

DOZEN PARAMETERS SOIL MAPPING USING THE REAL-TIME SOIL SENSOR

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ABSTRACT

The real-time measurement of soil parameters is essential for site-specific management on precision agriculture in large-scale farming.

Using the Real-time soil sensor (RTSS) for on-the-go estimate of soil parameters, primary results about moisture content (MC), soil organic matter (SOM), pH, nitrate nitrogen (N-n), total nitrogen (N-t) and total carbon (TC) were reported. In this study, we add 6 soil parameters as available phosphate (P-a), phosphorus absorptive coefficient (PAC), soluble nitrogen (N-s), soil ammonium nitrogen (N-a), electrical conductivity (EC) and cation exchange capacity (CEC) content to previous report. A total of 12 soil parameters calibration model were developed using near-infrared spectroscopy (NIRS) for the potential of the RTSS.

The RTSS equipment simultaneously captures several types of data as on-the-go measurement in agricultural soils: visible (VIS) and near infrared (NIR) underground soil reflectance spectra with a measurement range of 310–1700 nm, underground soil surface color images, soil resistance, electric conductivity by electrode device, DGPS data and etc.

The calibration model of 12 soil parameters were established under on-the-go conditions, on the basis of two fields (8.94ha) and two season sets collected from a commercial farm with an alluvial soil in Hokkaido, Japan, 2008. The calibration model of soil parameter was developed using partial least squares regression (PLSR) coupled with the full cross-validation technique. On the basis of the values of coefficients of determination (R^2), the standard error of calibration (SEC) and validation (SEV), these were evaluated as almost same with a previous study. We show you one of the results of the sensitivity analysis, the R^2 (calibration) of the 12 soil parameters obtained 0.95 MC, 0.92 SOM, 0.76 pH, 0.91 TC, 0.69 N-a, 0.50 N-n, 0.89 N-t, 0.73 N-s, 0.76 P-a, 0.92 PAC, 0.64 EC and 0.92 CEC.

12 soil maps were predicted by non-recalibration model using the RTSS in 2009. Those predicted soil maps using the RTSS were almost same as graphical pattern with soil analysis maps.

The grower used the pH map to scatter sulfur fertilizer on the site-specific location. As a result, high pH value location was improved.

Keywords: Real-time soil sensor, NIRS, PLSR, soil map, Precision agriculture.

INTRODUCTION

The visible (VIS) and near infrared (NIR) spectroscopy is one of the promising techniques that measure rapidly soil parameters. Many studies were based on measurements carried out in a laboratory environment, which soil samples were collected from agricultural fields. In our past many studies, the on-the-go type soil sensor collects the VIS-NIR soil reflectance spectra data in agricultural fields, a lot of soil samples of the same location was analyzed chemically, and the calibration model was developed.

The first prototype of Real-Time Underground Soil Spectrophotometer was designed and developed by Shibusawa et al. (1999, 2000, 2001). A few years later, Shibusawa collaborated to develop the Real-Time Soil Sensor (RTSS) of improvement type with SHIBUYA KOGYO Co., SI-SEIKO Co (SHIBUYA GROUP), the model name is SAS1000.

In 2007 the Japanese government, Ministry of Agriculture, Forestry and Fisheries funded a 5-year project for large-scale farms to introduce precision agriculture using Information Technology (IT) by 0.5 billion yen/year. We participated to one of the projects until 2009, and a task of our team was to develop a more effective soil management method available for clear cost reduction using the RTSS (Kodaira et al., 2009). We reported a part of the results in poster session of the 9th International Conference on Precision Agriculture in 2008 (Kodaira et al., 2008). That report was as follows: in the year of 2007, the experiment using the RTSS was the first time done in Japan at commercial farms larger than 1 ha. The RTSS traveled 10.9 ha of four fields, and the traveling line matched to fertilizer applicator (24 m spacing) in each fields. The traveling speed of the RTSS set it to 0.56m/sec. It was double speed of the custom. It took 1 ha per hour for the whole work. The R^2 of the sensitivity analysis using a multivariate statistical technique were almost same with a previous study. We obtained the 6 soil maps, moisture content (MC), soil organic matter (SOM), pH, nitrate nitrogen (N-n), total nitrogen (N-t) and total carbon (TC). The grower was able to remember with the pH soil maps that the large amounts of the lime fertilizer were spilt oneself. And then, the grower was making a plan to reduce the pH value.

Past the 2 years, in this study, we show some results that adopted VIS-NIR spectra which the RTSS collected in 2008. And we did not use collected VIS-NIR spectra in 2007. As for the reason, the amount of soil analysis in some soil

parameters was insufficient in quantity.

As a new result, we add 6 soil parameters as available phosphate (P-a), phosphorus absorptive coefficient (PAC), soluble nitrogen (N-s), soil ammonium nitrogen (N-a), electrical conductivity (EC) and cation exchange capacity (CEC) content to previous report. Calibration models of 12 soil parameters were evaluated using the sensitivity analysis. Actually, we selected the sensitivity analysis parameters same to compare with previous study. We are going to prove by introducing reasonably similar maps between soil analysis soil maps and predicted soil maps by the RTSS. The objectives of this study are:

- 1) to develop calibration model (regression coefficients) for the MC, SOM, pH, TC, N-a, N-n, N-s, N-t, P-a, PAC, EC and CEC;
- 2) to make soil analysis map and predicted soil maps by the RTSS, and to predict soil parameter using regression coefficients of non-recalibration model in 2009;
- 3) to show the result that the grower used the pH map, and scattered sulfur fertilizer to the site-specific location.

MATERIALS AND METHODS

Experimental farm

As shown in Fig. 1., the experimental farm is a commercial farm with an alluvial soil type in Memuro-Cho, Hokkaido, Japan. This farm is considered an average size (10 fields, 31.48 ha) for large-scale farming in Hokkaido. The crop rotation system is five crops for five years: wheat - sugar beet - soy bean - potato - green manure (oat).

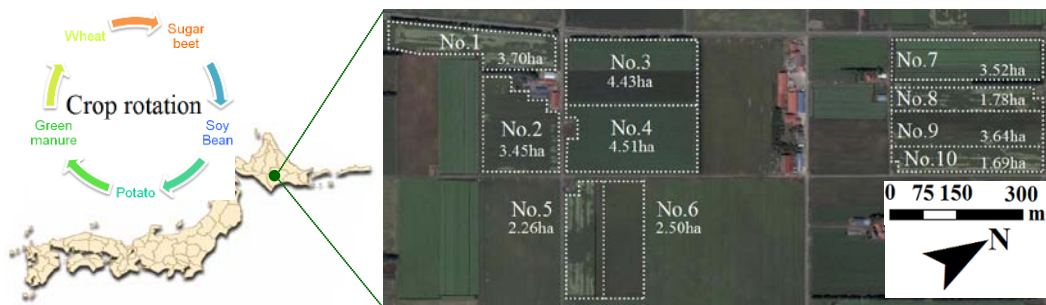


Fig. 1. Location of the experimental farm and the crop rotation system.

