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Improving Accuracy of Soil Property Measurements by NIR Spectroscopy

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Traditional wet chemical methods for testing of soil properties require extensive time and labor, and cause the discharge of pollutants, making them undesirable for routine soil analyses. This research was conducted to improve the accuracy of soil properties in soil fertility assessments. A total of 140 finely ground soil samples were used to obtain accurate calibrations and validation for estimating soil moisture, OM, and T-N. Finely ground soil samples satisfied the improved accuracy for routine NIR measuring of the field soils. The results indicated that NIR spectroscopy could be used as a routine method for quantitatively determining OM, moisture, and T-N of field soil, although this technique requires many combinations of sample pretreatments and data manipulations to obtain optimal predictions.

Key words: *near infrared (NIR) spectroscopy, multiple linear regression, partial least square regression, organic matter, total nitrogen, nondestructive estimation.*

In Korea agricultural practices have relied on heavy fertilization and intensive soil management to meet food production requirements. Nowadays these practices are becoming problematic. Farmers have begun to recognize the importance of precision farming. Soil fertility differs from field to field. Adjusting fertility to suit each field requires taking many soil samples. In addition, present soil property testing methods involve hours of labour and the use of complex chemicals.

A technique for accurate and rapid measurement of soil properties has been pursued. The spectra of NIR region contain some useful information on soil properties.[1,2,4,6] Ryu *et al.* developed a soil analyzer for moisture, organic matter, and total nitrogen in soil through NIR spectroscopy,[8] which Meyer used as a fertilizer advisory service.[5] Ryu *et al.* also reported on the various type of soil phosphorus using NIR spectroscopy.[10] However, the NIR technique does not exceed the traditional laboratory method in accuracy due to the calibration equation based upon the referenced analytical data.

Often research requires more accurate soil property data for fertilizer recommendation than the present data obtained by the NIR soil analyser developed by Ryu *et al.* Reeves reported that accuracy of NIR spectroscopy on soil properties was improved in ground soil samples.[7] Application of the soil property data obtained via NIR scanning, based on sample preparation improving the accuracy of the NIR method for soil properties, may allow soil testing within a few seconds. This study aimed to improve the accuracy of the NIR method to replace the traditional laboratory method.

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Abbreviations: NIR, near infrared; MLR, multiple linear regression (MLR); PLSR, partial least square regression.

Materials and methods

Preparation of soil samples. Over 400 soil samples from paddy, upland, orchard and other soils over the Youngnam and Honam regions in Korea were used for this study. They had wide range of soil constituents. Soil samples were air-dried and prepared to pass through 2.0 mm opening sieves (roughly ground soil). Among 400 samples, 140 were ground to pass through 0.2 mm sieve openings (finely ground soil), of which 85 were used for calibration and 55 were used for prediction.

Determination of soil properties. Moisture content of the soil samples was determined gravimetrically. Organic matter content (OM) and total nitrogen (T-N) were determined using the Walkley-Black and the Kjeldahl methods. All results are expressed on the basis of dry weight.

NIR spectral measurement of soils. NIR reflectance spectra of the soils were scanned at 2 nm interval from 1,100 to 2,500 nm with an InfraAlyzer 500 (Bran & Luebbe Co.). Calibration equations were based on a selection of the lowest standard error from the best combination set of several wavelengths with multiple linear regression (MLR) and partial least square regression (PLSR). Standard error of estimation (SEE) and prediction (SEP) were calculated based on the following equations.

$$SEE = (\text{mean square error})^{1/2}$$
$$SEP = [\Sigma(x - y)^2 / n\text{-}1]^{1/2}$$

Table 1. Regression statistics of the soil properties for ground and unground soils.

Components	Soil Preparation	Regression Mathmatic	Spectral Treatment	Term	Soil Range	R	SEE	SEP
Moisture	2 mm<	MLR	2D	9	0.55~8.32	0.883	0.498(277)	0.564(182)
	0.2 mm<	PLSR	2D	4	0.96~4.33	0.836	0.355(84)	0.447(54)
Total Nitrogen	2 mm<	MLR	2D	8	0.03~0.28	0.851	0.030(142)	0.031(92)
	0.2 mm<	PLSR	2D	7	0.02~0.41	0.968	0.016(83)	0.027(54)
Organic Matter	2 mm<	MLR	2D	9	0.43~6.84	0.946	0.418(73)	0.724(46)
	0.2 mm<	PLSR	2D	6	0.10~4.09	0.989	0.092(84)	0.266(55)

R, multiple correlation coefficient; SEE, standard error of estimate; SEP, standard error of prediction; ( ), no. of soil samples; PLSR, partial least square regression; MLR, multiple linear regression; 2D, 2nd derivatives of the spectrum; Term, no. of band used for calibration.

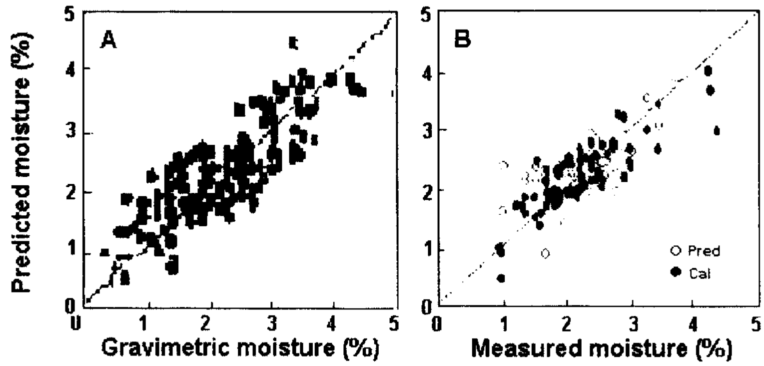

Fig. 1. Gravimetrically measured moisture for air-dried soil and predicted value via NIR method for the roughly ground soil (A) and finely ground soil (B).

