

USING A POTABLE SPECTRORADIOMETER FOR IN-SITU MEASUREMENT OF SOIL PROPERTIES IN A SLOPE CITRUS FIELD

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ABSTRACT

This study is aiming at the capability of VNIR-SWIR reflectance spectroscopy to predict soil properties and develop 3-D soil maps that are useful for site-specific soil management in precision agriculture. In the study, field experiment was carried out in a slope citrus field in Ehime prefecture, Japan. A potable spectrophotometer FieldSpec4 (ASD Inc.) was used to collect spectra data on the field based on fresh soil samples. To develop calibration models, 100 soil samples with 24 properties were collected and analyzed. A Global Positioning System (GPS) (Hipper, Topcon) was used to determine the location information (Longitude, Latitude, and Elevation) of the sampling points. The partial least squares regression (PLSR) analysis with full cross-validation was used to establish the relationship between soil reflectance spectra and the soil properties. The ArcGIS 10 (ESRI) was used to create the 3-D soil maps. As a result, 9 calibration models; moisture content (MC), pH, soil organic matter (SOM), electrical conductivity (EC), total nitrogen (N-t), hot water extractable nitrogen (N-h), available phosphorus (P-a), cation exchange capacity (CEC), Boron (B) were developed with coefficient of determination (R^2) range from 0.47 to 0.85, followed by residual prediction deviation (RPD) from 1.4 to 2.7. The 3-D soil property maps were developed using the spectroscopic models and the 100 soil samples analysis results.

Keywords: 3-D soil map, Reflectance spectroscopy, Partial Least Square Regression, Slope field, In-situ measurement

INTRODUCTION

Japanese citrus fields are mostly located at slope land because of good sunshine and natural drainage conditions. Successful cultivation of citrus in Japan depends on the adequate supply of water during dry season and maintains proper water stress during fruiting period by cutting off rain water using mulch cultivation (Kunihisa M, 2013). Introduction of mulch-drip irrigation system has improved the water-use efficiency and quality of fruit. However, the regular basis irrigation on current mulch-drip irrigation system is to supply the same amount of water to citrus trees in every block units of the fields. Due to the uneven distribution of groundwater, the variation can be seen in growth conditions and fruit qualities. To achieve uniformity of quality and yields, the challenge in the future is to control the variation of the fields as much as possible. Thus, rapid and cost effective understanding of variability within the field is required for site-specific management. (Kunihisa M., 2013)

The visible (VIS) and near infrared (NIR) reflectance spectroscopy is one of the promising techniques that show a high potential to fulfill these requirements. Soil moisture content (MC) was successfully measured using the non-mobile NIR spectroscopy (Dalal and Henry, 1986; Kano et al., 1985). Other researchers used the non-mobile NIR spectroscopy for the measurement of soil physical and chemical properties (Chang et al., 2001, Maleki et al., 2006, Mouazen et al., 2007). However, under the non-mobile conditions, continuously measurement of soil information at low cost cannot be fulfilled.

With the recent development in precision agricultural technologies, researchers have focused on developing an on-line soil sensor (Shibusawa et al., 1999), reported their achievements in developing the real-time soil sensor for prediction of soil property maps. Kodaira et al. (2013) developed 12 calibration models using the real-time soil sensor combined with the PLSR analysis. However, the sensor was mounted at a tractor which was not available for slope fields. Also, the sensors only measured soil variation in an arbitrary depth (X, Y coordinates system), which referred to two dimensional space in this study.

Researches can also be seen on using portable VNIR-SWIR reflectance spectrometers to predict soil properties and soil textures (T.Jarmer et al.,2008; D. Summers et al.,2011; D.Curcio et al., 2013). However, few researches has been done to investigate the capability of these portable reflectance spectrometers on the prediction of multiple soil properties.

On the context above, the main objectives of this study was to assess the performance of a portable spectrophotometer FieldSpec4 for online prediction of 100 soil properties collected from a slope citrus field. And then develop a general approach for online collection of soil spectra. Furthermore, to develop 3-D soil maps from spectroscopic models and soil chemical analysis results.

MATERIALS AND METHODS

Experimental site and soil sampling

The experimental site was a commercial citrus field (Fig. 1a) with an alluvial soil type located on a slope field in Iwagi Island, Ehime prefecture, Japan. The field has a triangle area of about 1200 m² with 89 citrus trees and 7 growing rows (Fig. 1b). Mulch-drip irrigation system was used to irrigate the field and the dripping line was put at 750 mm from growing rows. Liquid fertilizer was supplied simultaneously with drip irrigation water. To collect soil samples that can

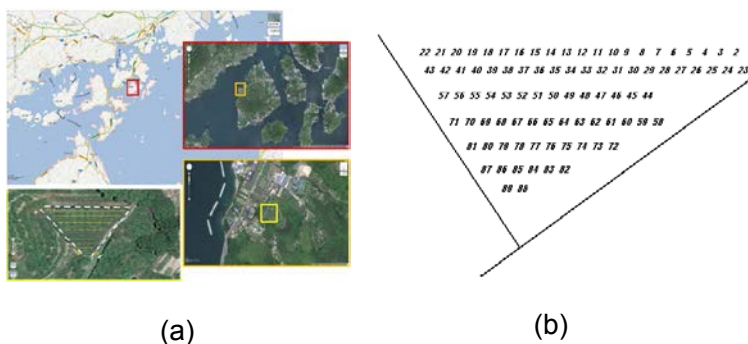


Figure 1. Location of experiment site: (a) Location of experimental area in Japan. (b) Row planting figure of the experimental area

best represent the soil nutrient distribution and avoid destroying the root system, the soil sampling points were determined based on the distance from dripping hole and the citrus trees. Eighty nine soil sampling points were determined at 2000 mm soil depth, 1000 mm from citrus trees (320 mm from dripping holes). Twelve soil sampling points were determined randomly at 20 mm soil depth within the field. A hundred soil samples were collected on December 12, 2013. The position information (longitude, latitude, elevation) of the sampling points was obtained by a dual-frequency GNSS receiver (Hiper, Topcon).