The real-time soil sensor

An outline of RTSS is shown in Fig. 2. RTSS was designed to collect the soil reflectance at depths of 0.05 to 0.35 m at 0.05 m spacing. The penetrator tip with flat plane edge ensures uniform soil cuts, and the soil flattener behind finishes to produce a uniform surface.

The sensor unit's housing included core devices of the system, such as a personal computer (Windows XP, Microsoft), a 150-W halogen lamp, two spectrophotometers (VIS and NIR, Carl Zeiss Co., Ltd.), Trimble DSM132 differential global positioning system (DGPS) receiver, etc. The DGPS antenna

was mounted on the roof. The spectrophotometer for VIS had a 256-pixel linear photodiode array to quantify the reflected energy in the spectral range of 310 to 1,100 nm. A 128-pixel linear diode array (Multiplexed InGaAs) for NIR was used to quantify the reflected energy in the spectral range of 950 to 1,700 nm.

In the housing of the penetrator, seven micro optical devices were arranged. Two additional optical fiber probes were used for collecting soil reflectance in the VIS-NIR ranges. One fiber bundle passed reflected energy in VIS spectral range, which the other optical probe carried reflected energy in NIR spectral range. A micro CCD camera was adjusted to monitor a 75 mm focus point on the soil surface.

As shown in Pic. 1., the touch monitor is able to display the soil surface images during the experiment from CCD camera, and recorded to the memory card too. The displayed images were used to watch for emergencies, such as blockage with obstacles, and the images gave information to eliminate data in data analysis, for example calibration outliers.

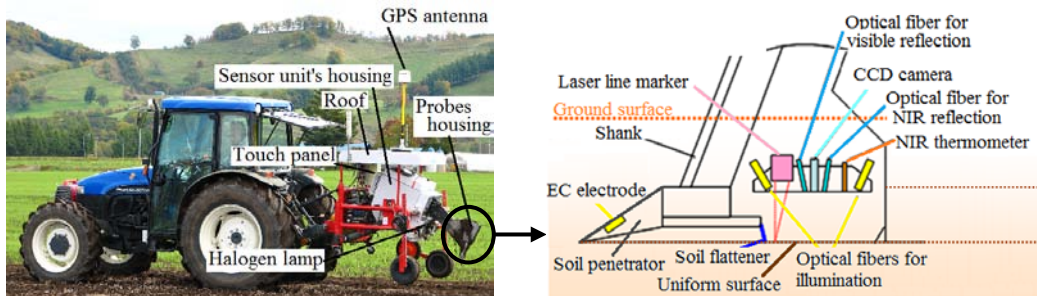


Fig. 2. A tractor-mounted RTSS and sensor probe arrangement.



Pic.1 The image data of the soil surface by CCD camera.

Soil sample and soil reflectance data collection

At the Field No.4 (August) and Field No.3 (November) in 2008, for calibration and soil analysis purposes, a total of 144 soil samples were collected at the respective scanning locations at the same depth as VIS-NIR soil reflectance data was collected.

Concretely, the traveling line of RTSS for site-specific management was matched to the fertilizer applicator. In the case of Field No. 3, RTSS traveled horizontally along 6 segments of 24 m spacing, VIS-NIR soil reflectance spectra were acquired every 2.24 m at a depth of 0.2 m to vertical direction. Soil samples were collected every 24.64 m at the same location and depth where VIS-NIR soil reflectance spectra were measured (Fig. 3.). Field No.4 is almost same too.

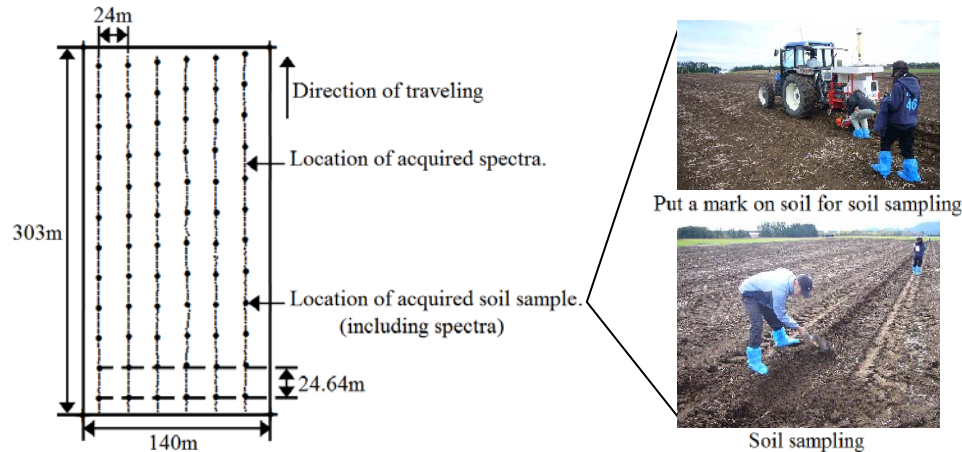


Fig. 3. The traveling line and sampling locations in Field No.3

Soil analysis

The soil parameters investigated in this study were pH, MC, SOM, TC, N-a, N-n, N-s, N-t, P-a, PAC, EC, and CEC. The pH, MC, SOM and EC were analyzed in our laboratory. But, we do not have other soil analyzer that analyzes other soil parameters. Therefore, results of soil analysis in the chemical research institute (Tokachi Fed. Agric. Coop. Agric. Res. Inst.) were used about other soil parameters.

In our laboratory, the fresh soil samples were crushed and sieved with a 2 mm sieve. The MC was measured on fresh soil samples by drying the soil samples in an oven at 110 °C for 24-hour. The pH was measured by glass electrode method (D-24, HORIBA) using a soil:distilled-water ratio of 1:2.5. The soil solution was shaken for 30 minutes and left for 1 hour. The pH was measured in the supernatant. In the probably same way, the EC was measured by AC bipolar method (D-24, HORIBA) using a soil:distilled-water ratio of 1:5. The soil solution was shaken for 30 minutes and left for 1 hour. The EC was measured in the supernatant. The SOM was measured using the drying soil samples in a muffle furnace at 750 °C for 3-hour.

The number of soil samples used to develop different calibration models for soil parameters are listed in Table 1.

