JARQ 34(4), 233 – 238 (2000) http://ss.jircas.affrc.go.jp

Prospects and Strategies for Precision Farming in Japan

Akira SASAO* **and Sakae SHIBUSAWA**

Faculty of Agriculture, Tokyo University of Agriculture and Technology
(3-8-5 Saiwai, Fuchu, Tokyo, 183-8509 Japan)

Abstract
Precision farming is bringing about a new revolution in agricultural farming systems with its high potential of reducing the environmental impact and increasing the productivity, based on the high efficiency of advanced technology. Variability management is the key approach in precision farming, using field maps and real-time sensing for temporal and spatial variation in soils, plant growth and yield, and other parameters related to cultivation. Site-specific field management can be implemented based on accurate information. Scale-free precision farming approaches are suitable for small-scale Japanese agriculture. Prospects and strategies for Japanese precision farming are introduced, followed by the results derived from investigations on soil mapping and the use of soil sensors.

Discipline: Agricultural engineering
Additional key words: small-sized farm, variability soil map, soil sensor

Introduction

Precision farming, which aims at reducing the environmental impact and increasing the productivity, has been rapidly developed in the world during the current decade. In the United States, for example, the National Research Council[6] suggested that the federal government should encourage research and development related to precision farming as a national strategy. European countries have also promoted the development of precision farming. In Japan, the Ministry of Agriculture, Forestry and Fisheries started an R&D project on Japanese precision farming in 1998, while several universities and companies have already studied specific issues.

Promotion of precision farming should affect related industries as well as agriculture due to technology innovation.

In this paper, the concept of precision farming is outlined and studies related to Japanese precision farming (soil mapping and soil sensors) are introduced.

Concept of precision farming

Precision farming is characterized by a systems approach to orient the total system of agriculture toward sustainability, as shown in Fig. 1[7]. Regulations for environmental conservation have become increasingly stricter worldwide. Specific problems such as pollution by chemicals, organic agriculture or agriculture without the use of pesticides have attracted a wide interest. However, such an agricultural system had focused on the improvement of only one or several aspects of agriculture, which sometimes resulted in reduced productivity, and did not enable to modify the whole system of agriculture supported by farmers. Precision farming aims at solving such trade-off problems on environmental conservation and productivity, using variability management and a systems approach[2].

Three fundamental techniques must be considered for integrating the components of precision farming systems.

1) Analysis of variability is the key concept of precision farming, in particular to analyze within-field variability, in order to adjust agricultural inputs to site-specific requirements. Variability should involve at least 3 aspects: spatial variability, temporal variability and predictive variability[2,8].
2) Variable-rate technology (VRT) is used for adjusting the agricultural inputs to site-specific requirements at each location in the field, which requires variable-rate working machinery while manual application can be

*Corresponding author: fax +81–42–367–5761, e-mail sasao@cc.tuat.ac.jp
Received 7 January 2000, accepted 8 February 2000.

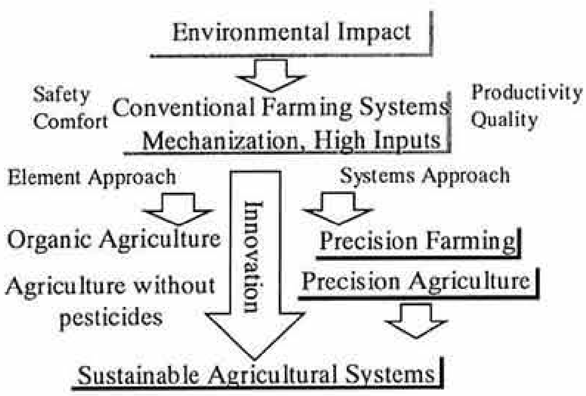

Fig. 1. Trends of agriculture and implications for precision farming

used in a small-scale farm. Variable-rate application allows: (1) accurate position in the field, (2) accurate information at the position, and (3) precise operations at the position.

3) Decision support system (DSS) offers some choices to a farmer in terms of trade-off problems such as productivity and environment. This component is characterized by a systems approach to optimize a complex system.

How to integrate the technology components to meet the conditions peculiar to Japan agriculture, is a major issue for researchers, engineers and politicians as well as farmers.

Scale-free precision farming

Japanese agriculture is characterized by a smallscale and labor-intensive operations based on individual plant management involving variability. Considering the variability of management in precision farming, the precision farming approaches can be adopted for any scale of farming as shown in Table 1.