Collection of VNIR-SWIR spectra using the FieldSpec4

Figure 2 shows the experimental setup for soil spectra collection. A portable ASD FieldSpec4 spectroradiometer (ASD Inc.) was employed for reflectance measurements. The instrument covers the VIS to SWIR wavelengths (350 nm - 2500 nm) with a sampling interval 1.4 nm for the 350 nm - 1000 nm region and 2nm for the 1000 nm - 2500 nm region. Reflectance measurements were acquired inside a garage located on the experimental site. Fresh soil samples were used for spectra collection. Soil samples were illuminated with a light source (ASD intensity contact probe, halogen bulb) fixed in a fixture and positioned perpendicular to the soil samples (Fig. 2b). Spectral measurements were taken from nadir at 5 mm above the soil samples.

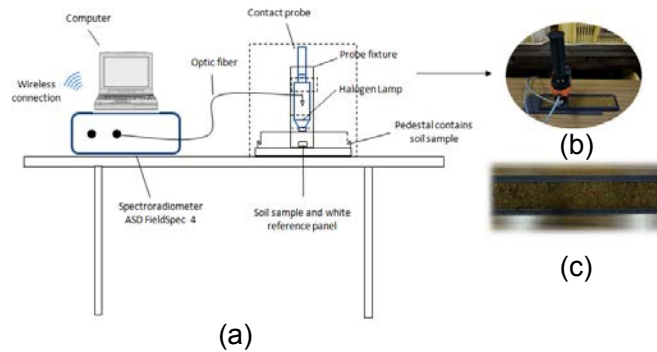


Figure 2. Experimental setup: (a) Experimental setup. (b) Contact probe and fixture. (c) Soil samples packed into rectangular pedestal

In order to set up the spectral measurement, soil samples were packed inside a rectangular pedestal (200 mm in length, 50 mm in width, and 5 mm in depth). Fresh soil samples were filled into the pedestal with no pressure put on the surface, and use a spatula to level the edge to obtain a relative smooth surface. The pedestal can be moved laterally to measure the different point of the soil samples. In order to confirm the variance, 10 points were measured for one soil sample and the measurement was duplicated for 5 times at each measuring point. In general, 50 spectra were collected for one soil sample, and the average for each sample was adopted as a dataset for the multivariate statistical analysis.

The measurement of reflectance was obtained based on measured white and dark level reference. The reflectance was calibrated against a white reference panel (Labsphere, SRS-99-020) before starting each soil sample measurement. A black-out cloth was covered the contact probe to avoid the contamination by stray light. Dark current was taken at the dark micro-environment created by covering with the black-out cloth. Fig. 3 shows the White Reference and Dark Current values.

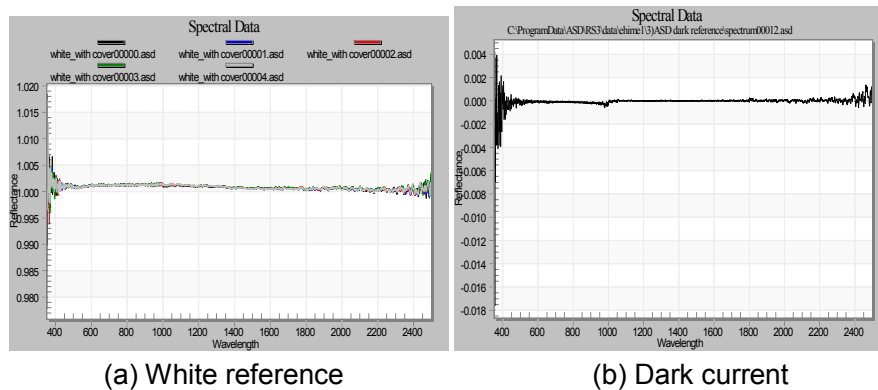


Figure 3. Measurement of white reference and dark current.

After finishing one soil sample measurement, the spectra data were checked through ViewSpec Pro software to confirm the variance and abnormal data, the soil sample was measured again if the variance was big. The abnormal data were

recorded and excluded during the subsequent spectra analysis. Soil sample images were captured to investigate the abnormal spectra data. The soil samples which were finished spectral collection were put in Ziplocs for subsequent chemical analysis.

Soil chemical analysis

To measure the amount of chemical components in the soil, two sets of 100 soil samples were collected from the experimental field. One set was analyzed at our laboratory (TUAT) and the other set was analyzed at the Agriculture Product Chemical Research Laboratory (APCRL; Federation of Tokachi Agricultural Cooperative Association, Hokkaido, Japan).

The set of samples sent to TUAT were transported in a refrigerator car at a temperature below 10 °C, and then stored at TUAT in a refrigerator at 5 °C. Soil chemical analysis for moisture content (MC), Soil organic matter (SOM), pH and Electronic conductivity (EC) were carried by TUAT using the standard procedures in the Hokkaido area in Japan (Souma and Kikuchi, 1992). MC were measured using the oven-dry method at 110°C for 24h. Soil pH was measured by glass electrode (D-24, HORIBA) using a soil: distilled water weight ratio of 1 : 2.5. Soil EC was measured by AC bipolar method (D-24, HORIBA) using a soil: distilled water weight ratio of 1 : 5. After shaking for 30min and equilibration, pH and EC were measured in the supernatant. The soil: distilled-water weight ratio for pH and EC were calculated using each MC result of soil samples. SOM was measured using soil samples sieved through a 1-mm sieve and dried in a muffle furnace at 800°C for 3h. Each soil analysis was conducted three times, and the average value was used in the multivariate statistical analysis.

The other set of 100 soil samples was sent to APCRL at the end of the day in which they were collected. Soil chemical analyses for P-a, N-t, N-h, CEC, B were carried by APCRL using the standard procedures in the Hokkaido area in Japan (Souma and Kikuchi, 1992). The 100 fresh soil samples were dried, crushed and sieved. The N-t was measured by Kjeldahl method. Other soil properties were measured by absorptiometry.

Table 1. Statistical results of soil chemical analysis.