Table 1. Sample statistics of calibration set used for partial least squares regression full cross-validation modelling scheme.

Parameter	Number of samples	Minimum	Maximum	Mean	Range	Standard deviation
pH	144	4.810	7.170	5.724	2.360	0.460
MC (%)	144	11.323	34.459	21.866	23.136	5.299
SOM (%)	144	3.883	10.220	6.595	6.337	1.139
TC (%)	144	0.791	3.130	1.878	2.339	0.465
N-a (mg/100g)	144	0.154	1.545	0.632	1.391	0.296
N-n (mg/100g)	144	0.210	4.180	0.703	3.970	0.533
N-s (mg/100g)	144	3.403	8.966	5.243	5.563	1.036
N-t (mg/100g)	144	0.066	0.241	0.144	0.175	0.033
P-a (mg/100g)	144	25.238	114.732	54.232	89.494	17.294
PAC	144	311.000	1069.000	632.278	758.000	148.350
EC (mS/cm)	144	0.025	0.267	0.069	0.242	0.034
CEC	144	5.861	22.615	14.625	16.754	4.360

Spectral pre-treatment and PLSR dataset

The first step in developing calibration models is the pre-treatment of the soil reflectance spectral data. Several pre-treatments were considered and the best performing pretreatment was withheld for each parameter. Information about the different pre-treatments considered is available as shown in Table 2.

To reduce the noise and enhance the weak signals, VIS-NIR soil reflectance spectra were subjected to the second derivative or mixed with the smoothing. The result of spectral pre-treatment was obtained using the unscrambler v9.2 software (CAMO ASA, Norway) including Savitzky-Golay method as shown in Fig. 4.

The sensitivity analysis for calibration was developed using the PLSR technique by the Unscrambler v9.8 software. PLSR is a popular modeling technique used in chemometrics and is commonly used for multivariate statistical technique. 144 soil samples were used as the calibration dataset for full-cross validation.

Table 2. Spectral pre-treatment of different soil parameters.

Parameter	Spectral pre-treatment	Parameter	Spectral pre-treatment
pH	Smoothing with S-G 2nd derivative with S-G	N-a (mg/100g)	2nd derivative with S-G
MC (%)	2nd derivative with S-G	N-n (mg/100g)	2nd derivative with S-G
SOM (%)	2nd derivative with S-G	N-s (mg/100g)	2nd derivative with S-G
TC (%)	2nd derivative with S-G	N-t (mg/100g)	2nd derivative with S-G
EC (mS/cm)	2nd derivative with S-G	P-a (mg/100g)	2nd derivative with S-G
CEC	2nd derivative with S-G	PAC	2nd derivative with S-G

S-G is Savitzky-Golay method.

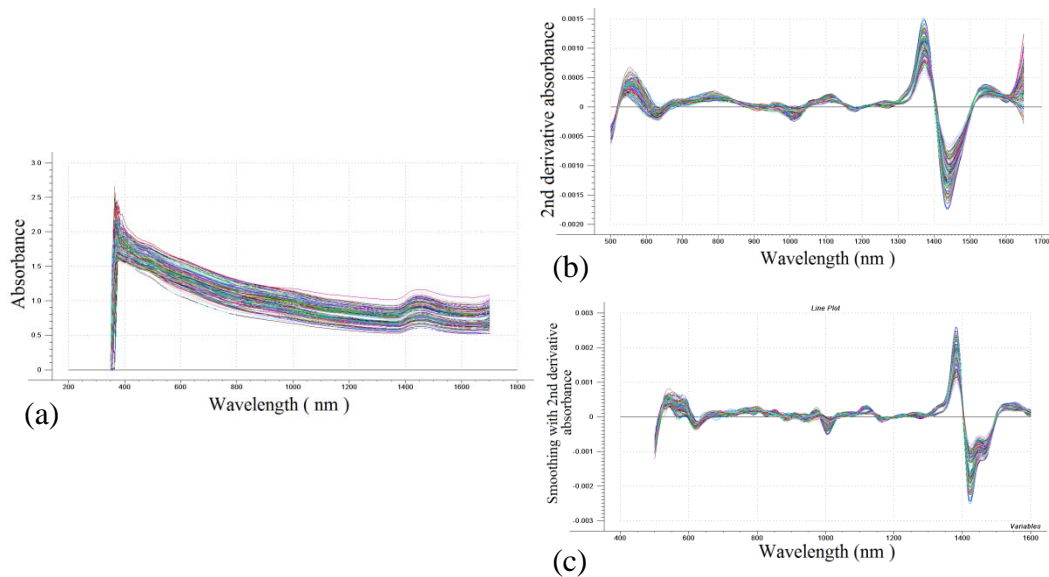


Fig. 4. Original soil absorbance (a), The 2nd derivative of the soil absorbance (b), The smoothing with the 2nd derivative of the soil absorbance (c).

Soil map preparation

The ArcMap GIS v9.3.1 software (ESRI Inc., USA) was used to draw the maps of pH, MC, SOM, TC, N-a, N-n, N-s, N-t, P-a, PAC, EC and CEC, predicted with the RTSS and same soil parameters measured with soil analysis. The predicted soil maps were developed based on data of a 2.24 m × 24 m grid. The measured soil maps were developed based on data of a 24.64 m × 24 m grid. The grid was interpolated using the inverse distance weighing (IDW) method. The colour classification was distributed to 7 categories.

RESULTS

As shown in Table 3., the sensitivity analysis of 12 models obtained the almost same results as a previous study (Rossel et al., 2006).

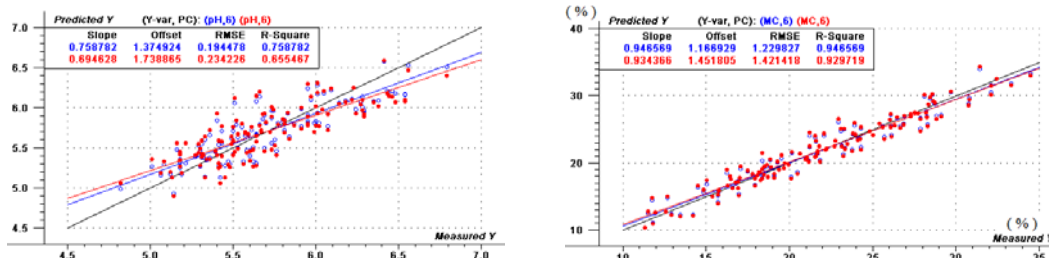
Table 3. Results of calibration and validation for soil parameter prediction