In the case of small farms, farmers should concentrate their activities on fields based on empirical knowledge. Information on each field on an average and use of simple monitoring techniques for mechanical applications, enable to conduct variable-rate controls for site-specific management based on farmers' skills. The variability management system deals with only averaged data per field. For the management of a farm of several hectares, it becomes difficult for the farmers to evaluate the variability within each cultivation field. This is more evident for farming on a much larger scale. Positioning by using GPS techniques, automatically sensing systems, etc. may enable to generate field maps to analyze the spatial and temporal variability. Sensor-based variable-rate control machines can be used for managing such large-scale farms because of the requirement of high-speed operations.

Consequently precision farming approach can be designed and re-arranged to fit any scale of farms, which is an important aspect for Japanese agriculture due to the diversity in field size, crop variety, field elevation, water management for paddy fields, climatic and soil conditions, etc.

Table 1. Prospects of scale-dependent main technology required for precision farming

Management scale (ha)	Positioning for operations	Soil mapping in a field	Yield mapping within a field	Variable-rate control
– 1	Empirical determination & intuition	Average for each field	Average for each field	Manual control with a monitor
1 – 10	Automatic field-based survey or machine positioning	Variability within a field determined by soil sensors	Variability within a field determined by yield monitor	Operator's skill with monitoring and automated machinery
10 – 50	GPS-oriented + field-based machine positioning	Variability within a field determined by GPS-based sensors + remote sensing	Variability within a field determined by GPS-based monitor + remote sensing	Sensor-based variable-rate control with GPS/GIS
50 –	GPS-oriented + field-based machine positioning	Within/regional field variability determined by GPS-oriented sensors + remote sensing	Within/regional field variability determined by GPS-oriented monitor + remote sensing	Sensor-based variable-rate control with GPS/GIS

Prospects and strategies

1) Paddy field precision farming

The concept of paddy field precision farming will be outlined here (Fig. 2). In general, a paddy field is a small-sized and flattened field with a well-organized irrigation and drainage system. The paddy fields located in a region are interdependent at least due to water management. In Japan, intensive farm works are implemented to achieve uniformity in the soil conditions, transplanting, crop management, etc. within a field with full mechanization. It was generally considered that there was less variability within such a paddy field, although variability within the field had been reported[5].

Regarding between-field variability, many variations can be found in terms of crop varieties cultivated, productivity and yield, water permeability of soil and working time. Large facilities for grain drying and processing have already been operated as "rice centers" throughout the rice production areas in Japan, in addition to the compact grain dryers owned by individual farmers. Moreover there are well-organized farmers' associations and cooperatives everywhere. If a yield monitor could be attached to a combine harvester and use of the cooperative facilities could be recorded accurately, it would be easy to observe the variability between fields. This could be the first step of paddy field precision farming, putting one field as a unit for observing the variability, followed by determinations on how to manage the variability. Global monitoring system can be used for observing and managing such regional variability.

On the other hand, environmental pollution associated with paddy farming has become a cause for concern. How to reduce the environmental impact requires the development of a monitoring system and measures for environmental conservation in the respective fields or locations in the field. As a result, management of within-field variability, aiming at reducing the environmental impact and at maintaining the productivity should be promoted. Sensor-based precision farming in paddy fields is thus required.

Sensing for within/between-variability, VRT machines and DSS algorithms that are the main technology components for precision farming should be developed as early as possible. These tools can also be used for evaluating the variability and for identifying the distinctive characteristics of precision farming in the respective countries.

2) Variability within a field

Temporal and spatial variability of NO_3-N in a corn field in a 30.5 m grid sampling was reported by Everett et al. [3], and soil nutrient mapping for short-range variability was also reported by Birrell et al.[1], but the minimum grid spacing was still 25 m. Grids with a narrower spacing with cells 6.1 m wide and 15.2 m long were used for investigating the temporal and spatial variability of soil parameters, and N recommendation maps were generated[4]. These grid spacings are still too wide for the small Japanese fields. Sampling using 1 m grids for NO_3-N mapping was conducted over a 10 m^2 area in a

