Development of a soil analyser using near infrared spectroscopy

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Introduction

In Korea, food self sufficiency is less than 30%. Therefore, agriculture requires intensive management and heavy fertilisation of small patches of cultivated land to meet food requirements. Nowadays since environmental impact from heavy fertilisation is becoming more problematic, farmers have begun to recognise the importance of sustainable agriculture. Sustainable agriculture, which reduces the environmental impact from heavy fertiliser, needs precise farming. Soil fertility differs from field to field and the adjusting of fertility requires many soil samples. Current simple soil testing methods for fertiliser recommendation under sustainable agriculture requires pH, total nitrogen or NO_3-N, available phosphorus, CEC, exchangeable Ca, Mg, K. Total nitrogen refers to organic matter content in paddy soils and available silicate and NO_3-N in upland soils. The rapid and accurate measurement of soil properties in a limited time required a special technique to be developed.

For the last 30 years near infrared (NIR) spectroscopy has been widely and increasingly used as a means of rapid and accurate determination of the properties and qualities of food and agricultural products. Some researchers have shown that the spectra of NIR reflectance contain some information about soil properties (Davies,[1] Krishnan *et al.*,[2] Kriscenko *et al.*,[3] Morra *et al.*,[4] Inoue *et al.*,[5] Ben-Dor *et al.*[6]). Kano *et al.*[7] have developed a very convenient portable soil moisture meter for measuring soils of different textures accurately. The application of NIR spectroscopy may allow the analysis of several soil components simultaneously within a few seconds.

Materials and methods

Soils

A total of 540 soil samples from paddy, upland, orchard and other field types were collected over the Youngnam and Honam regions of Korea. They are known to have differing compositions. Half of each soil sample was air-dried and ground to pass through a 2.0 mm sieve. The other half of the soil sample was kept in a refrigerator at below 5°C as a sample in field soil condition.

Determination of soil properties

The moisture content of the soil samples was determined gravimetrically by drying at 105°C to a constant weight (usually 24 h). Soil moisture for some soils was manipulated by adding water gradually to the saturated state and moisture content was controlled after adjusting the drying time in a drying oven and determined gravimetrically as well. Organic matter (OM) was determined by the

Walkley–Black method using a spectrophotometric observation. Total nitrogen(T-N) was determined by the Kjeldahl method. All results were expressed on the basis of dry weight.

Measurement of NIR spectra

The NIR reflectance spectra of soils was measured using an NIR spectrometer with filters selected for functional groups of moisture, organic matter and nitrogen in soils. The sample compartment was designed as a flow-type cell to accommodate field soil by natural gravity and this was compared with the closed cup sample system. About half of the soil samples were used for making a calibration equation and the other half of the samples were used for prediction. Multiple linear regression was used for making the calibration.

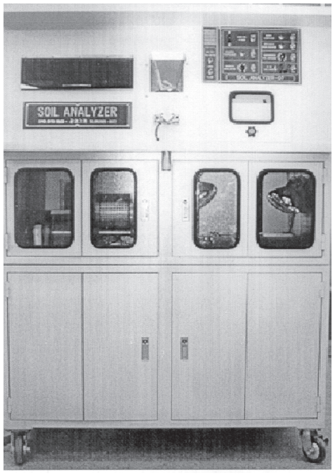
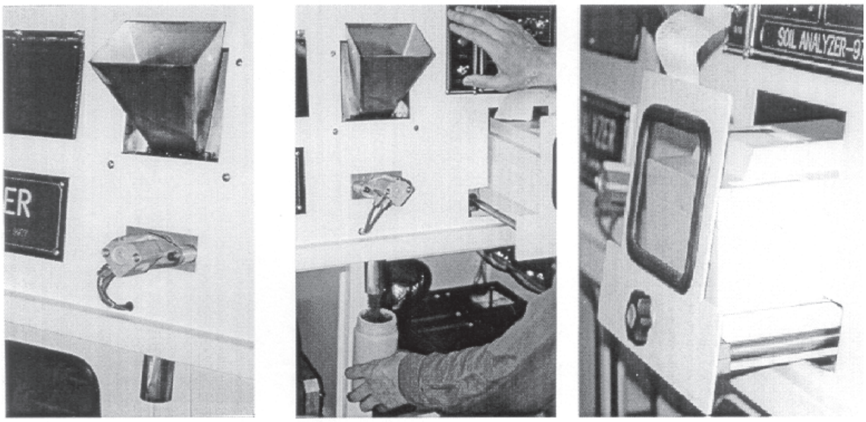


Figure 1. A set-up view of the soil analyser.

