A system for on-line measurement of key soil properties

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Abstract: This paper reports on on-line measurement of total nitrogen (TN), organic carbon (OC), moisture content (MC) and bulk density (BD) which was carried out in three European farms. The measurement system consists of a multiple sensor platform, which includes a mobile, fibre-type, visible and near infrared (vis-NIR) spectrophotometer, a draught (D) and a depth (d) sensor. The prediction models developed were tested in three fields in Denmark, Czech Republic and UK. Results revealed that the measurement accuracy was very good for TN (RPD = 2.33 - 2.38), very good/excellent for OC (RPD = 2.31 - 2.52) and excellent for MC (RPD = 3.16 - 3.25). A reasonably good correlation between the measured and on-line predicted BD (R^2 = 0.56 – 0.73) was obtained. The on-line measured maps were similar to those developed with traditional laboratory method of soil analysis.

Keywords: On-line measurement, sensor fusion platform, soil properties.

1. Introduction

Proximal soil sensing becomes one of the main requirements for successful implementation of precision agriculture. Among others, vis-NIR on-line sensors are characterised to be fast, robust, cost effective and environment friendly soil spatial variability detecting techniques. Among few vis-NIR on-line soil sensors available today, the system of Mouazen (2006) is a sensor fusion platform that enables measurement of several soil properties with the vis-NIR spectroscopy in addition to data fusion algorithm for the measurement of soil BD (Mouazen and Ramon, 2006). This paper aims at reporting on automatic data collection of multiple soil properties at farm scale using a sensor fusion platform (Mouazen, 2006) in three fields across three European farms.

2. Material and methods

The on-line measurement system designed and developed by Mouazen (2006) was used. An AgroSpec mobile, fibre type, vis-NIR spectrophotometer (Tec5 Technology for Spectroscopy, Germany) with a measurement range of 305-2200 nm was used to measure soil spectra in reflectance mode. The spectrometer was IP 64 protected for harsh working environments. A shear beam load cell (9 tonne capacity) for the measurement of D and draw wire linear sensor (connected to a depth wheel) for the measurement of subsoiler d were used. A single A DGPS (EZ-Guide 250, Trimble, USA) was used to record the position of the on-line measurements with sub-meter accuracy. A Panasonic semi-rugged laptop was used for data logging and communication. The spectrometer system, laptop and

DGPS were powered by the tractor battery. A total of 3 fields were measured in three farms in Czech Republic, Denmark and the UK in summer 2010. In each field, blocks of 150 m by 150 m, covering about 2 ha of land were measured. About 2 or 3 soil samples were collected from each measurement line with 28 to 48 soil samples collected from each field.

Soil chemical analyses and optical measurements were carried at Cranfield University. Soil OC and TN were measured by a TrusSpecCNS spectrometer (LECO Corporation, St. Joseph, MI, USA) using the Dumas combustion method. Soil MC was determined by oven drying of soil at 105 ºC for 24 h. Having MC measured, BD was calculated for all samples.

Each soil sample was dumped into a glass container and mixed well. Big stones and plant residue were excluded. Then each soil sample was placed into three Petri dishes, which were 2 cm in depth and 2 cm in diameter. The soil in the Petri dish was shaken and pressed gently before levelling with a spatula. The soil samples were scanned with the same AgroSpec spectrophotometer used for on-line measurement. A 100 % white reference was used before scanning. A total of 10 scans were collected from each cup, and these were averaged in one spectrum.

Soil spectra were first reduced to 371 - 2150 nm to eliminate the noise at both edges of each spectrum. Spectra were further reduced by averaging three successive points in the vis range, and 10 points in the NIR range. The Savitzky-Golay smoothing, maximum normalisation and first derivation were successively implemented using Unscrambler 7.8 software (Camo Inc.; Oslo, Norway). The pre-treated spectra and the laboratory chemical measurement values were used to develop calibration models for OC, TN and MC.

General calibration models developed previously for TN, OC and MC, using 480 soil samples collected from 4 farms across 4 European countries were used in this study. Out of 188 samples collected from the three fields in Europe, 63 samples were randomly selected for the calibration and the remaining 125 samples were used as independent validate set. However, the range of variation of each property for both the calibration and validation sets was almost identical. The calibration samples were spiked into the original calibration set of the general calibration models developed for European soils. The calibration spectra were subjected to a partial least squares regression (PLSR) with the leave-one-out cross validation using the Unscrambler 7.8 software.

A model (Eqn. 1) to predict BD based on measured D, d and MC was developed by Mouazen et al. (2009), which is valid for sand, loam, silt loam and silt loam/silt soils. Equation (1) was used to predict BD in this study.

$$BD = \left(\sqrt[3]{\frac{D + 21.36\,MC - 73.9313\,d^2}{1.6734}}\right) \times (1.240 - 0.592MC - 0.000792clay) \qquad (1)$$

Where *D* is subsoiler draught [kN], *MC* is gravimetric moisture content [kg kg^{-1}], *d* is cutting depth [m] and *BD* is bulk density [Mg m^{-3}] and clay is expressed in %.