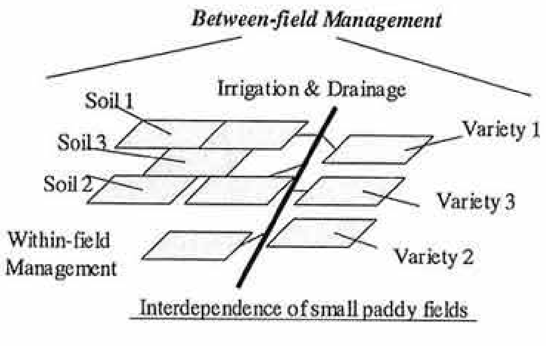

Fig. 2. Paddy farming in relation to variability management

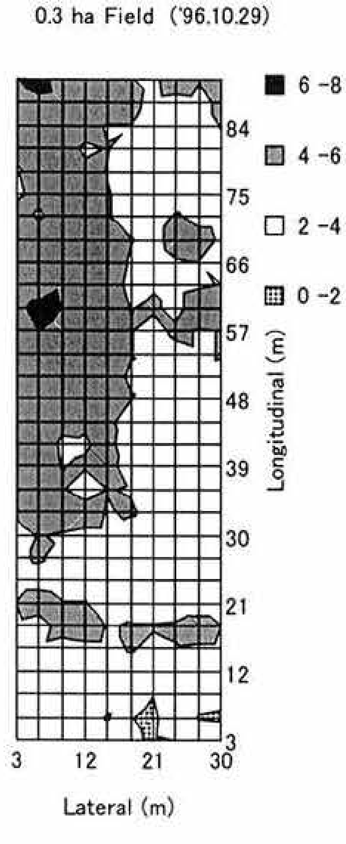

Fig. 3. Map of nitrate nitrogen content at 5–15 cm depth in a 0.3 ha dry land field (3 m grid spacing)

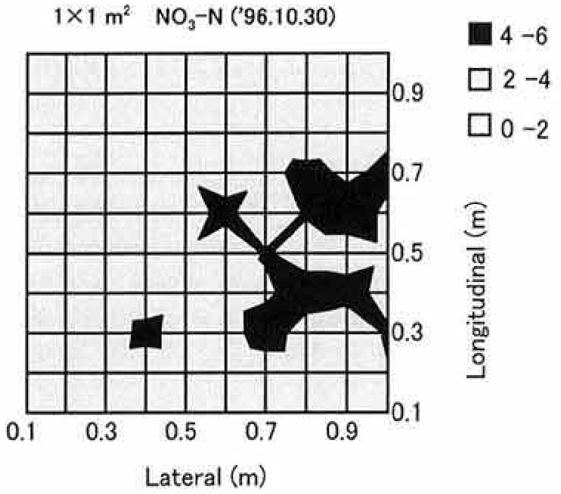

Fig. 4. Map of nitrate nitrogen content at 5–15 cm depth within a 1×1 m^2 area (0.1 m grid spacing)

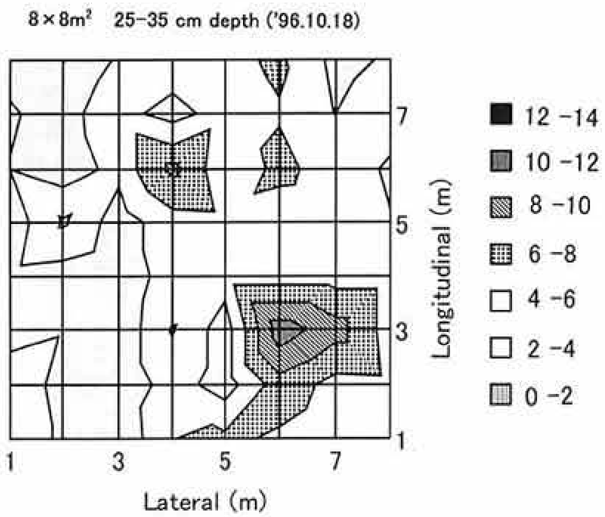

Fig. 5. Map of nitrate nitrogen content at 25–35 cm depth within a 8×8 m^2 area (1 m grid spacing)

small Japanese field and temporal and spatial variability was confirmed[5], although the whole field was not observed. Japanese farming is sometimes characterized by crop-stubble management with intensive farm works in a small field, and it is generally considered that there is less variability within a field.

Analysis of the variability is the first step for precision farming. Our studies have focused on within-field variability of nitrate nitrogen (NO_3-N) in a 0.3 ha field, a typical size in Japan, because NO_3-N is water-soluble and infiltrates groundwater easily, and it is also an important parameter of soil fertility.