Parameters	Wavelength (nm)	Multivariate method ^(a)	N _{calib} / N _{valid} ^(b)	Calibration			Validation			References
				correlation	R ²	SEC	correlation	R ²	SEV	
pH	500-1600	PLSR (6)	130 Full X-val	0.87	0.76	0.20	0.81	0.66	0.24	This paper
pH	400-2400	SMLR (959,1214)	15 10	—	0.71	0.10	—	0.54	0.13	Shibusawa et al. (2001)
MC (%)	500-1600	PLSR (6)	130 Full X-val	0.97	0.95	1.23	0.96	0.93	1.43	This paper
MC (%)	400-2400	SMLR (606,1329,1499)	15 10	—	0.91	1.89	—	0.66	3.11	Shibusawa et al. (2001)
SOM (%)	500-1600	PLSR (6)	130 Full X-val	0.96	0.92	0.30	0.95	0.90	0.35	This paper
SOM (%)	400-2400	SMLR (606,1311,1238)	15 10	—	0.95	0.26	—	0.65	0.56	Shibusawa et al. (2001)
TC (%)	500-1600	PLSR (5)	130 Full X-val	0.95	0.91	0.13	0.94	0.89	0.15	This paper
TC (g/kg)	400-2498	PLSR (5)	76 32	0.65	0.91	—	—	—	—	Chang and Laird (2002)
N-a (mg/100g)	500-1200	PLSR (8)	130 Full X-val	0.83	0.69	0.14	0.73	0.54	0.17	This paper
N-n (mg/100g)	1100-1650	PLSR (5)	130 Full X-val	0.71	0.50	0.14	0.67	0.45	0.15	This paper
N-n (mg/100g)	400-2400	SMLR (589,1014)	15 10	—	0.80	3.70	—	0.54	4.74	Shibusawa et al. (2001)
N-s (mg/100g)	500-1600	PLSR (7)	130 Full X-val	0.85	0.73	0.47	0.77	0.59	0.58	This paper
N-t (%)	500-1600	PLSR (5)	130 Full X-val	0.94	0.89	0.01	0.93	0.87	0.01	This paper
N-t (g/kg)	400-2498	PLSR (7)	76 32	0.04	0.86	—	—	—	—	Chang and Laird (2002)
P-a (mg/100g)	500-1600	PLSR (4)	130 Full X-val	0.87	0.76	7.48	0.85	0.72	8.03	This paper
P-a (mg/kg)	400-1100	NN	41	—	0.81	—	—	—	—	Daniel et al. (2003)
PAC	500-1600	PLSR (6)	130 Full X-val	0.96	0.92	42.18	0.95	0.90	48.13	This paper
EC (mS/cm)	1200-1600	PLSR (6)	130 Full X-val	0.80	0.64	0.016	0.75	0.57	0.017	This paper
EC (mS/cm)	400-2400	SMLR (456,984,1014)	15 10	—	0.74	0.024	—	0.65	0.042	Shibusawa et al. (2001)
CEC	500-1600	PLSR (6)	130 Full X-val	0.96	0.92	1.26	0.94	0.89	1.44	This paper
CEC	350-2500	MARS	493 247	—	0.88	—	—	—	—	Shepherd and Wash (2002)

^a Multivariate techniques include stepwise multiple linear regression (SMLR), multivariate adaptive regression splines (MARS), partial least-squares regression (PLSR). Shown in brackets are the spectral bands used or the number of bands or number of PCR components or number of PLSR factors used in the predictions.

^b n_{calib} | n_{valid} show the number of samples used in the spectral calibration and the number of factors use in the validation. X-val suggests that the validation was conducted independently using a statistical cross-validation technique.

The scatter plots of measured vs. predicted 12 soil parameters were obtained as shown in Fig. 5.