Property	N ^a	Min	Max	Mean	Range	Skewness	Kurtosis	Variance	S.D.	Analyzing method	Operator
MC %	100	11.5	24.4	17.5	13	0.21	-0.41	7.81	2.79	Oven dry	TUAT
pH	100	4.1	7.7	5.3	3.6	1.25	0.81	0.74	0.86	Glass electrode	TUAT
SOM %	100	0.2	2.3	0.9	2.1	1.08	1.11	0.2	0.45	Muffle furnace	TUAT
EC mS cm ⁻¹	100	0.04	0.24	0.07	0.2	2.33	7.51	0.001	0.03	Ac bipolar	TUAT
CEC me 100g ⁻¹	100	5.7	13.3	8.9	7.6	0.84	1.84	1.63	1.28	Absorptiometry	APCRL
N-t %	100	0.02	0.13	0.06	0.11	0.58	-0.01	0.0005	0.02	Kjeldahl method	APCRL
P-a mg 100g ⁻¹	100	24.7	162.8	77.8	138.1	0.64	0.62	770.94	27.77	Absorptiometry	APCRL
N-h mg 100g ⁻¹	100	1.3	6.0	2.87	4.7	0.96	0.87	1.02	1.01	Absorptiometry	APCRL
B mg 100g ⁻¹	100	0.4	1.3	0.7	1.0	0.76	-0.03	0.05	0.23	Absorptiometry	APCRL

Spectra pretreatment and establishment of calibration models

The measured reflectance spectra were transformed and exported at soil absorbance format through the software RS3 (ASD Inc.) The exported absorbance data were defined as follows:

$$\text{Absorbance spectra} = \text{Log } 1/R$$

where R is the soil sample reflectance spectra. The average value of the measured absorbance spectra for all soil samples are shown in Fig. 4.

The next step was pretreatment for original absorbance. This study used the commonly used correction techniques smoothing second derivative (Savitzky and Golay, 1964). Figure 5 shows the spectra after 2nd derivative treatment. To remove noises from both sides, the spectra range from 450 nm to 2450 nm was selected for build calibration models (Fig. 5b). The final step in the development of calibration models was PLSR coupled with full cross-validation.

Sample outliers are detected by using the residual sample variance plot after the PLSR. Individual samples located far from the zero line of residual variance on the validation views are considered to be outliers and are excluded from the analysis. The best calibration model was recalculated for several times using PLSR with full cross-validation. And the evaluation of the calibration model is based on the smallest root mean square error (RMSE) and highest coefficient of determination (R_{val}^2) close to one. And these works were performed using the Unscrambler X software (Camo, USA).

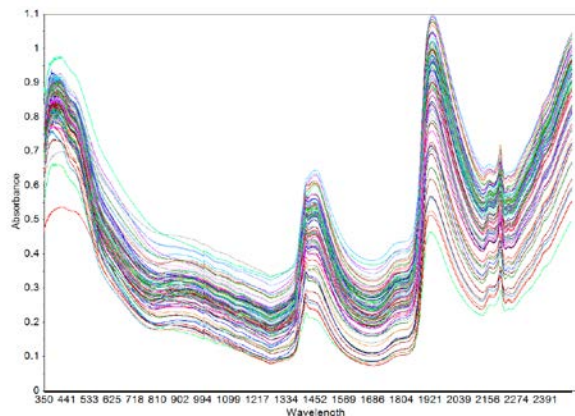


Figure 4. Measured absorbance spectra for 100 soil samples

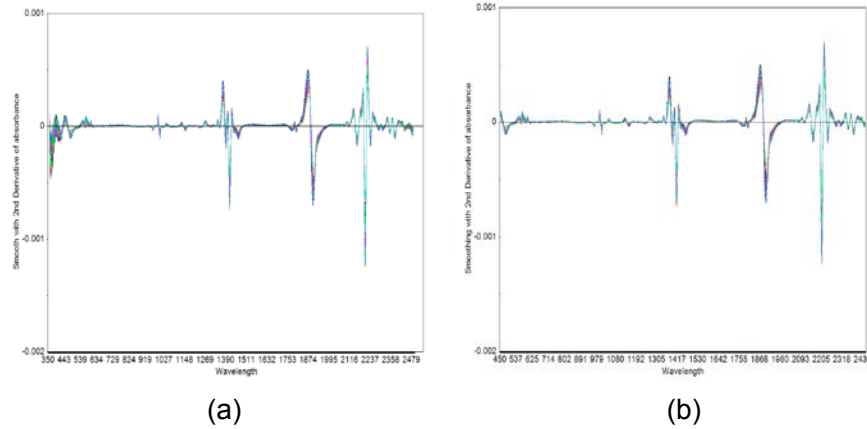


Figure 5. Pretreated absorbance using smoothing and 2nd derivative: (a) Full range. (b) Selected range for developing calibration models

Development of 3-D soil maps

The ArcScene10 was used to draw the 3-D soil maps. In order to make the maps easy to use, the elevation information (z coordinate) was added to the original two dimensional soil maps (x, y coordinate system). Thus, the spatial variability of soil properties with elevation change could be visualized on the soil maps. The grid was interpolated using the inverse distance weighing (IDW) method. In order to have useful comparison between measured and predicted soil maps, the same number of classes (seven classes) was considered for the maps. Furthermore, the range of each class was made identical for both of the maps. Which means the color's classification was adjusted to have equal maximum and minimum value of each class.