Figs. 3 to 5 show NO_3-N contour maps for 3 study areas within the field[9]. Value levels were classified for every 2 mg/100 g. The whole field at the top 5–15 cm depth, as shown in Fig. 3, displayed 4 levels of NO_3-N with the predominance of the middle 2 levels. The 1×1 m^2 area at the top 5–15 cm depth, located in the southern part of the field, exhibited a fairly uniform distribution, as shown in Fig. 4. The 8×8 m^2 area at the 25–35 cm depth showed 7 levels of the NO_3-N and a complicated pattern, as indicated in Fig. 5. It was therefore confirmed that the NO_3-N distribution varied with the observation scale as well as depth. Implications of the variability for agricultural practices should be further investigated.

3) Spectrophotometer [10]

On-line real-time sensing of soil parameters *in situ* has been an important issue for scientists and engineers engaged in precision farming research. Spectroscopic approach is one of the issues for real-time soil sensing because multiple parameters could be evaluated at the same time, since the photometric properties of many soil parameters can be included in a wide range of spectral absorption/reflectance records.

(1) Prototype spectrophotometer

A diagrammatic representation of the spectrophotometer is presented in Fig. 6. It was composed of 3 main parts as follows.

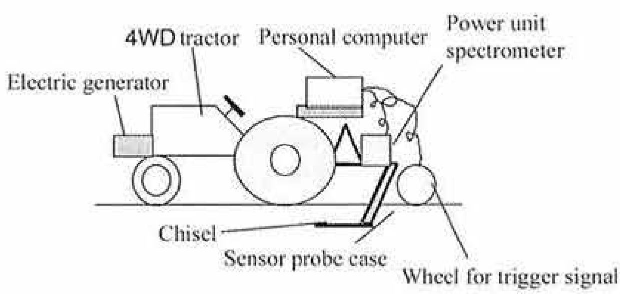

Fig. 6. Portable spectrophotometer system developed for *in situ* soil sensing

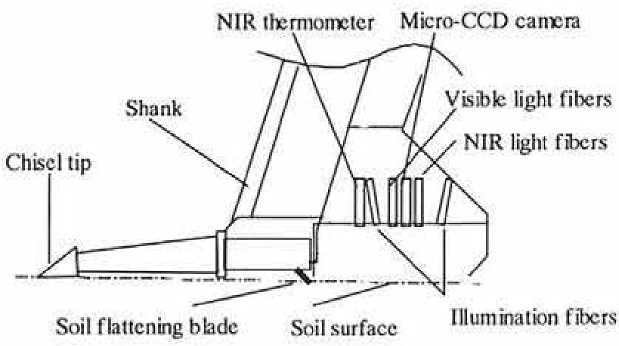

Fig. 7. Soil penetrator and optical fiber probes

A soil penetrator chisel equipped with micro-optical devices operated as a tunnel for continuous space measurement in soil and to collect the light reflected at the same time, as shown in Fig. 7. The optical units consisted of 2 optical fiber probes from a 150 W illumination halogen lamp, visible and NIR optical fiber probes, and CCD camera. The case for the sensor probes, about 600 mm long, 200 mm high and 50 mm thick, was equipped with a shank 700 mm deep, 100 mm wide and 25 mm thick. A micro-NIR thermometer was also installed for the calibration of temperature variations.

A spectrometer with linearly arrayed photo-diodes to detect the spectra of reflected light was used. It can simultaneously measure 256 channel spectra in a range of 400 to 900 nm by using the visible device and 128 channels in 900 to 1,700 nm by using the NIR device.

A control and data logging device of personal computer (233MHz, RAM 128 MB), liquid crystal display and a pulse generator with a free rotating wheel and rotary encoder to trigger timing signals were used. The soil penetrator was attached to a 4WD 18kW tractor with a three-point hitch. All the components were also placed on the tractor.