3. Results and discussion

The measurement campaign proved that the sensor fusion platform can provide simultaneous measurement of several soil properties. This platform enabled the collection of around 3000 data points from each field with an average of around 2 points per meter travel distance. The chemical analysis values of the manually collected samples were compared with the on-line predicted concentration values using vis-NIR spectra collected in the same positions. Table 1 summarises the results of general model accuracy and on-line validation results. The general calibration models refer to those developed originally using 480 samples with the spiked 65 samples from the three fields measured in this study. The validation of the on-line measured data was based on 125 samples collected from the three fields for validation. Examining the ratio of prediction deviation (RPD), which is the standard deviation (SD) divided by root mean square error of prediction (RMSEP), revealed that RPD values were above 2 for all soil properties in all fields. An RPD value between 1.5 and 2 and between 2.0 and 2.5 indicates good and very good quantitative model predictions, respectively. Values above 2.5 indicate excellent prediction results (Viscarra Rossel et al., 2006). Adopting this classification system of the prediction accuracy reveals that prediction performance for TN, OC and MC is very good to excellent performance (Table 1).

		OC		**TN**		**MC**		**BD**
Validation		RMSEP %	RPD	RMSEP %	RPD	RMSEP %	RPD	R^2
	CZ field	0.07	2.33	0.007	2.52	0.72	3.16	0.56
	DK field	0.05	2.38	0.004	2.47	0.37	3.25	0.72
	UK field	0.09	2.38	0.008	2.31	0.59	3.25	0.73
Calibration models		0.104	2.89	0.009	2.93	1.05	4.32	-

Table 1. Calibration and field validation results of the on-line measurement in 3 fields

The prediction of BD with the on-line sensor fusion platform provided reasonably good accuracy (Table 1). Although the model was developed for fields in Belgium (Mouazen et al., 2009), the R^2 values shown in Table 1 confirm that the model (Eqn 1) can be expanded to other fields across the European countries considered in this study, as long as the same soil textures to those used to build the original calibration model (Eqn. 1) are used.

Using an ArcGIS 10 (ESRI, USA) mapping software, maps for the selected soil properties were developed. The inverse distance weighting (IDW) method was used for the spatial interpolation. In order to allow for useful comparisons between reference and on-line measured maps, the same number of classes (seven classes) was considered for all maps. Figure 1 compares between maps of on-line and laboratory measured TN in the UK field, taken as an example. The same number of samples (18 validation samples) was used to develop both maps. A comparison between maps of measured and predicted TN shows large similarity, which was also achieved for OC, MC and BD (data is not shown).

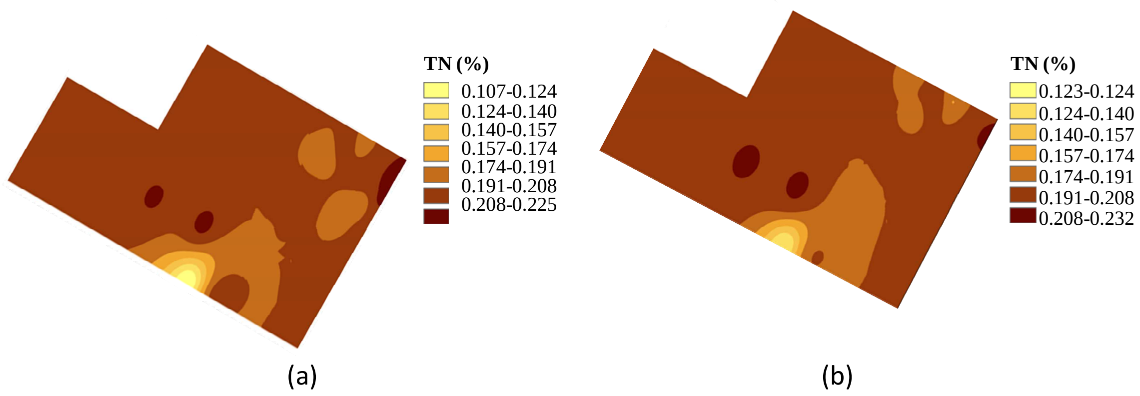

Figure 1. Comparison between laboratory (a) and on-line (b) measured total nitrogen (TN) in the UK field, using 18 validation samples

4. Conclusions

This paper reports on the performance of on-line sensor fusion platform for the measurement of multiple soil properties at farm scale in Europe. Results reported in this study allow the following conclusions to be drawn:

1- The on-line sensor fusion platform enabled the collection of large data points (about 3000 points per field).

3- The accuracy of on-line measured OC, TN and MC was classified as very good to excellent prediction performance. Reasonable good measurement of BD was reported.

References:

Mouazen, A. M., De Baerdemaeker, J., Ramon, H. (2005). Towards development of on-line soil moisture content sensor using a fibre-type NIR spectrophotometer. *Soil & Tillage Research*, 80, 171-183.

Mouazen, A. M. (2006). Soil Survey Device. International publication published under the patent cooperation treaty (PCT). World Intellectual Property Organization, International Bureau. International Publication Number: WO2006/015463; PCT/BE2005/000129; IPC: G01N21/00; G01N21/00.

Mouazen, A. M., Ramon, H. (2006). Development of on-line measurement system of bulk density based on on-line measured draught, depth and soil moisture content. *Soil & Tillage Research*, 86, 218-229.

Mouazen, A. M.; Ramon, H., (2009). Expanding implementation of an on-line measurement system of topsoil compaction in loamy sand, loam, silt loam and silt soils. *Soil & Tillage Research*, 103, 98-104.

Viscarra Rossel, R. V., McGlyn R. N., McBratney, A. B. (2006). Determining the composition of mineral-organic mixes using UV–vis–NIR diffuse reflectance spectroscopy. *Geoderma*, 146, 403-411.