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# On-Line Real Time Soil Sensor

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**Abstract**: Achievements in the real-time soil spectro-photometer are: an improved soil penetrator to ensure a uniform soil surface under high speed conditions, real-time collecting of underground soil reflectance, getting underground soil color images, use of a RTK-GPS, and all units are arranged for compactness. With the soil spectrophotometer, field experiments were conducted in a 0.5 ha paddy field. With the original reflectance, averaging and multiple scatter correction, Kubelka-Munk (KM) transformation as soil absorption, its 1st and 2nd derivatives were calculated. When the spectra was highly correlated with the soil parameters, stepwise regression analysis was conducted. Results include the best prediction models for moisture, soil organic matter (SOM), nitrate nitrogen ($NO_3$-N), pH and electric conductivity (EC), and soil maps obtained by block kriging analysis.

**Keywords:** Soil Sensing, Real-time Sensor, Soil Mapping, GPS, Precision Farming

## Introduction

Understanding of soil spatial variability is the first step in the practice of precision farming. Accurate maps should be produced for improving the quality of information acquired in the field, though the cost of soil sampling by means of conventional methods is in many cases unaffordable. Ground-based real-time soil sensing with a GPS is an attractive issue for generating soil maps with high resolutions as well as reducing cost and time, compared with a conventional strategy of soil sampling-analysis approach. Spectroscopic approach has high potential to real-time sensing because a wide range of spectral reflectance can offer the photo-metric properties of many soil parameters under non-contact treatment.

Shonk *et al* (1991) developed a portable soil organic matter sensor with photodiodes using a single wavelength. Sudduth and Hummel (1991) investigated the feasibility of spectral reflectance to sense soil organic matter, and a portable NIR spectrophotometer was designed to evaluate soil organic matter, CEC and moisture on the cut soil surface at 35 to 50 mm depths (Sudduth & Hummel, 1993a; Sudduth & Hummel, 1993b). The approaches above can be useful to get information on the field surface, but still required is in-situ soil sensing in a zone of root development for practical uses in the crop management. Shibusawa *et al* (2000) developed a real-time soil spectrophotometer with a RTK-GPS to sense underground soil parameters at depths of 150 to 400 mm.

The objective of this paper is to introduce the real-time soil spectrophotometer for generation of detailed soil maps of paddy field, to assist in implementation of precision farming.

## Feature of the Soil Sensor

The soil spectrophotometer developed (see Fig. 1) can collect the soil reflectance at depths of 150 to 400 mm in sub-meter spacings as well as accurate locations and soil images (Shibusawa *et al* 2000). In addition instrumentation for soil strength and electric conductivity was also installed though the data obtained are not mentioned in this paper.

Figure 2 illustrates the soil-penetrator with the housing for micro optical devices. The penetrator tip with flat plane edge ensures uniform soil cuts, and the soil flattener behind finishes to produce a uniform surface. In the housing seven micro optical devices were arranged. Two optical fiber probes, passing light energy with wavelengths of 400 to 2400 nm, were used for illumination giving an illuminated area of about 50 mm diameter on the soil surface. Two additional optical fiber probes were used for collecting soil reflectance in the visible and NIR ranges. One fiber bundle passed reflected energy in the 400 to 900 nm wavelength range, while the other optical probe carried reflected energy in the 900 to 2400 nm wavelength range. A micro CCD camera was adjusted to monitor a 75-mm focus point on the soil surface.

The sensor unit's housing (see Fig. 1 midde) included core

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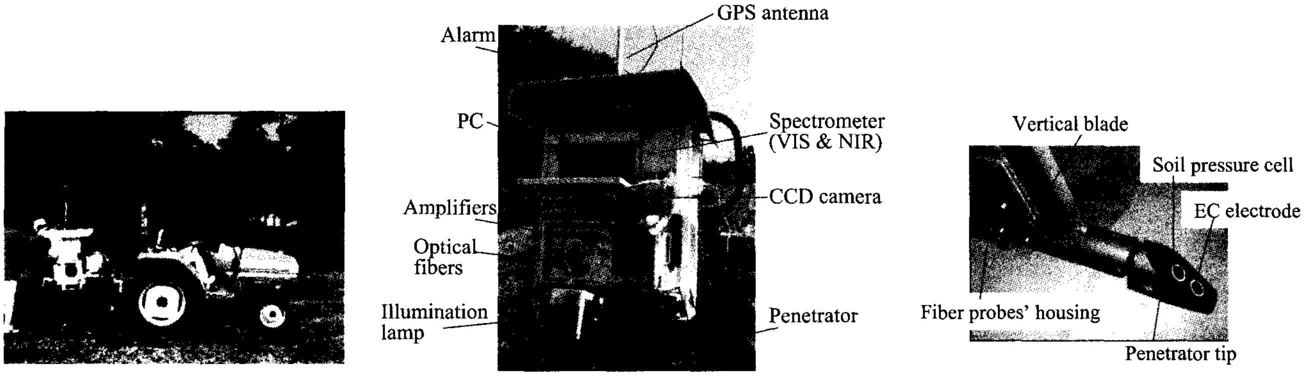