Results and discussion

In Figure 1, the upper part is the optical system composed of an NIR filter wheel, input and output of soil samples and printer. The lower part is the sample preparation system for field soil samples composed of an infrared beam for drying and a rotating sieve for preparation of the sample with the required particle size. Figure 2 shows the details of soil preparation for field use. The time needed for NIR measuring differed from soil to soil. The overall drying time of the field soil sample for optimum condition for NIR measuring in the field was less than 15 minutes as shown in Figure 4.

Multiple linear regression was used to obtain equations with a high correlation between the given constituent and the spectral responses of several NIR absorptions. Calibrations were evaluated by using the equations to predict moisture, organic matter and total nitrogen for the samples that were not used in the calibration procedure.



(A) Sample in (B) Sample discharge after measurement (C) Print out

Figure 2. Operating procedure for the field soil analyser.

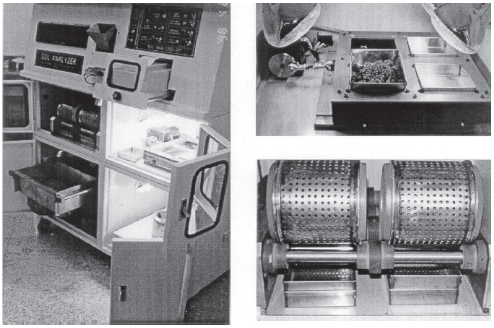


Figure 3. Operating procedure for preparation of field soil sample.

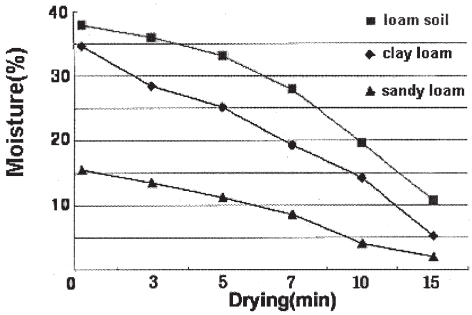


Figure 4. Change in soil moisture under the field soil preparation.

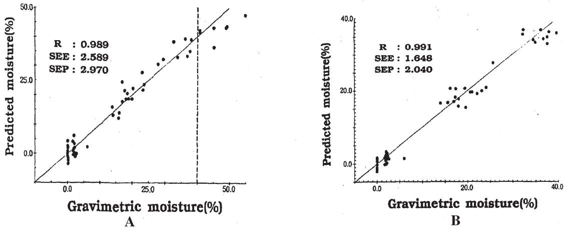


Figure 5. Gravimetric moisture vs NIR predicted moisture of the soil samples.

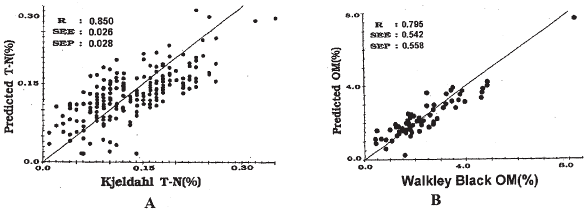


Figure 6. The predicted value of total nitrogen and organic matter by NIR reflectance method and the measured value by Kjeldahl (A) and Walkley–Black (B) method for air-dried soils.

The relationships between gravimetric and NIR-predicted moisture of the soil samples are shown in Figure 5. The response for soil moisture was quite linear up to 40% of gravimetric moisture content and above 40% the response slightly levelled off when soil moisture reached saturated or over-saturated condition(A). This trend was similar to the results of the portable soil moisture meter (Kano *et. al.*[7]). Another correlation between gravimetric and NIR-predicted soil moisture for the soil samples of less than 40%, showed better correlation as shown in B of Figure 5. Soil moisture data predicted by the NIR reflectance method were used to compensate the dry mass of soil for moistened field soil samples.

