

Estimating soil properties using near infrared spectroscopy to assess amendments in intensive horticultural production

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Introduction

Over the past ten years, near infrared (NIR) spectroscopy has been successfully applied to the analysis of a wide range of agriculture products. Previous studies^{1,2} have shown the potential of this technology for soil analysis, estimating a number of parameters with a single scan. The main advantages of NIR applications in soils are the speed of response, which enables an increase in the number of samples analysed for defining a particular soil and the instantaneous production of recommendations for fertilisation and soil amendment. A further advantage of this technique is that it obviates the need for chemical reagents and is, therefore, environmentally safe. The measurement of soil organic carbon (C_{org}) and organic nitrogen (N_{org}) is essential to proper management of the organic amendments which are of major importance in intensive horticultural crops in Mediterranean regions. In a wide area of the Mediterranean, low organic carbon content poses a considerable limitation for horticultural use, since it may be associated with soil structure degradation. Fast routine analysis for C_{org} and N_{org} may be valuable in assessing the organic amendment rate. Traditional methods of measuring C_{org} and N_{org} are time-consuming and involve the use of dangerous reagents such as dichromate, Hg or Se. These problems could be minimised with the use of NIR spectroscopy.

Material and methods

Samples

This study analysed a set of 125 samples of representative greenhouse soils in southern Spain. Samples were selected in such a way as to encompass a wide range of agricultural and soil uses. Samples were taken from the surface horizon, processed (dried, milled and filtered through a 2 mm sieve) and analysed for organic carbon (C_{org} , by dichromate oxidation), total nitrogen (N_T , by salicylic thiosulphate modification of the Kjeldahl method according to Bremner³), inorganic nitrogen (nitrate

Table 1. Soil composition of analysed samples.

	<i>N</i>	Mean	Minimum	Maximum	<i>SD</i>
C : N ratio	108	4.94	0.65	16.86	2.856
C _{org}	117	0.371	0.05	1.37	0.260
EC	117	279	97.5	869	118.317
f _{HH}	125	0.982	0.947	0.993	0.008
HH	125	1.84	0.70	5.51	0.798
NH ₄ ⁺	115	27	13.5	38	4.320
NO ₃ ⁻ + NO ₂ ⁻	117	31	0.57	141	27.376
N _{org}	105	0.076	0.013	0.227	0.038
N _t	108	0.081	0.01	0.23	0.038
pH	117	8.48	7.69	9.07	0.229

f_{HH} is the factor of HH; organic nitrogen (N_{org}) was estimated as the difference between total (N_t) and inorganic (NO₃NO₂ + NH₄)

In % data for HH, C_{org}, N_t and N_{org}; in mg kg⁻¹ for NO₃⁻, NO₂⁻ and NH₄⁺; in μS cm⁻¹ for EC

and ammonium) following Mulvaney,⁴ hygroscopic humidity (HH), humidity factor (f_{HH} = 100-HH / 100) pH and electrolytic conductivity (EC) in a 1 : 1 extract. Soil characterisation was performed using ten analytical parameters, as shown in Table 1.

NIR hardware

A Foss-NIRSystems model 6500 scanning monochromator (NIRSystems Inc., Silver Spring, MD, USA) was used to measure reflectance spectra from 400 to 2498 nm at 2 nm intervals. Analysis was performed using a spinning module, which employs standard ring cells.

NIR software

All spectra were manipulated and processed and all calibrations were obtained using ISI software NIRS3 ver. 4.0 and WINISI ver. 1.50 (Infrasoft International, Port Matilda, PA, USA).

Results and discussion

Table 2 shows the calibration statistics for the different parameters used in the study. In general, there is a significant correlation between the value obtained by traditional methods and that obtained using NIR spectra for several properties relating to organic matter and moisture content, i.e. C_{org} and f_{HH}, respectively.

