us to develop generally applicable decision support applications. Therefore, data orientated case base reasoning seems to be more promising than mechanistic approach in practical decision supports. This means that continuous data collection is needed in each farm (even in each parcel) locally and we need to wait for a certain period to make enough data accumulated. Actually, many of the farmers don't record their farming and don't know income and expenditure balance of each parcel basis. Moreover, they also need to collect environment and crop conditions as well to conduct sustainable and optimal farming, and risk managements.

There have been several tools developed to help such data collections [5, 9, 11, 12, 13]. FieldServer [5], for example, is a WIFI based autonomous device to collect data automatically. In addition to ordinal environmental sensors such as air temperature, soil temperature, humidity and solar radiation, it can observe soil moisture, soil EC, CO_2, precipitation etc. by choosing proper sensors. It has a built-in camera and images can be used to record farm actions as well as crop conditions through image analysis. Several new sensors are still being developed for FieldServer. Insect counting trap which collects particular pest insects by pheromone and counts the number is an example. RF-ID based farm recording system is also being studied [14]. To handle data collected efficiently, GIS is a strong tool [15].

Recently, an integrated multi sensor platform named Field Doctor was proposed to collect several environmental, crop and farming data. In the idea, in addition to farm built-in sensors such as FieldServers, a vehicle that carries several equipments to measure soil contents, crop nutrition level, etc., visits farms periodically to collect such data. Field Doctor is a part of a service to provide famers present status of their farms. This is a kind of service to show skill level of farmers by quantitatively comparing the present level with a target level (e.g. nutrition content level, soil organic content, energy consumption). With this service, farmers can identify the discrepancy between target level and present level and will try to improve their farming to reach the target.

V. Efficient Knowledge Transfer

Empirical knowledge often takes important roles in agriculture. Particularly, organic farming which may become a core of sustainable agriculture has been being conducted by skillful farmers and how to transfer such knowledge to the next generation is an urgent issue, facing the aging issue of such farmers. This is a way to quantify invisible empirical knowledge by converting tacit knowledge to explicit knowledge. One of possible approaches is to utilize accumulated text data and provide a good retrieval system so that users can learn former cases that are similar to their present cases to find out good solutions. This approach is a kind of case based reasoning (CBR) and useful for agricultural cases [16, 17].

A group of farmers in Hokkaido, Japan have been storing their farming records in a digital diary named Cyfar's (Cyber farmer) diary for 10 years. They record real time data by mobile phones and usually corresponding images of their fields are also stored often with GPS positioning data of the phones. The diary is shared by the group members. While, the real time data is useful to know present status (e.g. emergence of pest) , they also realized that the series of data for 10 years is highly useful to learn past cases and corresponding solutions and to make proper decision.

VI. Optimization and Risk Management

Risk management and optimization are the goal of data collection and knowledge transfer. A simple data mining is the first step where we compare environmental condition, crop condition and farming record to find out rules among the conditions. This kind of heuristic approach can be sometimes powerful with graphical tools [18]. With such an approach, a type of rules such as "high relationship between yield and air temperatures of 4 to 7 days before harvest" is found and farmers may make the next decision based on it. Series of images taken everyday can be utilized to identify the best timing of harvest by comparing the color of fruit with a color chart taken in the same picture.

Tools to reduce human errors such as Pesticide Navigation System [6, 7] are extremely helpful. This leads to proper use of chemicals and can be used to control environmental impact by setting up strict initial plan of pesticide applications. The data collected are also utilized for certification on GAP and traceability, LCA assessment and farm managements.

As mentioned above, pest prediction is also very important to minimize use of chemicals, which leads to cost reduction, lower emission and energy saving. For example, an early waning system of rice blast has been being utilized by some part of Japan [19]. An airborne pest immigration prediction system is another case. This system predicts the area and timing of rice hopper immigration from the outside of Japan [20]. The prediction is conducted by combining weather forecast of westerlies which convey the insects, a diffusion model to trace insect diffusion, an insect behavior model to define timing of taking off, a crop growth model to define paddy rice growth stage at the origin and satellite image analysis to identify the positions of paddies at the origin. By the system, extension staffs and farmers can know the best timing of pesticide application and can reduce the number of the applications. Chilling weather warning system is another example of early warning, which is helpful for farmers protecting paddy rice in deep water against cold weather damaging rice panicles.