RESULTS AND DISCUSSIONS

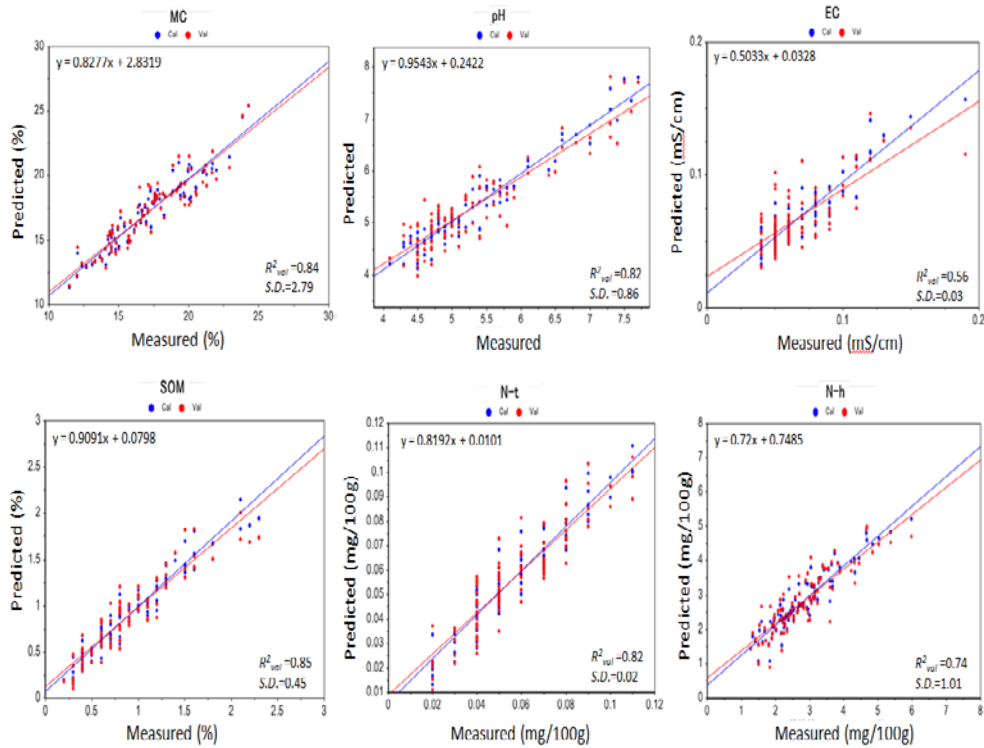
Development of calibration models

The PLSR analysis coupled with full cross-validation was used to establish the relationship between pretreated VNIR-SWIR absorbance data and soil chemical results for the 100 soil samples. The PLSR results of the validation sets were shown in Table 2. The RPD is a factor to evaluate the calibration model. The ratio is desired to be larger than 2 for good calibration (Sinnave et al., 2001). MC, pH, SOM, N-t, N-h showed good level of accuracy with value of RPD was from 2.2 to 2.7. EC, P-a, CEC, Boron showed a moderately poor level with the RPD value between 1.4 and 1.6.

Scatter plot of the prediction was obtained as shown in Fig. 6. The primary regression equations are also shown in the figure.

Table 2. Summary of PLSR results for the nine soil properties datasets.

Property	Unit	Range	Pre-treatment	N	nF	R_{val}^2	S.D.	RMSE	RPD
MC	%	450nm-2450nm	2nd Derivative	93	5	0.84	2.79	1.14	2.5
pH	pH unit	450nm-2450nm	2nd Derivative	96	9	0.83	0.84	0.37	2.5
SOM	%	450nm-2450nm	2nd Derivative	96	6	0.85	0.45	0.17	2.7
EC	mS/cm	450nm-2450nm	2nd Derivative	93	9	0.56	0.03	0.02	1.5
N-h	mg/100g	450nm-2450nm	2nd Derivative	97	6	0.74	1.01	0.47	2.2
N-t	mg/100g	450nm-2450nm	2nd Derivative	95	6	0.82	0.02	0.01	2.3
P-a	mg/100g	450nm-2450nm	2nd Derivative	99	10	0.47	27.77	20.32	1.4
CEC	me/100g	450nm-2450nm	2nd Derivative	97	11	0.61	1.29	0.82	1.6
Boron	ppm	450nm-2450nm	2nd Derivative	98	5	0.61	0.23	0.14	1.6



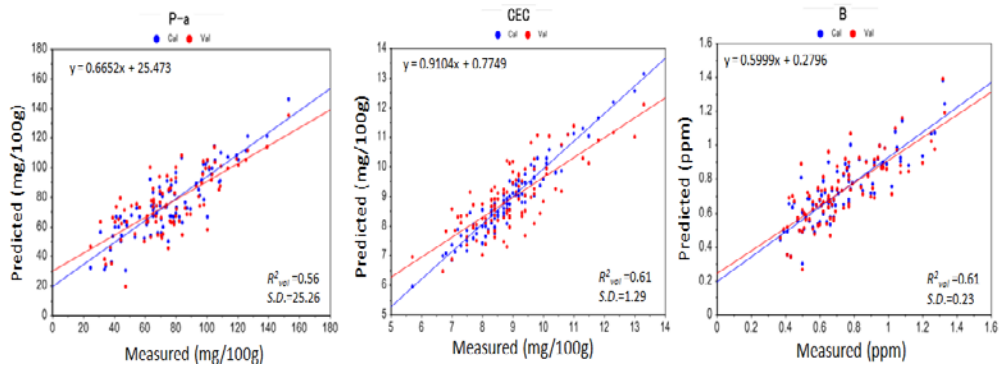
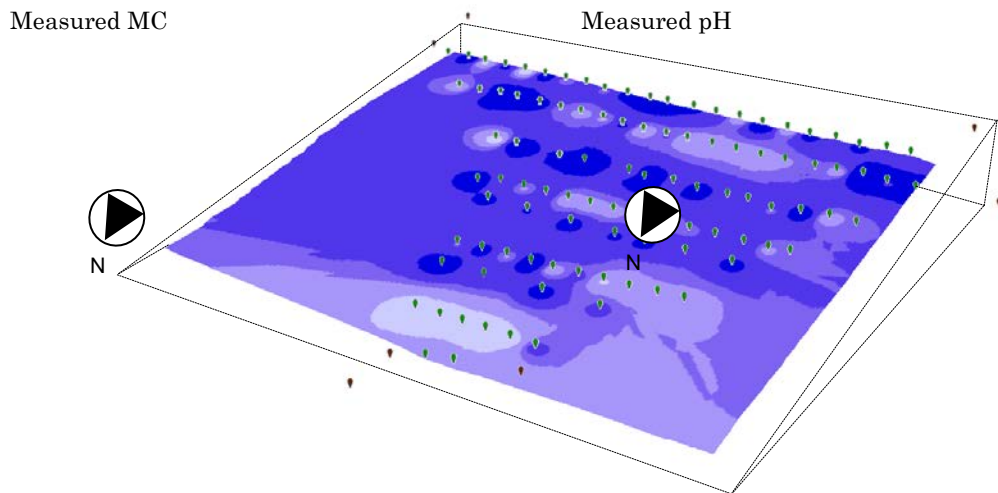
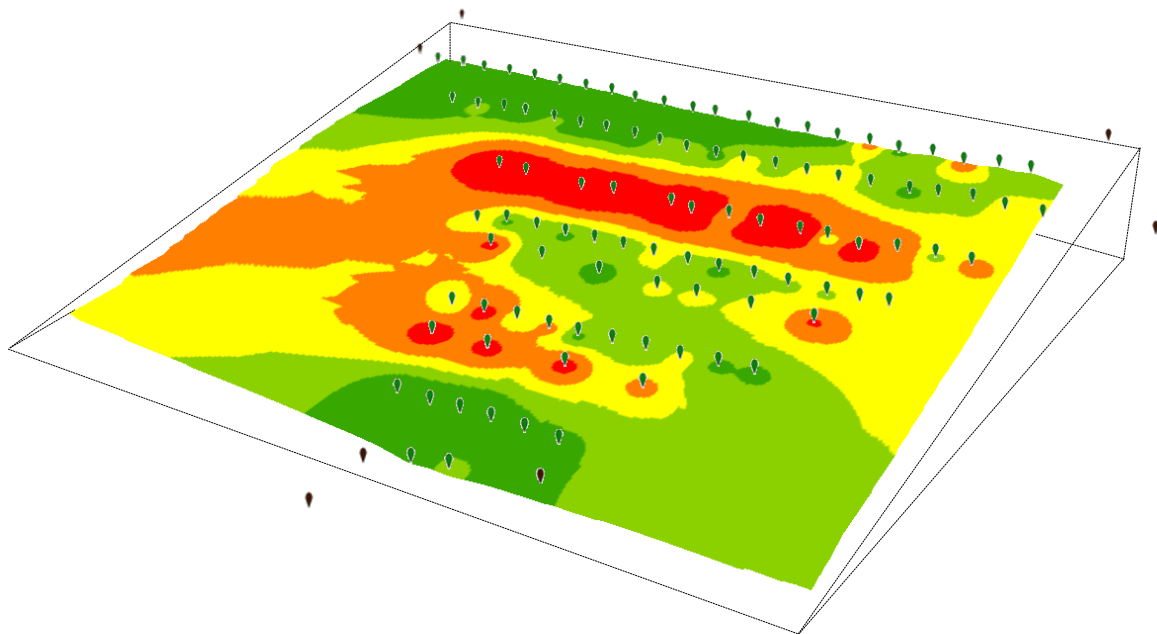