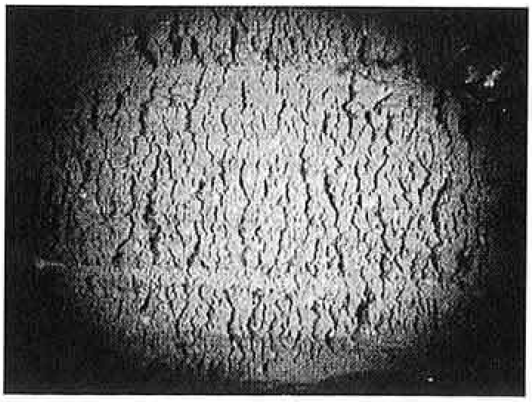

Fig. 8. Soil surface image through the CCD camera

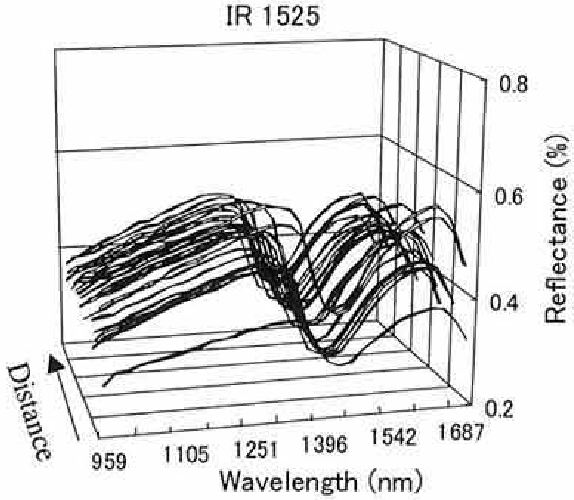

Fig. 9. NIR spectral reflectance

(2) Field test

Test runs were conducted in a clay paddy field after harvesting and in an upland loam field. The paddy field test is briefly introduced below. The instrument for measuring the soil surface was flattened by the blade, as shown in Fig. 8.

A distinct photo-spectrum reflectance was obtained from the underground soil at a 28 cm depth and at a spacing of about 1 m, as shown in Fig. 9. It was confirmed that the correlation coefficients between soil parameters and spectrum reflectance were 0.83 (1,462 nm) for the soil moisture level, 0.78 (1,488 nm) for the pH, 0.80 (1,462 nm) for the electric conductivity (EC), 0.93 (1,538 nm) for the content of soil organic matter (SOM), and 0.44 (1,462 nm) for the content of nitrate nitrogen. Other information can be obtained from the soil spectrum reflectance collected.

Conclusion

In this paper, the concept of precision farming was outlined and studies related to Japanese precision farming (soil mapping and soil sensors) were introduced as follows.

1. Precision farming is characterized by a systems approach and variability management for farming on any scale, aiming at the maintenance of both productivity and environmental conservation. Analysis of the variability is the first step for promoting precision farming.
2. Paddy field precision farming could be initiated for between-field variable management, while technology components should be developed as early as possible.
3. The variability of the soil parameters was demonstrated in a small field in Japan.
4. A real-time on-line portable spectrophotometer was developed for collecting data on underground soil reflectance, which enabled to determine the moisture level, pH, EC and SOM content.

References

1) Birrell, S. J., Sudduth, K. A. & Kitchen, N. R. (1996): Nutrient mapping implications of short-range variability. Proc. 3rd Int. Conf. Precision Agriculture, ASA-CSSA-SSSA, Madison, WI, USA, 207–216.
2) Blackmore, S. (1994): Precision farming; An introduction. *Outlook Agric.*, **23**(4), 275–280.
3) Everett, M. W. & Pierce, F. J. (1996): Variability of corn yield and soil profile nitrates in relation to site-specific N

management. Proc. 3rd Int. Conf. Precision Agriculture, ASA-CSSA-SSSA, Madison, WI, USA, 43–53.

4) Ferguson, R. B. et al. (1996): Soil sampling for site-specific nitrogen management. Proc. 3rd Int. Conf. Precision Agriculture, ASA-CSSA-SSSA, Madison, WI, USA, 13–22.

5) Li, M. et al. (1999): Local variability of soil nutrient parameters in a Japanese small size field. *J. JSAM*, **61**(1), 141–147 [In Japanese].

6) National Research Council (NRC) (1997): Precision Agriculture in the 21st Century. (Committee on Assessing Crop Yield: Site-Specific Farming, Information Systems, and Research Opportunities), National Academy Press, Washington DC., pp. 149.

7) Shibusawa, S. (1998): Precision farming requests further advancement in terrain-vehicle dynamics. *Terramechanics (Japan)*, **18**, 107–112 [In Japanese].

8) Shibusawa, S. (1998): Precision farming and terramechanics. Proc. 5th Asia-Pacific Regional Conference ISTVS at Seoul, 251–261.

9) Shibusawa, S., Sasao, A. & Sakai, K. (1999): Local variability of nitrate nitrogen in a small field. Precision Agriculture '99 Proc. 2nd European Conference on Precision Agriculture/Denmark, July, 377–386.

10) Shibusawa, S. et al. (1999): On-line real-time soil spectrophotometer. Precision Agriculture '99 Proc. 2nd European Conference on Precision Agriculture/Denmark, July, Poster 43.