Dozen-soil-parameter mapping using a real-time soil spectrophotometer

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Abstract

Visible (VIS) - near infrared (NIR) spectroscopy is a promising technique for rapidly measuring soil parameters. Our objectives are to develop dozen-soil-parameter calibration models based on VIS-NIR soil reflectance data measurements directly carried out in agricultural fields using a real-time soil spectrophotometer (RTSS), and to develop dozen-soil-parameter soil maps for site-specific soil management.

Keywords: Soil sensing, Near-infrared spectroscopy, Partial least-squares regression, Soil map, Site-specific soil management

Introduction

In this study, calibration models of a dozen soil parameters were developed: moisture content (MC), soil organic matter (SOM), total carbon (TC), pH, electrical conductivity (EC), total nitrogen (N-t), nitrate-nitrogen (N-n), soil ammonium nitrogen (N-a), soluble nitrogen (N-s), available phosphorus (P-a), phosphorus absorptive coefficient (PAC), and the cation exchange capacity (CEC). These calibration models were calculated using the partial least-squares regression (PLSR) method coupled with the full cross-validation technique using the Unscrambler V9.8 (CAMO SAS, Norway) software. Based on the values of sensitivity analysis, coefficient of multiple determination (R^2) and root mean square error (RMSE) or standard error (SE), these results were almost the same or better than those of a previous study (Rossel et al., 2006). When these models were validated using real-time measured spectra, dozen soil maps were appeared as predicted soil maps for site-specific soil management. ArcMap V9.3.1 (ESRI Inc., USA) software was used to draw the soil maps.

Materials and methods

The experimental field was a commercial farm with an alluvial soil type, located in Hokkaido, Japan (Figure 1). It has a crop rotation system of five crops for five years: wheat - sugar beet - soy bean - potato - green manure. The total area is about 8 ha. The tram line of the RTSS for site-specific soil management was matched to the fertilizer applicator line. There were 6 tram lines of 24 m spacing from the narrow side of the field. The VIS-NIR soil reflectance data were acquired every 2.24 m at a depth of 0.20 m on the tram line. Soil samples for soil analysis were collected at the same time every 24.64 m at same location and same depth (Kodaira et al, 2009). An outline of the RTSS (Shibusawa et al, 1999) is shown in Figure 2. A DGPS receiver and 350-1700 nm range spectrophotometers were mounted. A total of 144 soil samples were collected to investigate the correlation between soil reflectance data and soil analysis values at Field B (after harvesting wheat, August), and at Field A (after harvesting sugar beet, November) in 2008. The ArcMap software was used to draw maps of the dozen parameters, predicted from the RTSS data and measured by soil analysis. The maps were interpolated using the inverse distance weighing (IDW) method.

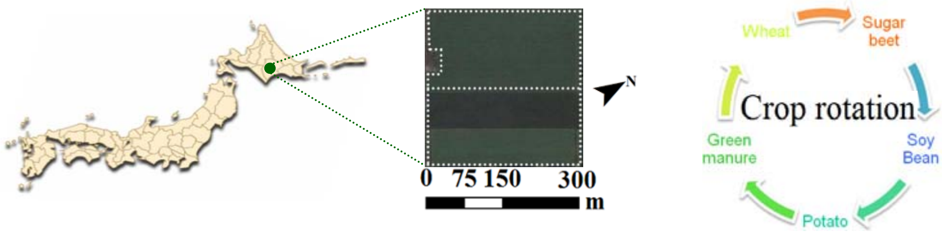


Figure 1. Location of the experimental field and the crop rotation system.

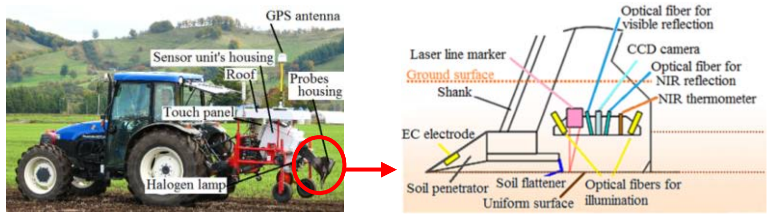


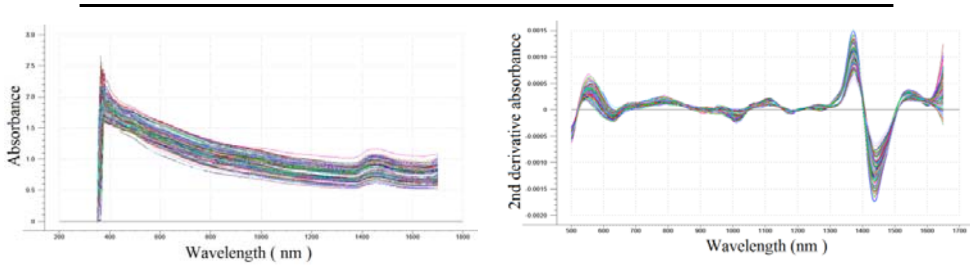
Figure 2. The RTSS connected with a tractor and sensor probe arrangement.

Results

The ranges of the soil analysis statistics for 144 soil samples are listed in Table 1. To reduce the noise and enhance the weak signals, the Vis-NIR original absorbance of 144 data were subjected to second derivative calculation using Savitzky-Golay's method (Figure 3). The sensitivity analysis and multiple equations of calibration models were derived using the after-treatment absorbance data. Then, the 144 data were used as the calibration dataset for full-cross validation. Sensitivity analysis values of the dozen parameters were obtained as listed in Table 2. As shown in Figure 4, the dozen-soil-parameter maps at Field A in 2009 were developed using the calibration models of 2008.