**Fig. 1 A tractor-mounted soil spectrophotometer (midde), a feature of soil sensor units (left) and soil penetrator (right).**

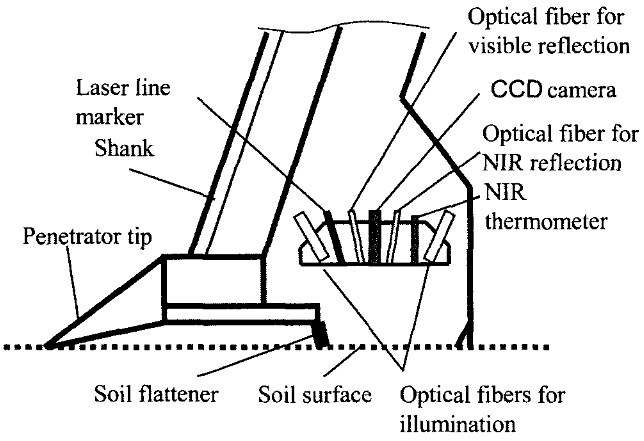


**Fig. 2 Soil penetrator and sensor probes arrangement.**

devices of the system, such as a 150 W halogen lamp, a spectrophotometer (Carl Zeiss Ltd.), a FA computer, an RTK-GPS (Trimble MS740) receiver. The spectro-photometer had a 256-channel linear photodiode array to quantify the reflected energy in the 400 to 900 nm wavelength range. A 128-channel linear photodiode array was used to quantify the reflected energy in the 900 to 1700 nm wavelength range. Data scanning time was more than 4 ms. Integration of scanned data was carried out at a single scanning treatment to get averages at respective spectra.

A video data recorder/monitor on the tractor immediately displayed the soil surface images during the experiment, as shown in Fig. 3. The displayed images were used to keep watch the operation in emergency, such as blockage with

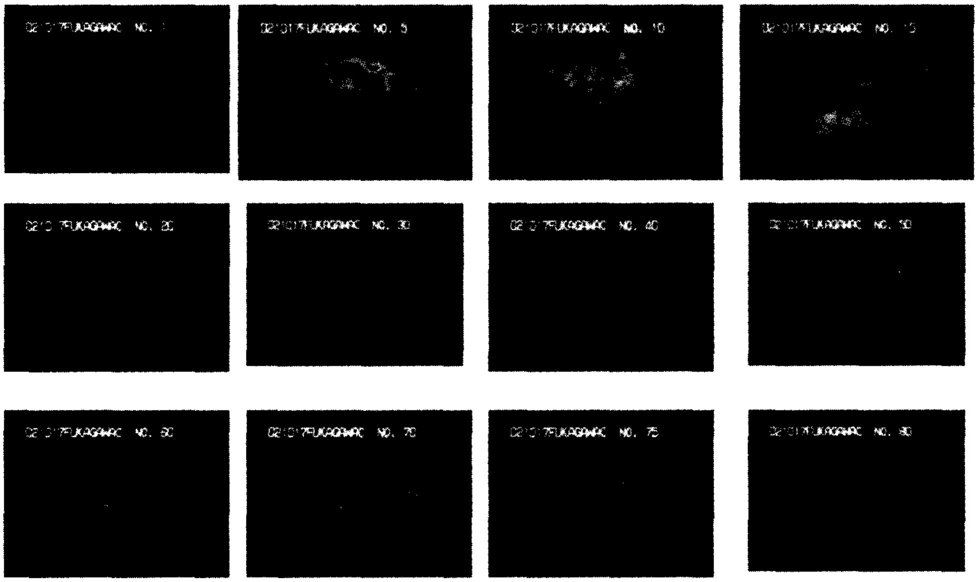


**Fig. 3 Soil images collected by every 1 m spacing at a depth of 30 cm in a paddy field. (Soil images above are picked up at every 5 m interval)(A paddy field in Hokkaido, September, 2002).**

obstacles, and the images gave information to eliminate data in data analysis. The liquid crystal display monitor served as a touch control panel, and the mouse and keyboard were also available to make access to the FA computer.