Figure 6. Scatter plot of measured values versus VNIR-SWIR predicted values using PLSR coupled with full cross-validation datasets for: Moisture content (MC), pH, soil organic matter (SOM), electrical conductivity (EC), total nitrogen (N-t), hot water extractable nitrogen (N-h), available phosphorus (P-a), cation exchange capacity (CEC), Boron (B).

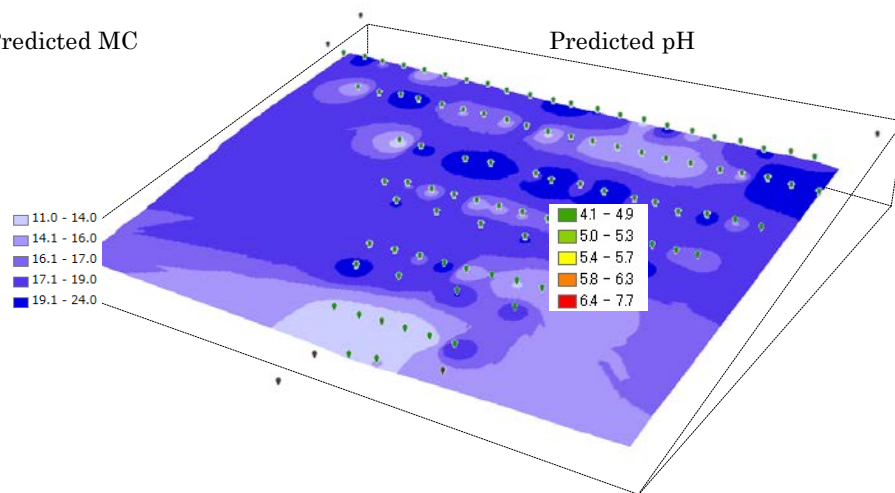
3-D soil properties mapping

Maps of 3-D soil property for the slope citrus field were developed as shown in Fig. 7. The measured soil property maps were drawn using the chemical results of the 100 soil samples collected in Dec. 12, 2013. The predicted 3-D soil property maps were developed using the 5000 spectra data collected on the field by FieldSpec4 using the 100 fresh soil samples. Table 3 shows the comparison between mean values measured and predicted for each property.