Rice growth prediction system which estimates date of panicle emergence, date of maturity and yield based on weather condition is also helpful to find out optimal timing of planting, optimal cultivar of crops and, dynamic and proper crop managements (e.g. fertilizer application, water management and harvesting timing). It can be also used to simulate crop responses under global warming condition using climatic scenario data.

Remote sensing with satellite images is also often to help farmers' decisions. Estimation of water contents of wheat for identification of the best timing of harvest, estimation of rice quality based on nitrogen contents and estimation of paddy damage for agricultural insurance are good examples of successfully utilizing satellite images.

To provide Good user interface of applications is also an important factor of good decision support systems [21].

VII. Seamless Data Integration

In agriculture, several different types of data sets are required to run models and to make decisions because agriculture is a complex system affected by many conditions. Those data sets are usually maintained and managed by different organizations such as research institutes, weather networks, farmers' unions, extension services and private sector organizations, and are located in different places. Therefore, presently, one has to collect data sets one by one for some decision, resulting in ineffective duplications of the same data sets in multiple locations. If these distributed data sets are virtually integrated and become sharable for agricultural decision support, it will surely accelerate effective decisions supports in agriculture. In this approach, multiple users can share a single executable module, avoiding duplication of software development and maintenance while multiple programs can share the same data set, avoiding duplicated data maintenance and management [22, 23].

To realize such a mechanism, we have to have a framework for seamless data exchange which standardizes data and application interfaces. One of the major challenges to realizing such a framework lies in addressing the heterogeneity of databases while retaining their autonomy. For example, typical weather databases accessible through the Internet rarely have the same data format, measured items, resolutions, and interface, so client application programs must be specially adapted for each database. To solve the issue of database heterogeneity, we proposed the use of data brokerage middleware to provide client applications with consistent access to databases and practically implemented the idea as MetBroker for meteorological data mediation [24, 25]. MetBroker has been operational, providing more than 22,000 stations of 25 heterogeneous metrological data bases of the world that client applications can access with the same interface.

Adopting the idea of data broker, a broker system for image data transfer and exchange was developed [26]. The system named ImageBroker provides a P2P based platform for the functions. Another example of agricultural data broker is a data exchange and retrieve service for distributed crop data [27]. Using the service, one can easily store own spreadsheet based daily crop data to a common database sharable among a group and extract a part of integrated data among different locations according to the query given. This service also provides a function to extract weather data corresponding to retrieved crop data based on locations and date.

VIII. Disucussion

In this paper, an approach to realize sustainable agriculture using ICT was discussed with some applications that are presentably operational. Unfortunately, no integrated tool to support even farm-level optimization for sustainability is available. However, several tools / models that can be parts of the integrated tool exist, and an initial stage of such integration should start soon.

Human beings receive tremendous benefits from ecosystem services and agriculture is a part of the service. Therefore, sustainability of such service is absolutely important. In this paper, I used the term “sustainability” with much broader sense than in ordinal case where people consider only low input and resource saving for lower impact on environment. Human beings are also a part of ecosystem services and their existence must be also sustainable. That is, stable and sufficient production of food is also inevitable for human sustainability. Such stable production is also secured indirectly by environmentally sustainable agriculture which preserves resources such as soil and water. Considering sustainability of farmers, farmer welfare should be also included in the definition of sustainable agriculture. I always wonder why those who enjoy comfortable urban life can force farmers to eradicate weed by hands without using herbicide. A similar thing happens in the definition of the term “safety food”. In the case of agricultural products, people usually think of crop without pesticide with this term. This should, however, cover much wider sense including stable and sufficient productivity, low emission and human welfare.

As a conclusion, ICT helps the shift from maximization to optimization in agriculture through continuous data collection, utilization and transfer of empirical knowledge, decision support systems and their integrations.

References

[1] FAO STAT, http://faostat.fao.org/site/339/default.aspx, 2010

[2] V. Smile, Feeding the world: A challeng for the twenty-first century, The MIT Press, Boston, 2000, pp.362

[3] N. Iwasawa, Kyukyoku-no tanbo, Nihon Keizai Shinbun Press, 2010, pp. 209, in Japanese.

[4] Wikipedia, Ecosystem services, http://en.wikipedia.org/wiki/Ecosystem_services.

[5] T. Fukatsu and M. Hirafuji, Development of Field Servers for a field monitoring system, Agricultural Information Research 12, pp1-12, 2003, in Japanese with an English summary.

[6] T. Nanseki, K. Sugawara, T. Watanabe, T. Oguchi, H. Kikuchi, T. Suzuki and H. Endo, A navigation system for propriety pesticide use: design and implementation, Agricultural Information Research 14, pp159-170, 2005, in Japanese with English summary.