## Test Field and Methods

The experiment was conducted in a 0.5 ha of paddy field on the Experimental Farm of Kyoto University, Kyoto, Japan in December 1999. The soil texture of the fields was 47% sand, 30% silt, and 23% clay. The working speed was about 1 km/h, under 20 ms scanning time and three seconds of scanning period, which resulted in about 1 m scanning interval along a segment. The spectral collections were performed along the field with about 5 m spacing from one to another segments, which resulted in more than 800 locations for soil reflectance data. The working depth was 200-250 mm.

For the calibration purposes, 25 soil samples were collected at the same position and depth as the scanning points and analyzed in the laboratory for moisture, soil organic matter (SOM) content, nitrate nitrogen ($NO_3$-N), pH and electric conductivity (EC) of soil solution. Fifteen samples were used for calibration and the remaining ten samples were used for validation.

The spectral reflectance was analyzed by linearization with a Kubelka-Munk transform, elimination of the optical interference with multiplicative scatter correction, correlation analysis derivative operation, and then stepwise multiple linear regression. The calibration model was quantified using the standard error for calibration, standard error for prediction and coefficient of determination ($R^2$). Semivariance analysis was performed and soil maps were obtained by the block kriging method.

## Results and Discussion

Results of calibration and validation analysis (Table 1) produced higher scores of $R^2$ and fewer errors for respective soil parameters. The second derivatives of light absorption tended to provide best-fit prediction models (I Made Anom *et al.* 2001, Shibusawa *et al* 2001).

With the prediction models, values for soil parameters were evaluated at 860 locations in the field. The means and standard deviations were 48.4% and 6.5% for moisture content, 9.51% and 1.06% for SOM content, 42.1 mg/100 g and 11.0 mg/100 g for $NO_3$-N content, 6.83 and 0.39 for pH, and 173.1 $\mu$S/cm and 69.6 $\mu$S/cm for EC, respectively. With the evaluated values as observation, the semivariance analysis was performed. Experimental semivariograms for SOM and $NO_3$-N, as shown in Fig. 4, illustrate the fit of data using the spherical model, and $R^2$ values of 0.95, 0.93, 0.94, 0.99, and 0.93 were obtained for moisture content, SOM content, $NO_3$-N content, pH and EC, respectively. Within the experimental field, the SOM content had the shortest range of spatial correlation (29.20 m), followed by $NO_3$-N content (34.50 m), moisture content (38.60 m), pH (40.40 m), and EC (46.60 m).

With the results of the semivariance analysis, the soil parameter maps were then developed (Fig. 5). The maps were interpolated by block kriging with 10-neighborhood interpolation. Errors of kriged to observed values were estimated over 40 grids of 10 m square in illustration. Error means and standard deviations were -0.35 and 2.25 for moisture content, -0.01 and 0.46 for SOM content, 0.08 and 2.72 for $NO_3$-N content, -0.04 and 0.22 for pH, and 3.31 and 12.26 for EC, respectively (I Made Anom *et al* 2001, Shibusawa *et al* 2001).

The variability distribution of the soil parameters shows some stripes in the west-east direction, such as a high moisture belt in the east part as well as a high SOM, a high $NO_3$-N, a high EC and a low pH belts. The irrigation gate was located at the north west and the drain gate was at the south east, which could have induced the stripe-like maps since water flowed from north to south.

**Table 1 Results of calibration and validation for soil parameter prediction**

| Parameters | Treatment | Calibration (n=15) | | Validation (n=10) | | Wavelength (nm) |
|---|---|---|---|---|---|---|
| | | $R^2_{cal}$ | SEC | $R^2_{val}$ | SEP | |
| Moisture (% db) | 2nd deriv. | 0.908 | 1.893 | 0.655 | 3.111 | 606, 1329, 1499 |
| SOM (%) | 2nd deriv. | 0.948 | 0.259 | 0.647 | 0.559 | 606, 1311, 1238 |
| $NO_3$-N (mg/100g) | 2nd deriv. | 0.803 | 3.699 | 0.539 | 4.741 | 589, 1014 |
| pH | 1st deriv. | 0.714 | 0.101 | 0.541 | 0.127 | 959, 1214 |
| EC ($\mu$S/cm) | 2nd deriv. | 0.735 | 23.975 | 0.650 | 41.718 | 456, 984, 1014 |