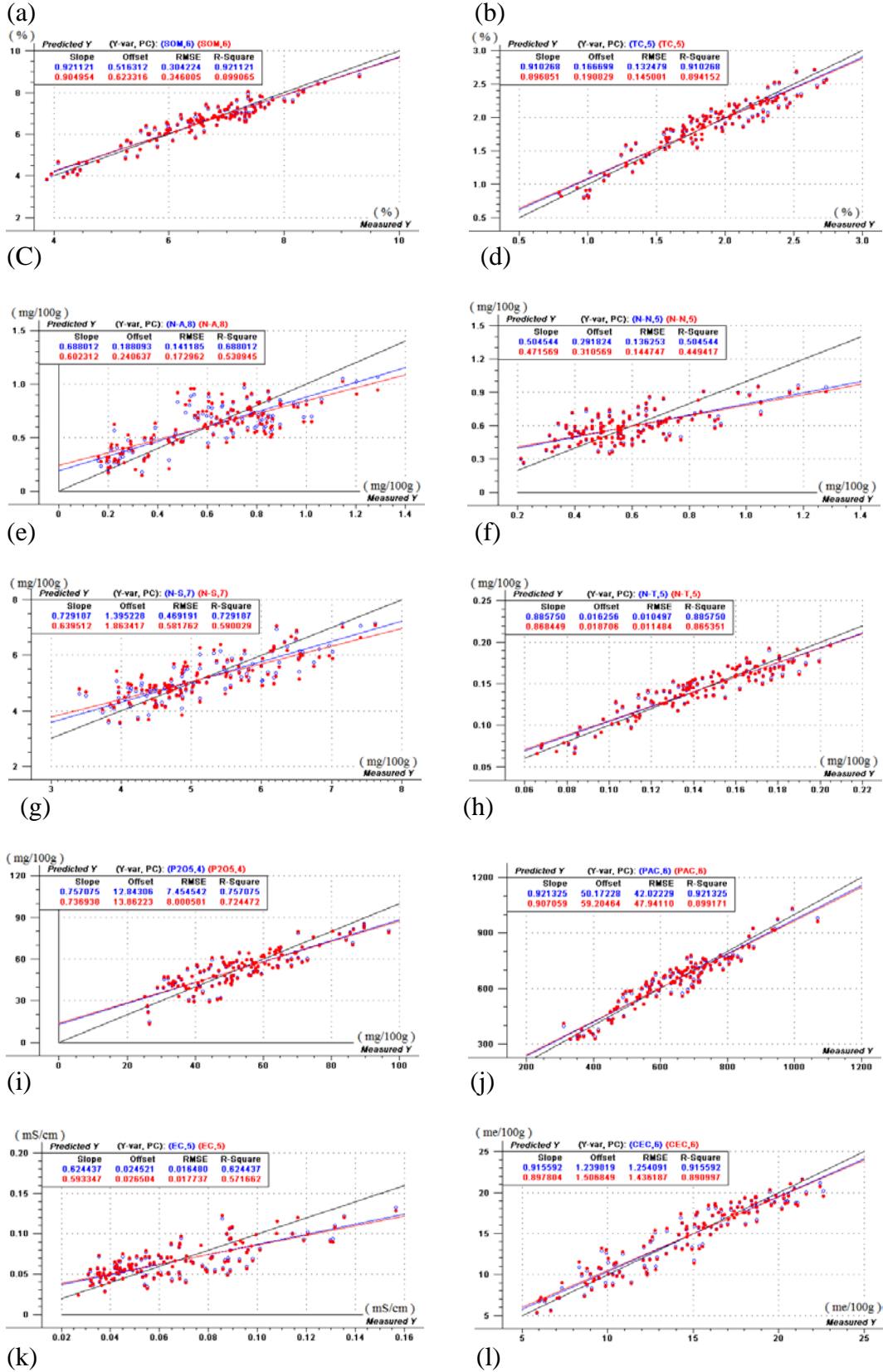
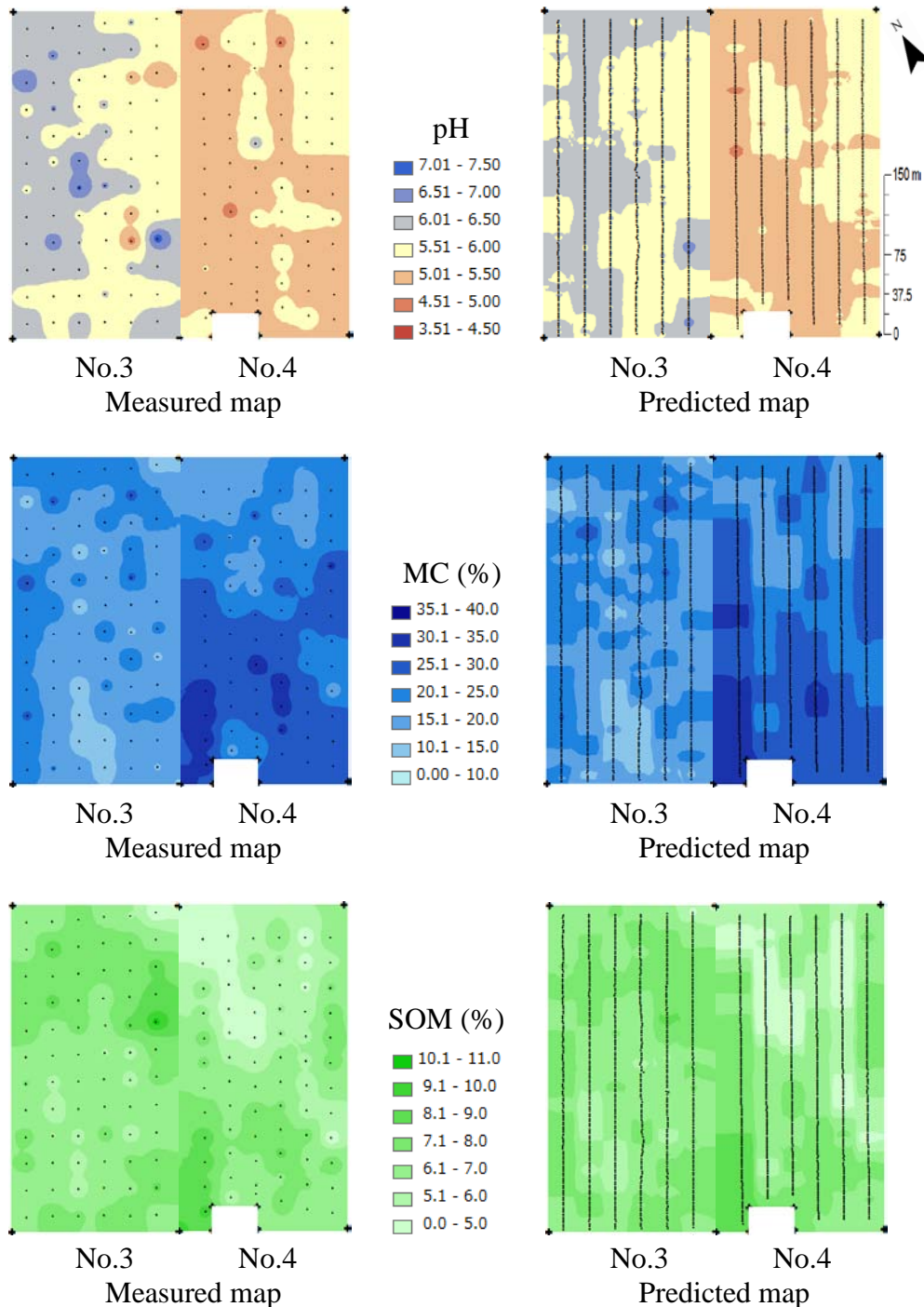
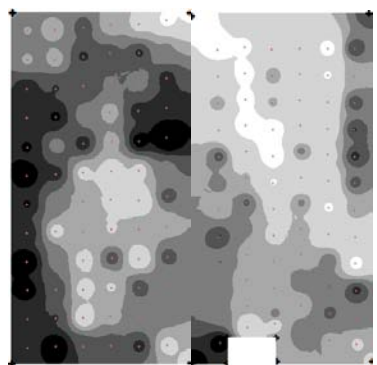


Fig. 5. Scatter plots of measured vs. predicted pH (a), moisture content (MC) (b), soil organic matter (SOM) (c), total carbon (TC) (d), soil ammonium (e), soil nitrate (f), soil phosphorus (g), soil potassium (h), soil calcium (i), soil magnesium (j), soil sulfur (k), and soil zinc (l).

nitrogen (N-a) (e), nitrate nitrogen (N-n) (f), total nitrogen (N-t) (g), soluble nitrogen (N-s) (h), available phosphate (P-a) (i), phosphorus absorptive coefficient (PAC) (j), electrical conductivity (EC) (k) and cation exchange capacity (CEC) (l). The blue shows a result of the calibration, and the red shows the result of the validation.

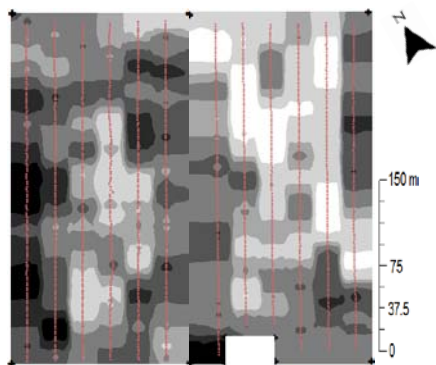
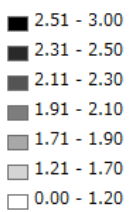
As shown in Fig. 6., soil maps of 12 soil parameters for Field No.3 and No.4 were predicted by each regression coefficients (Predicted map). The soil analysis maps (Measured map) of 12 soil parameters were obtained, too.