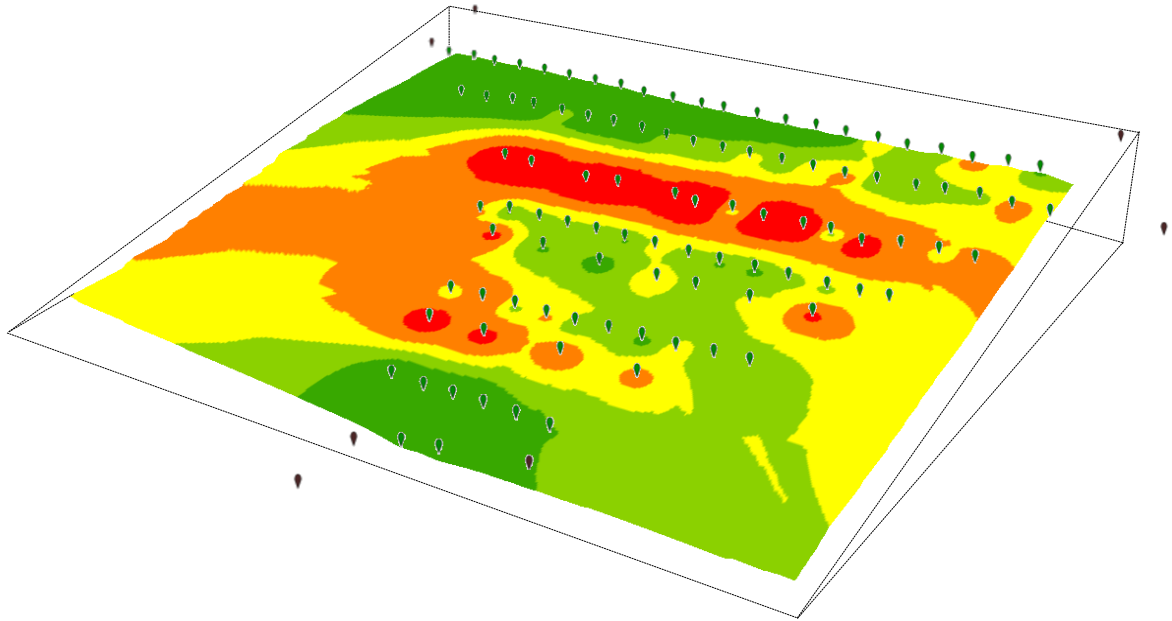




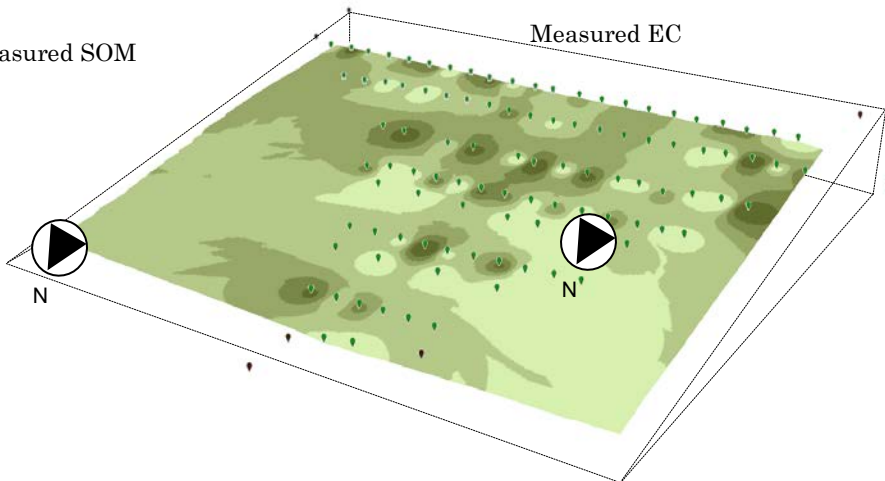
Predicted MC



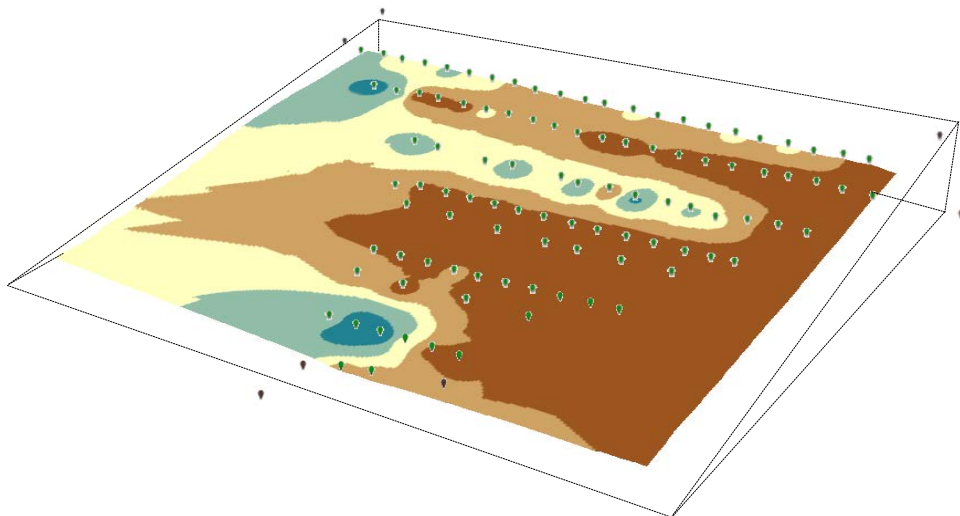
Predicted pH



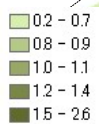
Measured SOM



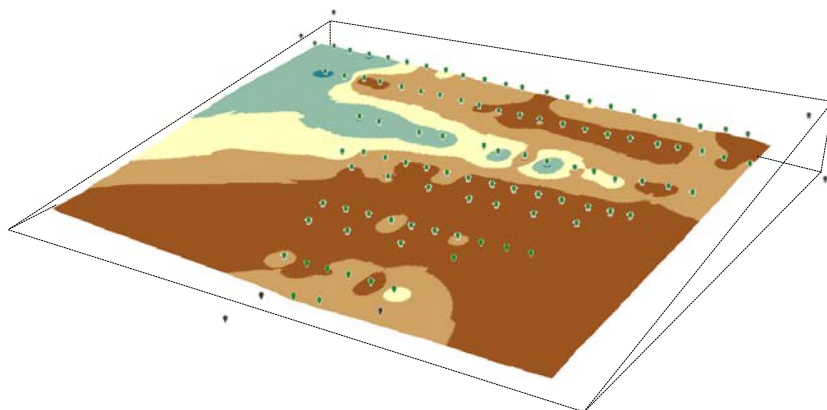
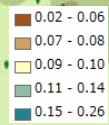
Measured EC