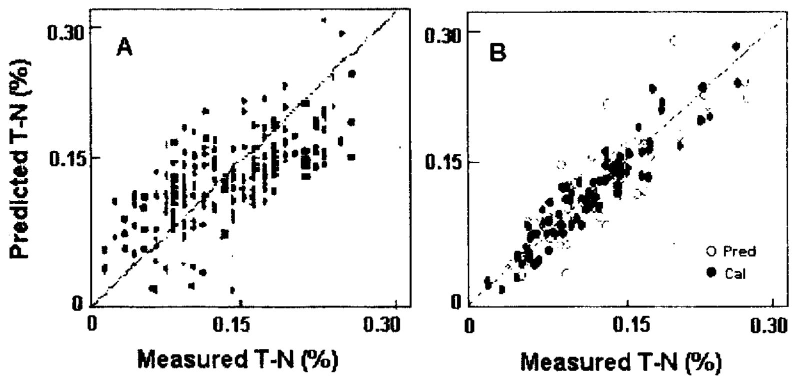

Fig. 2. Total nitrogen measured by Kjeldahl method and NIR predicted value for the roughly ground soil (A) and finely ground soil (B).

where x is the soil constituents, y is the predicted value from NIR calibration equations for the soil constituents, and n is the number of samples.

Results and Discussion

Table 1 shows the overall results of prediction accuracy of the soil properties between the roughly and finely ground soil samples. In the NIR analysis an orientation of decreased particle size was important in obtaining reproducible NIR reflectance, which allows even reflection of NIR spectra for soil components. Increase in the measuring bands of MLR was considered to increase the estimation accuracy of soil properties by obtaining better correlation for diffuse reflection. In PLSR a high correlation coefficient was obtained by giving the least error of estimation.

Relationships between the soil moisture and the predicted moisture contents through gravimetrically calculated and NIR methods are shown in Fig. 1. The response for soil moisture after air drying obtained through multiple linear regression was closely linear which was similar to the soil moisture meter developed by Kano *et al.*[3] A different correlation with PLSR between gravimetric and NIR predicted soil moisture for finely ground soil samples showed no better correlation

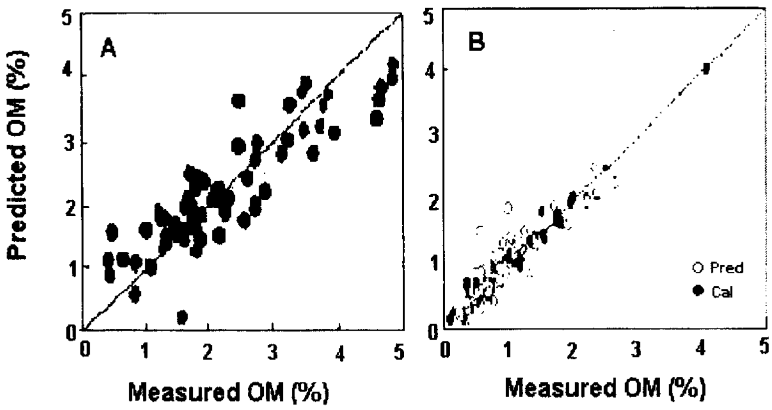

Fig. 3. Soil organic matter using Walkly-Black method and predicted value via NIR method for the roughly ground soil (A) and finely ground soil (B).

(Fig. 1B). Standard error of prediction for moisture estimation of finely ground soil was similar to the roughly ground soil samples. Soil moisture data predicted through NIR reflectance method could be used to calculate the dry mass of soil for field moistened samples.

Fig. 2 shows the values of total and predicted nitrogen based on Kjeldahl and NIR methods, respectively for the roughly ground soil (A) and finely ground soil (B). The roughly ground soil of less than 2 mm in particle size was in relatively good agreement with 1 : 1 line of measured and predicted value having a few outliers. Finely ground soil showed a better correlation coefficient, hence scatter of each measurement and prediction concentrate near on 1 : 1 line. However, standard error of prediction was not significantly different. Fig. 3 shows the values of organic matter obtained through Walkly-Black method and predicted through NIR method for the roughly ground soil (A) and finely ground soil (B). Finely ground soil showed a better correlation coefficient, hence scatter of each measurement and prediction concentrate on 1 : 1 line. Therefore, the standard error of prediction for organic matter content was reduced by 50%. Total nitrogen and organic matter for finely ground soil showed that most of the points fell in the vicinity of 1 : 1 line as revealed by Reeves (Figs. 2B and 3B).[7]

Table 1 and Figs. 1 to 3 explain the scope of the applicability of the NIR method with a reasonable accuracy in the routine soil analyses as used by Meyer for the fertilizer advisory service.[5] For using the NIR spectra technique in fertilizer recommendation, further studies are required for other soil components, in addition to moisture, nitrogen, and organic matter in soil.

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