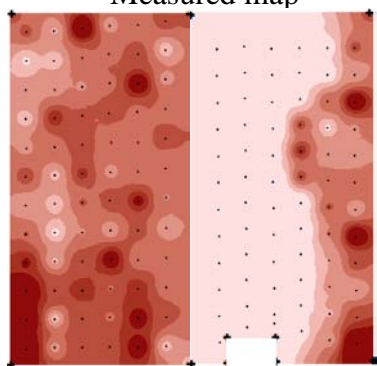


No.3 No.4
Measured map

TC (%)

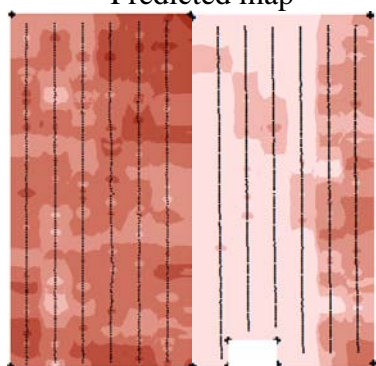
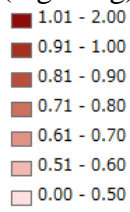


No.3 No.4
Predicted map

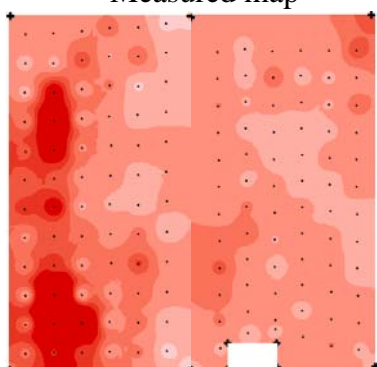


No.3 No.4
Measured map

N-a
(mg/100g)

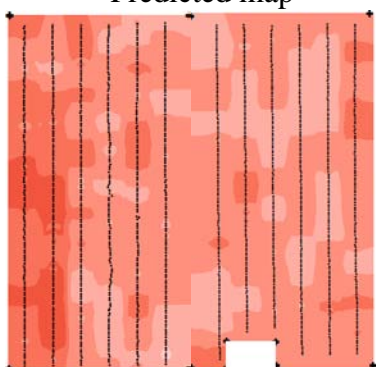
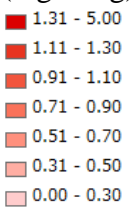


No.3 No.4
Predicted map

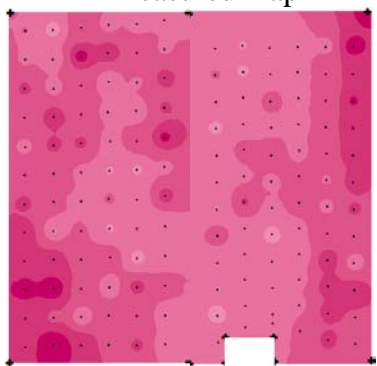


No.3 No.4
Measured map

N-n
(mg/100g)

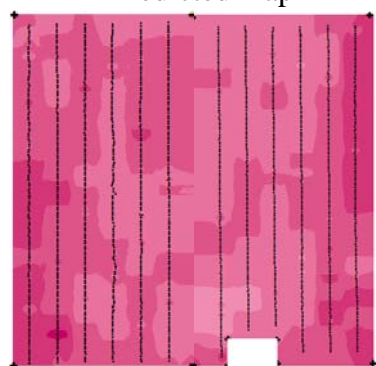
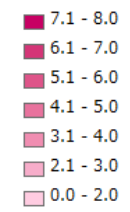