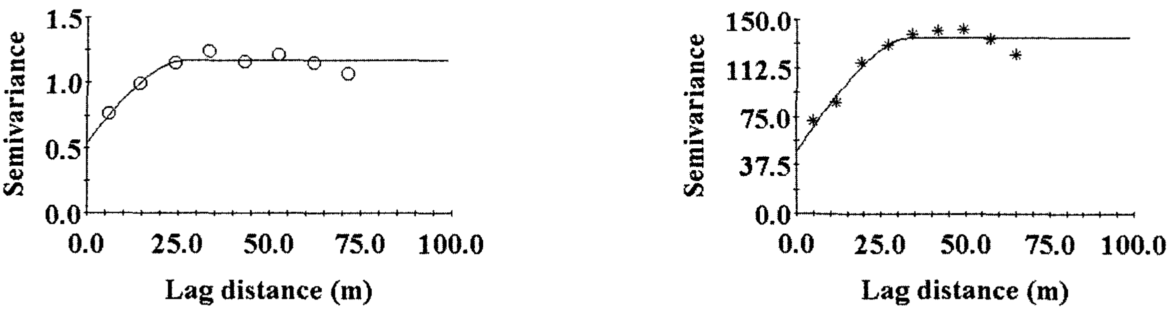
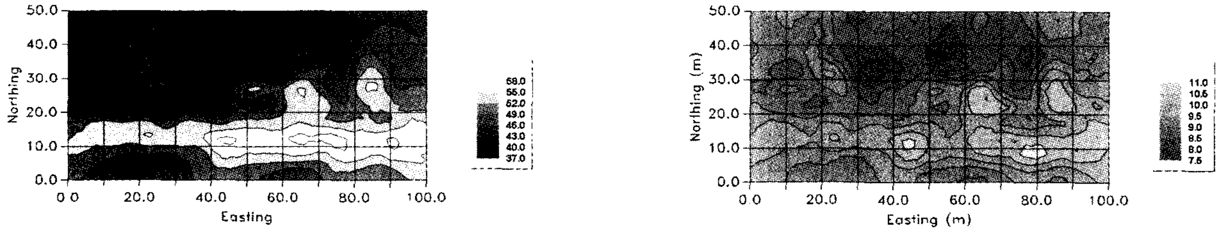
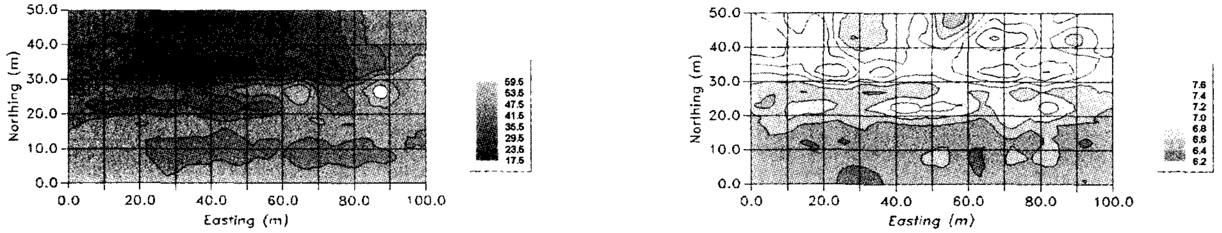


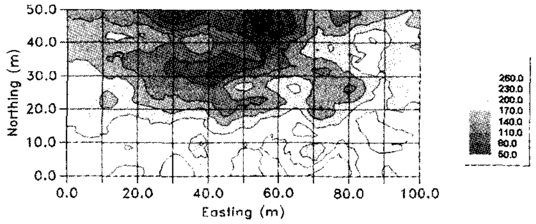
**Fig. 4 Semivariograms of SOM content (left) and $NO_3$-N content (right) of a 0.5 ha paddy field.**



**(a) Moisture** **(b) SOM**



**(c) $NO_3$-N** **(d) pH**



**(e) EC**

**Fig. 5 Soil parameter maps of a 0.5 ha paddy field using soil reflectance collected by the real-time soil spectrophotometer. 860 data points at depths of 200 to 250 mm depth.**

## Conclusions

The real-time soil spectrophotometer performed well to collect soil reflectance data at more than 800 locations under 200-250 mm working depths in a 0.5 ha paddy field. With soil analysis data of 25 best-fit prediction models were obtained in terms of moisture content, SOM content, $NO_3$-N content, pH, and EC. The prediction models offered those soil parameter values at 860 locations on the field. Semivariance analysis and mapping by block kriging described the variability of soil parameters in detail within the paddy field, one which could be best information for site specific paddy management.

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