The high correlation between C_{org}, N_{org} and estimated values using NIR (1-VR values were 0.862 and 0.886, respectively) can be accounted for by modifications in the NIR spectra associated with absorbance of organic compounds in the NIR range. This would also account for N_t values, since most of the total N corresponds to organic N (N_{org}): in most cases, inorganic N (NO₃NO₂ + NH₄) accounted for less than 5% of N_t. These properties are important in evaluating the potential of Mediterranean agricultural soils, since organic matter is related to good physical properties and N_{org} represents forms not easily available for leaching, such as NO₃⁻, which is normally the main inorganic compound among N forms. Thus, the organic N pool represents the soil N reserve available to plants in the medium to long

Table 2. Calibration statistics for selected equations.

	<i>N</i>	Mean	<i>SD</i>	<i>SECV</i>	1- <i>VR</i>	Derivative	Region
C : N ratio	104	4.648	2.422	1.421	0.658	1,4,4,1	vis + NIR
C_{org}	113	0.359	0.240	0.089	0.862	1,10,10,1	vis + NIR
EC	113	268.826	100.618	67.837	0.548	1,4,4,1	NIR
f_{HH}	120	0.983	0.006	0.003	0.690	1,10,10,1	NIR
HH	120	1.791	0.657	0.365	0.690	2,5,5,1	vis + NIR
NH_4^+	108	26.824	3.532	3.245	0.169	2,10,10,1	vis + NIR
$NO_3^- + NO_2^-$	113	28.857	23.696	18.986	0.358	1,4,4,1	NIR
N_{org}	99	0.073	0.035	0.012	0.886	1,4,4,1	vis + NIR
N_t	102	0.079	0.036	0.012	0.897	2,10,10,1	vis + NIR
PH	115	8.492	0.218	0.161	0.451	0,0,1,1	vis + NIR

term. The information provided concerning the C : N ratio may also be of interest. Although the calibration statistics are not as good as those obtained for other properties relating to organic matter, the technique may be reasonably useful in providing an approximate value that enables us to establish the degree of decomposition of organic matter in soils (Table 2).

The good statistics obtained for f_{HH} calibrations may be related to the high absorbance of water in the NIR range and might even be improved by reducing the gap between wet chemistry and NIR analysis of soil samples. HH or f_{HH} calibrations may be of great value, since these parameters are highly correlated with soil clay content and could provide an estimation of clay content when used in a group of soils with uniform clay-fraction mineralogy. This might account for the good correlation between clay content and NIR estimated data previously reported by other authors.⁴

Salinization is a major agronomic problem in arid and semi-arid areas. Wide horticultural areas of southern Europe (for example, south-eastern Spain) are saline, due to unsuitable use of irrigation water and to the intrusion of seawater in underground water deposits. A fast method for determining soil salt content might also be of value in establishing reclamation procedures. Although there is no chemical reason for any correlation between salt content (measured as EC) and NIR spectra, a significant correlation was recorded between observed and estimated values. Cross-validation determination coefficients were not high (1-*VR* = 0.55), but this calibration would at least enable the division of samples into different classes, i.e. high, medium and low saline soils.⁵ Although the standard error of cross-validation was relatively high, there are reasons to consider the technique as viable not only for the implementation of a classification model but also for the development of a preliminary method to assess the EC of soils in the 1 : 1 extract. This can be explained in terms of the effect of texture type on the fraction of applied water that is lost by drainage. A sandy soil has less water retention capacity and thus a higher drainage fraction than a clay soil for the same irrigation rate and the same crop water consumption, giving rise to lower salt accumulation in the soil matrix.

Conclusions

NIR affords a valuable method for estimating organic carbon, organic nitrogen, total nitrogen and hygroscopic humidity in soils. Organic carbon and nitrogen data are of great value when deciding on

organic amendments. Hygroscopic humidity is related to the textural class of the soil (clay content) and indicates the utility of the method for determining soil texture. Saline classes might also be established on the basis of NIR data.

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