Figure 6 shows the predicted value of total nitrogen and organic matter by NIR reflectance method and the measured value by Kjeldahl(A) and Walkley–Black(B) method for air dried soils. Total nitrogen and organic matter showed that most of the points fell in the vicinity of the 1 : 1 line with a few out-

Table 1. Comparison of prediction accuracy between closed cup and flow type NIR cell in the measurement of soil properties.

Soil properties	Cup type	*R*	*SEE* (%)	*SEP* (%)	Range (%)	Selected bands(nm)
Moisture	Closed cup	0.888	0.634	0.658	0.200–9.060	1982, 2100, 2139, 2208, 2310
	Flow (air dry)	0.916	0.626	0.618	0.450–9.990	1445,1778,1982, 2100, 2139, 2180, 2208,2230,2310
	Flow(field soil)	0.885	2.206	2.420	0.600–19.24	1680,1722,1759,1778,1982, 2230, 2345
T-N	Closed cup	0.850	0.026	0.028	0.044–0.275	1680,1734,1818,2139,2190, 2310
	Flow(air dry)	0.825	0.027	0.028	0.018–0.275	1445,1680,1722,1818,2100, 2139, 2208,2230,2310
	Flow (field soil)	0.774	0.031	0.031	0.044–0.265	1445,1680,1734,1818,1940, 2139
OM	Closed cup	0.795	0.542	0.558	0.360–4.645	1445,1680,1722,1759,2336
	Flow (air dry)	0.789	0.546	0.549	0.325–4.505	1445,1680,1734,1818,1982, 2180, 2270,2345
	Flow (field soil)	0.799	0.426	0.439	0.410–3.475	1445,1680,1734,1778,2230, 2345

R: Multiple correlation coefficient
SEE: Standard error of estimate
SEP: Standard error of prediction
No. of soil samples for closed cup : Cal(242), Pre(158)
No. of samples for Flow(air dry) : Cal(242), Pre(158)
No. of samples for Flow(Field soil) : Cal(106), Pre(68)

liers and this means that diffuse reflectance can be used to estimate total nitrogen and organic matter in soils.

Bowers and Hanks[8] observed the particle size effect on reflectance. Wetzel[9] explained the influence of particle size and compacting pressure of the samples and the use of logarithmic reflectance terms to accommodate the scattering effect as part of the calibration.

Table 1 shows the result of prediction accuracy of the soil properties between closed cup and flow-type NIR cells. In the NIR analysis an orientation of particle was important in obtaining reproducible NIR reflectance which allows the interpretation of soil components. Increasing the measuring bands was believed to increase estimation accuracy of soil properties by obtaining better mean diffuse reflection. A recently developed flow type cell gave reproducible reflection for the soil properties and satisfied the required conditions for NIR measuring,. (such as even orientation or regimentation of soil particles, durability of spectra measuring window and increased measuring area for the field soil). The wavelength of selected bands in the NIR analysis and the correlation with the soil properties did not show much difference between organic matter and total nitrogen. Table 1 shows the regression analysis of soil properties using NIR method between closed cup, flow-type cell and air-dry and field soil samples. Therefore, Table 1 explains the scope of the applicability of the flow-type cell for the NIR method with reasonable accuracy in the routine analysis of field soil samples. Further studies are required for using the NIR spectral technique in fertiliser analysis for other soil components in addition to nitrogen and organic matter.

Conclusions

Traditional wet analytical methods of soil properties take time and labour and lead to the discharge of harmful and pollutant wastes, which makes the method undesirable for field measurement. The overall objective of this research was to develop a new technique to measure some field soil properties that are rapid, accurate and objective in soil fertility assessments. The NIR instrument was composed of NIR filter wheel, input and output of soil samples, printer and sample preparation system for field soil samples. A total of 540 soil samples from fields subjected to different crops and soils over the various regions were used to obtain calibrations and validation estimating soil moisture, OM and T-N. Multiple linear regression analysis was used to develop a calibration from readings taken from the new NIR instrument, which was specially designed to obtain reproducible reflections of field soil samples. A new design of flow cell satisfied the required conditions for continuous NIR measuring of field soils. Field soil samples could be prepared for NIR measuring within 15 minutes of removal from the field. The results lead to the conclusion that NIR spectroscopy could be used routinely and rapidly as a method for quantitatively determining OM, moisture and T-N for the field soil samples. However the NIR technique actually requires many combinations of samples and data manipulations to obtain optimal predictions.

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