[7] K. Sugawara, A. Otuka, K. Tanaka and T. Nanseki, An application to judge and record appropriate pesticide uses runing on mobile phones, Agricultural Information Research 15:381-394, 2006, in Japanese with an English summary.

[8] S. Ninomiya,Is ICT promising in agriculture?, In Food System Development and Information Technology in Rural Sector for the Globalizing Asia-Pacific Region, Asia Pacific Agricultural Policy Forum, Anyang, Korea, pp279-294, 2007.

[9] K. Sugawara, Farming diary system using internet-enabled cellular phones, Internet Workshop 2001 Proc.II Applications, pp247-252, 2001.

[10] A. Otuka and T. Yamakawa,An application for insect field serveys using a handheld computer, Agricultural Information Research 12, pp113-124, 2003.

[11] A. Otuka and K. Sugawara, A labor management appliation using handheld computers, Agricultural Information Research 12, pp95-104, 2003.

[12] J. H. Xin, H. Beck, L. Halsey, J. Fletcher and F. Zazueta, Using digital cameras and the Internet to identify plant insect and disease problems. Computer in Agriculture 1998, pp352-358, 1998.

[13] T. Kamiya and T. Machida, Studies on the automatic journal system for field work by using GPS, Agricultural Information Research 11, pp263-272, 2002, in Japanese with an English summary.

[14] T. Nanseki, K. Sugawara and T. Fukatsu, Farming operation automatica recognition system with RFID, Agricultural Information Research 16, pp132-140, 2007, in Japanese with an English summary.

[15] T. Yoshida, H. Takahashi and I. Teramoto, Developing of plannning and management support software for farm work using a geographical information system-compatible field map, Agricultural Information Research 18, pp187-198, 2009, in Japanese with an English summary.

[16] A. Otuka and S. Ninomiya, Conceptual Retrieval of Agricultural Cases with Latent Semantic Indexing Approach, Proceeding of International Conference on Engineering of Decision Support Systems in Bio-Industries, Montpellier, France, pp.37-38, 1998.

[17] A. Otuka and C. Kitamura , Agriculture case base; Decision support by harnessing knowledge and experience, Bul. Natl. Agr. Res. Centr. 1, pp.45-56, 2002.

[18] T. Hoshi, T. Sasaki, H. Tsutsui, T. Watanabe and F. Tagawa, A daily harvest prediction model of cherry tomatoes by mining from past averaging data using topological case-based modeling, Computer and Electronics in Agriculture 29, pp.149-160, 2000.

[19] K. Tanaka, A Java Framework for Developing a Plant Growth and Disease Prediction Model, Agricultural Information Research, 15, pp.183-193, 2006.

[20] T. Otuka, T. Watanabe, Y. Suzuki, M. Matsumura, A. Furuno and M. Chino : Real-time prediction system for migration of rice planthoppers Sogatella furcifera and Nilaparvata lugens, Applied Entomology and Zoology, 40, pp.221-229, 2005

[21] K. Tanaka and M. Hirafuji, Map Interfaces Using Web Map Services in an Agricultural Model, Agricultural Information Research, 18,. pp.98-109, 2009.

[22] S. Ninomiya, Network Computing for agricultural information systems -GRID for agricultural decision support-. Proc. 3rd AFITA; Asian Agricultural Information Technology and Management. Ed. F. Mei:26-30, 2002.

[23] S. Ninomiya, S, M. Laurenson and M. Hirafuji, An approach to agricultural information system based on Grid concept, EFITA/WCCA2005 Proceedings, ISBN972-669-646-1:1092-1100, 2005.

[24] M. Laurenson, A. Otuka and S. Ninomiya, Developing agricultural models using MetBroker mediation software. J. Agric. Meteorol. 58:1-9, 2002.

[25] M. Laurenson, T. Kiura and S. Ninomiya, Providing agricultural models with mediated access to heterogeneous weather databases. Applied Engineering Agric. 18: 617-62, 2002.

[26] N. Iguchi, Y. Motonaga, F. Uchio, S. Ninomiya and T. Kameoka, Development of image broker system using P2P for sharing of agricultural product image. Agricultural Information Research 15:155-164, 2006, in Japanese with English summary.

[27] X. Yu, A. Yamakawa, T. Kiura, T. Hasegawa and S. Ninomiya, CROWIS: A System for sharing and integrating crop and weather data, Agricultural Information Research 16(3):124-131, 2007.