Predicted SOM



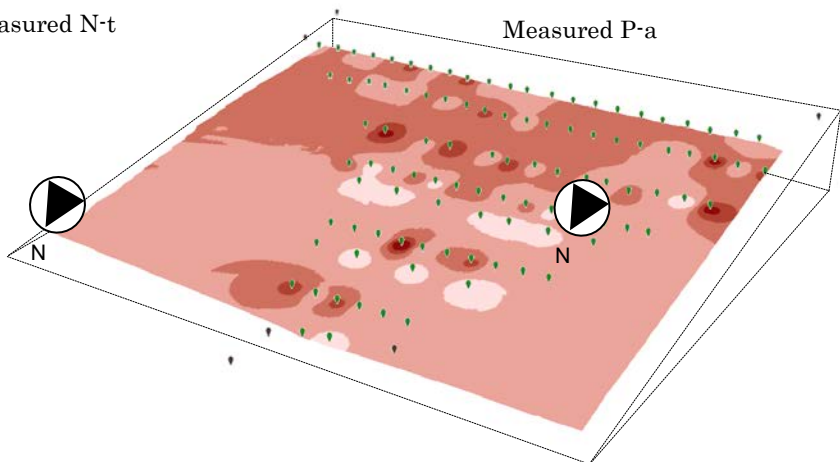
Predicted EC



Measured N-t



Measured P-a



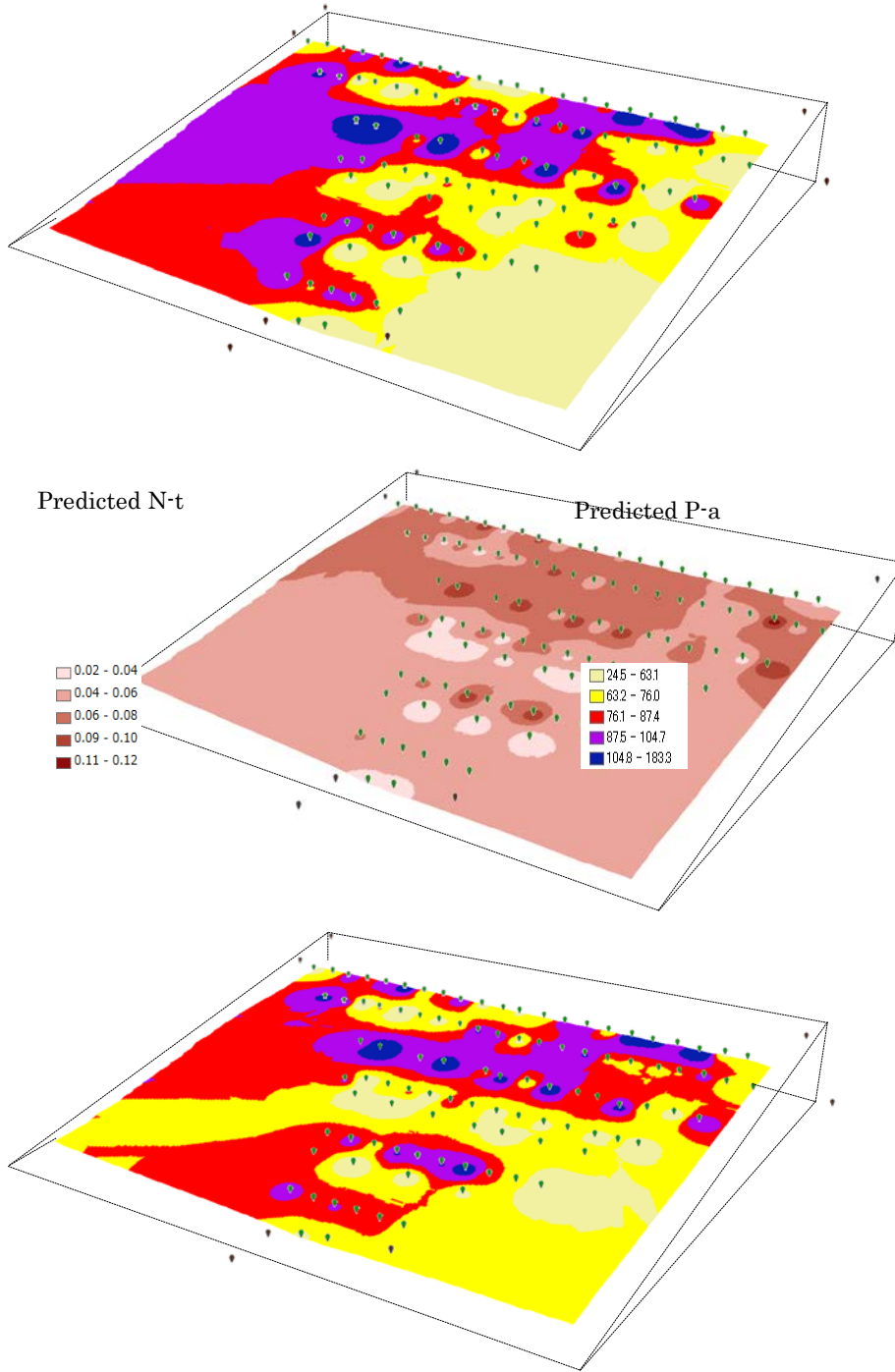
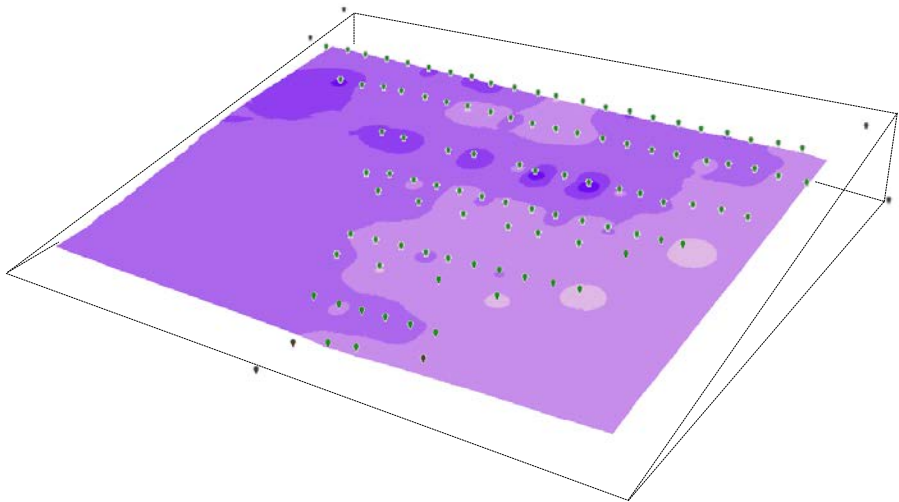
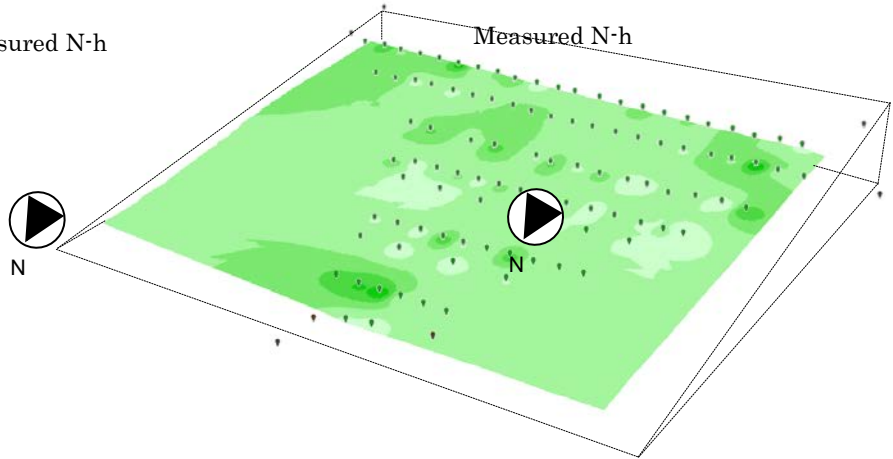
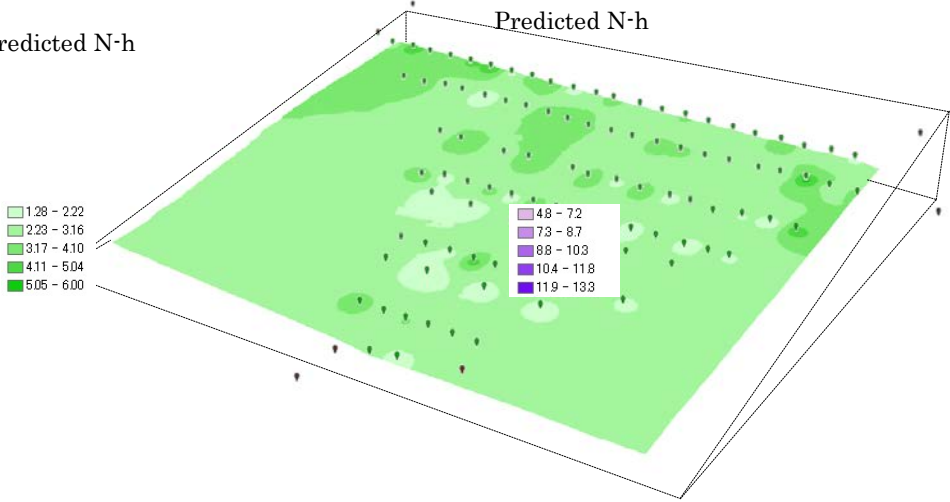