No.3 No.4
Predicted map

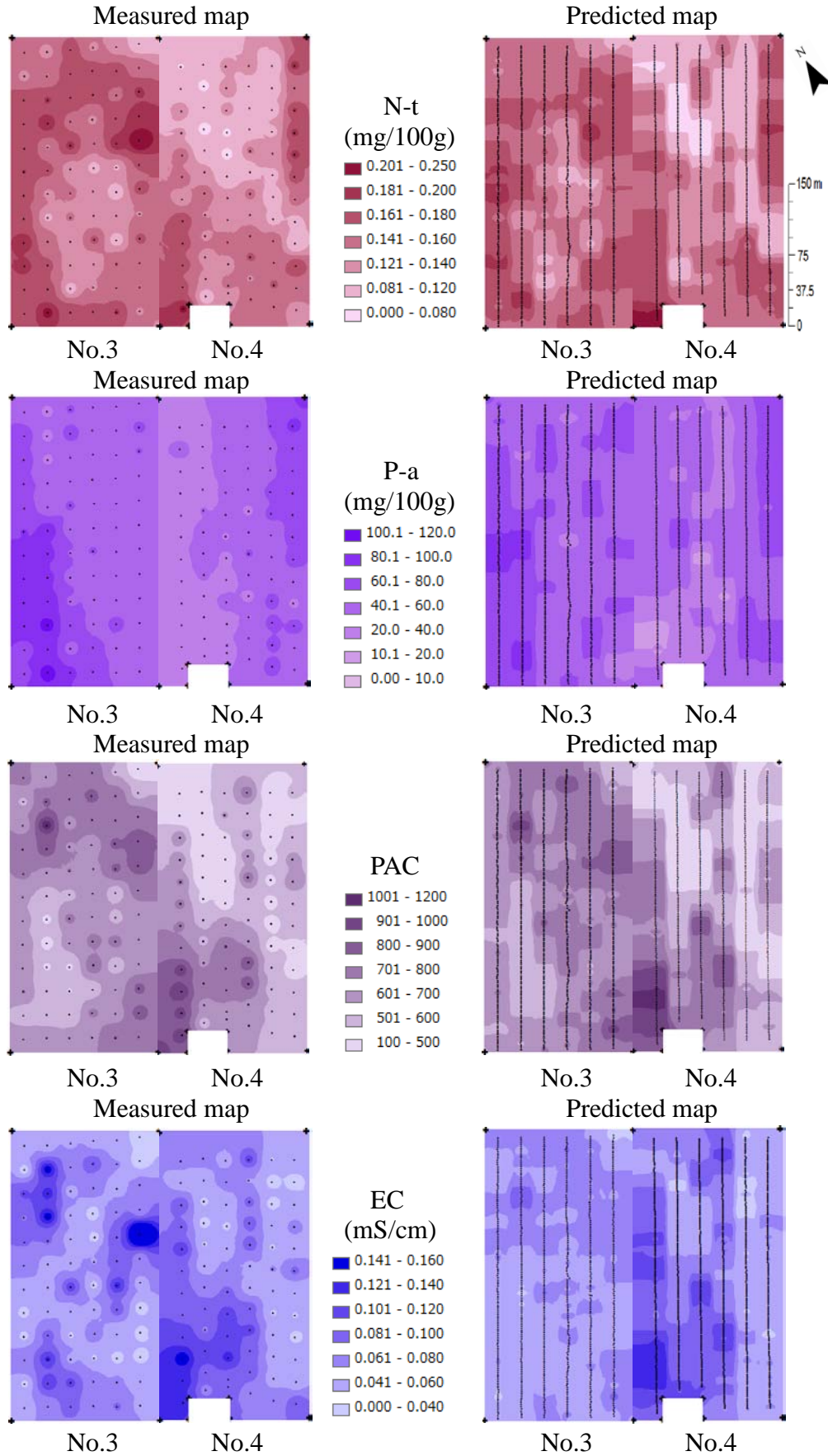


No.3 No.4

N-s
(mg/100g)



No.3 No.4



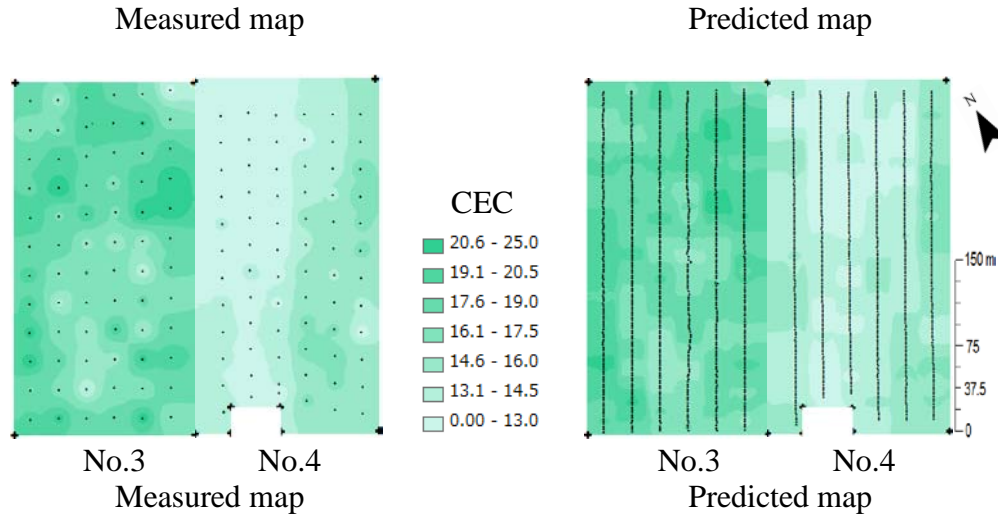
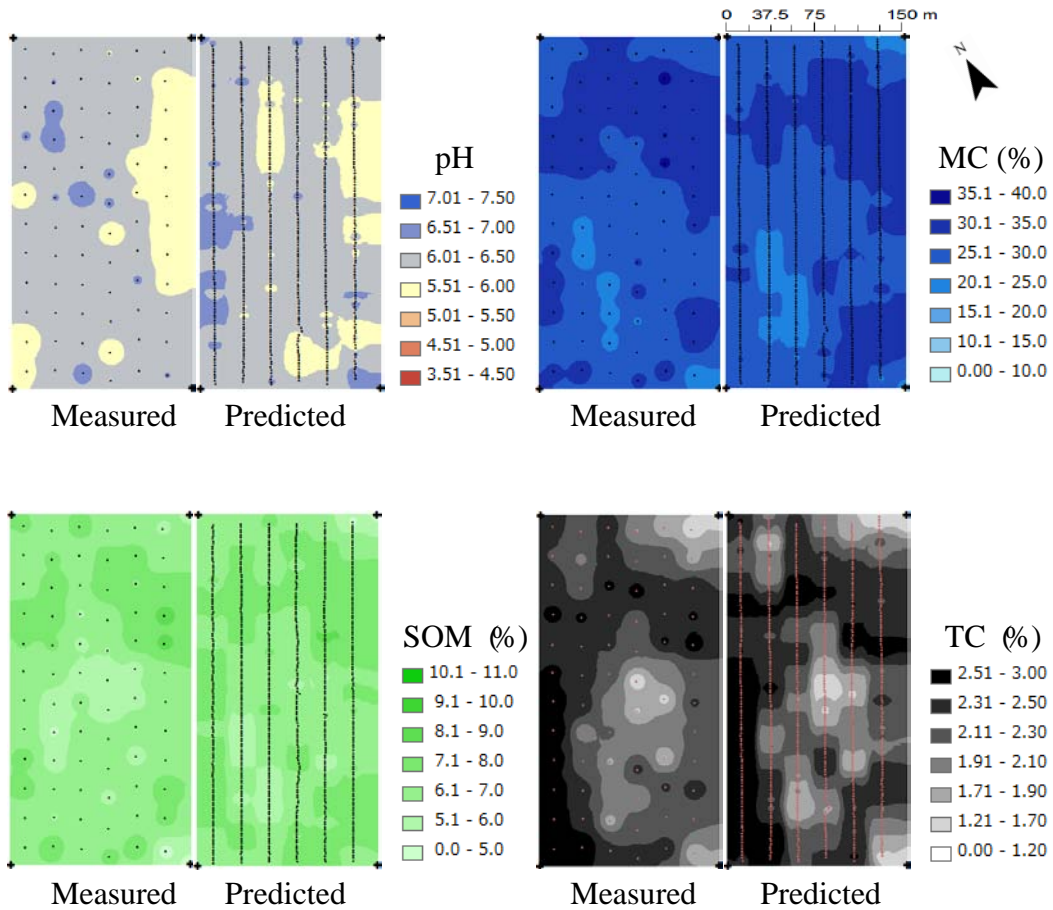


Fig. 6. Comparison of Measured map and Predicted map.

As shown in Pic. 7., predicted maps were predicted by non-recalibration model of 2008 at Field No.3 in 2009. Measured maps of Field No.3 were obtained, too.