Table 1. Ranges of sample statistics of soil analysis.

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



(a) (b)

Figure 3. Original absorbance data (a), After-treatment absorbance data (b).

Table 2. Comparison of sensitivity analysis results.

Parameters	*Wabelength (nm)*	*Multivariate method* [(a)]	*N calib |N valid* [(b)]	*Calibration* correlation	*Calibration* R^2	*Calibration* SEC	*Validation* correlation	*Validation* R^2	*Validation* SEV	*References*
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 Walsh (2002)

[(a)]: Multivariate techniques include stepwise multiple linear regression (SMLR), and multivariate adaptive regression splines (MARS). 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 used in the validation. X-val suggests that the validation was conducted independently using a statistical cross-validation technique.

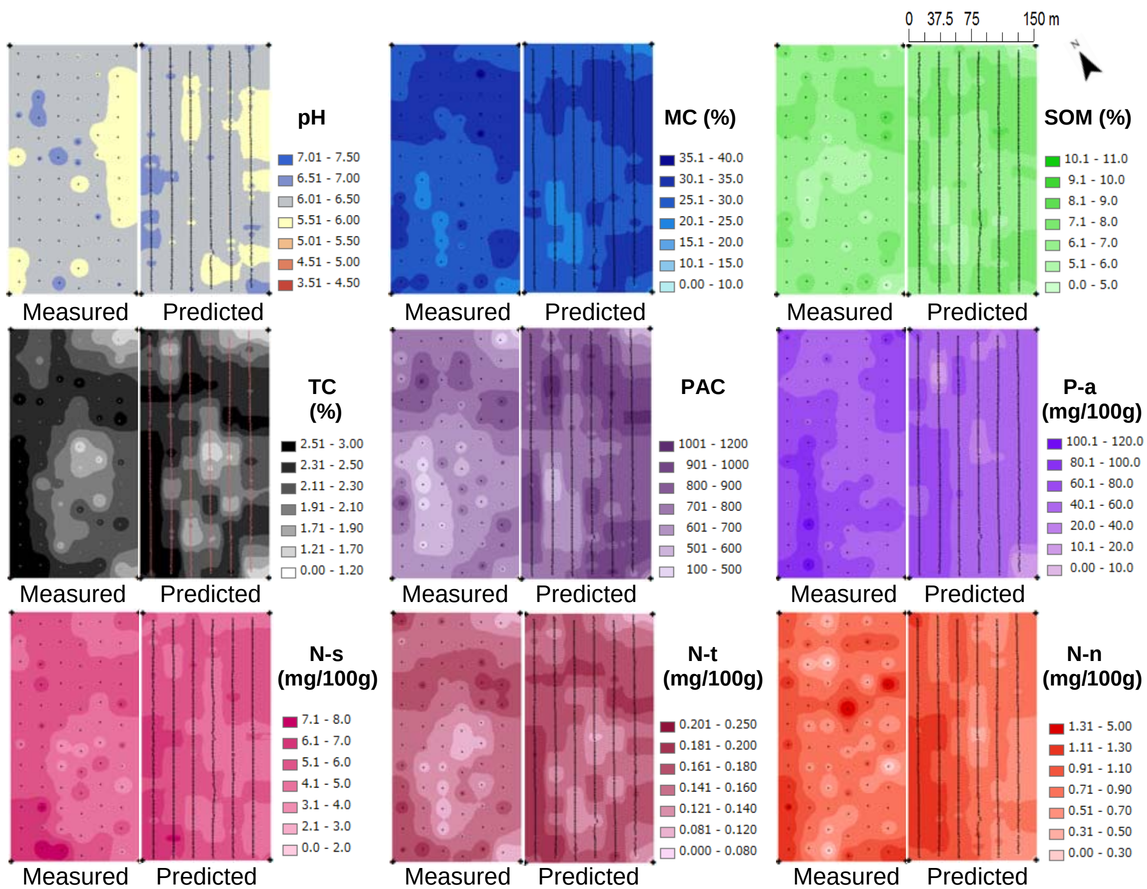


Figure 4. Measured map and predicted map in Field A, November 2009.

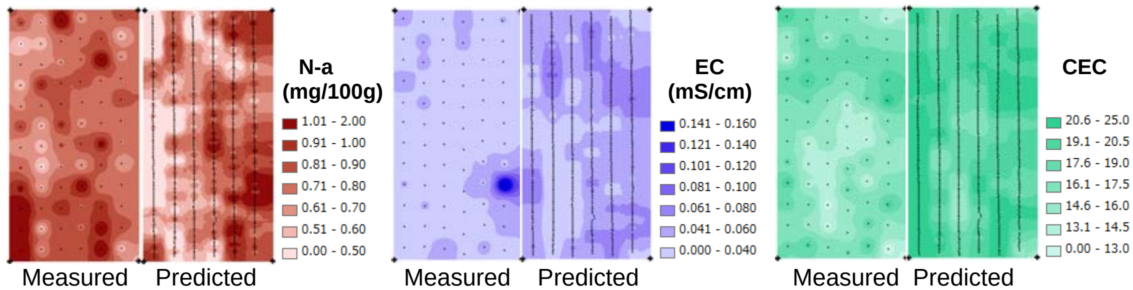


Figure 4. Measured map and predicted map in Field A, November 2009 (continued).

Conclusions

In this experiment, the results of the sensitivity analysis using the PLSR method were almost the same as or better than those of a previous study.

The calibration models were able to predict dozen-soil-parameter maps for site-specific soil management without adjusting each calibration model.

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