Figure 7. Measured and predicted 3-D soil property maps for the slope citrus field

Measured N-h



Predicted N-h



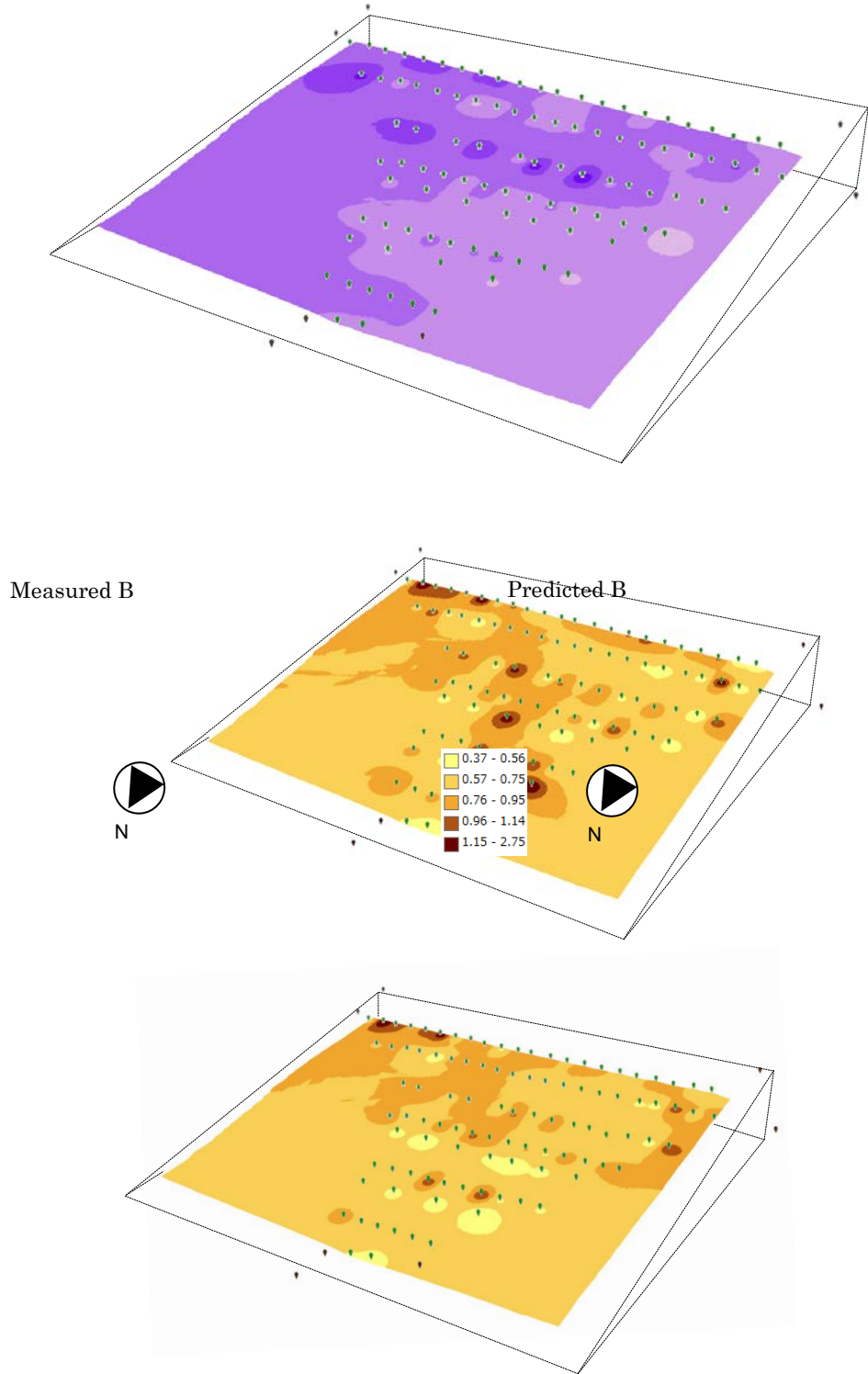


Figure 7. (Continued)

Table 3. Comparison of measured and predicted mean values.

Property	Measured	Predicted	Error %
MC	17.468	17.289	1.02
pH	5.298	5.298	0.00
SOM	0.873	0.873	0.05
EC	0.071	0.068	3.53
P-a	77.781	77.210	0.73
N-t	0.058	0.057	0.67
N-h	2.874	2.818	1.96
CEC	8.924	8.899	0.28
B	0.739	0.723	2.19

CONCLUSIONS

In this study, nine spectroscopic calibration models based on VNIR-SWIR fresh soil samples reflectance spectra collected by a portable spectrophotometer FieldSpec4 in a slope citrus field were developed using PLSR with full cross-validation. Also 3-D soil property maps were developed using the 100 soil samples based on the calibration models and soil chemical analysis results. The spectra data were not good enough to predict multiple soil properties. Future work need to compare the calibration results with previous studies and find the aspect that need to be improved. Also, the representative soil properties need to be examined to reduce the large time and cost on soil properties analysis.

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