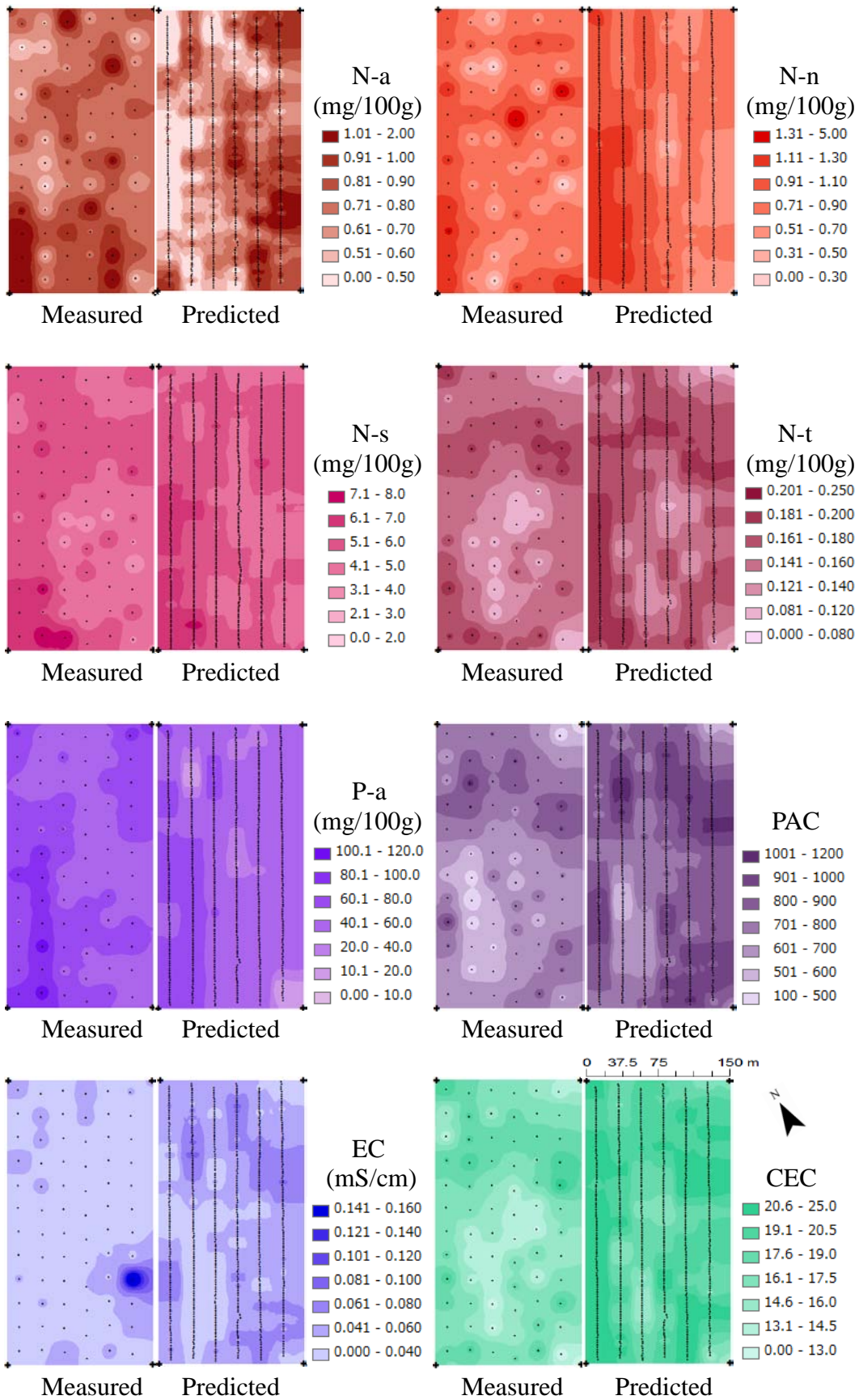


Fig. 7. Comparison of Measured map and Predicted map in Field No.3.

As shown in Fig. 8., Using the pH map, the grower scattered sulfur fertilizer to the site-specific location in May 7th, 2009. As a result, high pH value location was improved.

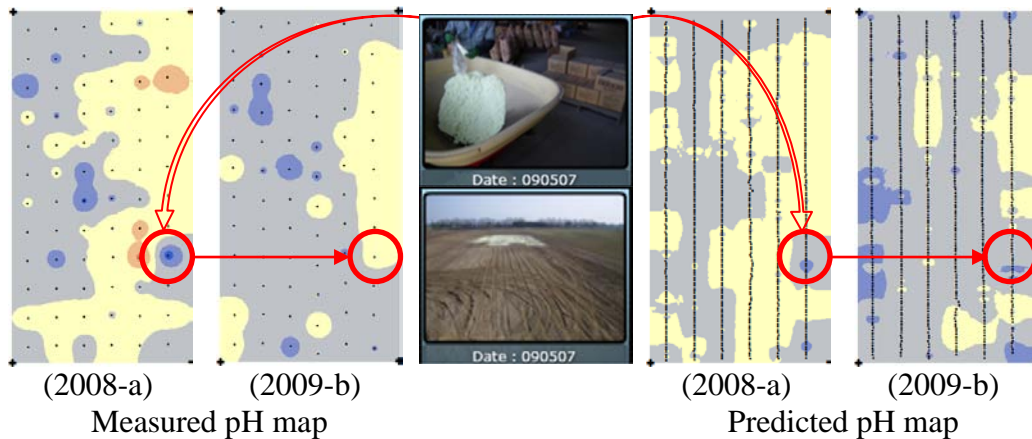


Fig. 8. Comparison of the before scatter map (2008-a) and the after scatter map (2009-b) scattered sulfur fertilizer to the site-specific location.

CONCLUSIONS

In this study, our purpose demonstrated the potential of the RTSS using the VIS-NIR spectroscopy. Two VIS-NIR spectrophotometers in the range of 310–1100 and 950-1700 nm were used to measure soil reflectance spectra. These spectrophotometers were used to develop calibration models of 12 soil parameters for pH, moisture content, soil organic matter, total carbon, soil ammonium nitrogen, nitrate nitrogen, total nitrogen, soluble nitrogen, available phosphate, phosphorus absorptive coefficient, electrical conductivity and cation exchange capacity. These calibration models were used to provide quantitative prediction of soil parameters investigated using soil reflectance spectra measured by the RTSS.

The R^2 is one of the sensitivity analysis using a multivariate statistical technique were the almost same with the results of a previous study. We predicted 12 soil parameters without adjusting the calibration models to confirm the performance of regression coefficients. Those soil maps as distribution situation of soil parameters were almost same with soil analysis maps.

The grower used the pH map to scatter sulfur fertilizer on the site-specific location in May 7th, 2009. We confirmed that a high pH value location was improved in November, 2009. This is the example that site-specific soil management was carried out by the grower as precision agriculture.

A major result of this study was that the RTSS was accepted by the grower as one of a decision-making support tool.

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