On-the-go measurement of key soil properties in European farms

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Abstract

This work reports on the results of on-the-go measurement of total nitrogen (TN), organic carbon (OC) and moisture content (MC), which was carried out in summer 2010 in three European farms. A mobile, fibre-type, visible and near infrared (vis-NIR) spectrophotometer (AgroSpec, Tec5, Germany), with spectral range of 350 - 2200 nm, coupled to the on-the-go measurement system of soil properties was used. Results proved the on-the-go measurement system to be quick, stable and robust. Results revealed that the measurement accuracy was very good/excellent for TN (RPD = 2.18 - 2.52), very good for OC (RPD = 2.28 - 2.38) and excellent for MC (RPD = 3.06 - 3.96).

Introduction

One of the strategies to minimize the production costs through enhanced productivity and economic profits while simultaneously conserving the environment is precision agriculture (PA). Conventional description of soil spatial variability usually involves manual soil sampling, sample pre-treatment, laboratory chemical and physical analyses and mapping. This procedure is very expensive, time consuming and provides very few measurement points. Therefore, the development of a fast, robust, cost effective and environment friendly soil spatial variability detecting method is a preliminary task for the implementation of precision agriculture. To date there is only few soil on-the-go Vis-NIR systems (Shibusawa et al. 2001; Mouazen et al. 2005; Christy et al. 2008) available and the measurement accuracy is still far from satisfactory to allow a useful use of on-the-go collected data for site specific application of different inputs.
This paper aims at reporting on progress made on automatic data collection of soil properties at farm scale using a Vis-NIR on-the-go measurement system (Mouazen, 2006) in fields in three European farms.

Material and methods

Experimental fields and soil samples
A total of 5 fields were measured in European Farms in summer 2010, namely, Mespol Medlov, A.S. farm in Czech Republic, Bramstrup Estate farm in Denmark and Silsoe farm in UK. In each field, blocks of 150 m by 150 m, covering 2 ha of land were measured. Each measured line was 150 m long with 10 m intervals between adjacent transects. The texture analysis results are based on a mixed sample from each field, which was subjected to wet sieving and hydrometer test to determine the particle size distribution. Texture was determined according to the United State Department of Agriculture (USDA) classification system. A total of 188 soil samples were collected from 5 fields in European farms from the bottom of trench at about 15 cm depth during the on-the-go field measurements (Table 1). These samples were used for the model calibration and validation purpose. About 2 or 3 soil samples were collected from each measurement line with 28 to 48 soil samples collected from each field (Table1). The sample position was carefully recorded using a DGPS (EZ-Guide 250, Trimble, USA) in order to validate the accuracy of the on-the-go measurement system. Around 200 g of soil was collected from each sample and was

kept frozen (-18 ⁰C) until analyses. Soil chemical analyses and optical measurements were carried at Cranfield University.

Chemical analysis
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 the soil samples at 105 ⁰C for 24 h.

Optical measurement
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. A smooth soil surface ensures maximum light reflection and high signal to noise ratio. The soil samples were scanned by an AgroSpec portable spectrophotometer with a wavelength range of 305 nm to 2200 nm and a sampling resolution of 3 nm (Tec5, Germany). 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.

Sample pre-treatment and development of calibration models
The 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.
A general calibration model developed previously for European soils was used in this study. Out of 188 samples collected from the five fields in European (Table 1), 63 samples were used for the calibration and the remaining 125 samples were used as independent validate set. The calibration samples were spiked into the original calibration set of the general calibration model 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. The number of latent variables for a model was determined by examining a plot of the leave-one-out cross-validation residual variance against the number of latent variables obtained from the PLSR. The latent variable of the first minimum value of residual variance was selected. Outliers were detected using the residual sample variance plot after PLSR. Samples located far from the zero line of residual variance were considered outliers and excluded from the cross-validation sample set.

On-the-go measurement system
The on-the-go measurement system designed and developed by Mouazen (2006) was used. Detailed information about this system can be found in Mouazen et al. (2005). 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 DGPS (EZ-Guide 250, Trimble, USA) was used to record the position of on-the-go 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.

Results and discussion

The measurement campaign proved the on-the-go measurement system to be quick, stable and robust. The on-the-go measurement system enabled the collection of around 3000 data points from each field with an average of around 2 points per meter travel distance. The same spectra pre-treatment was used for the on-the-go collected spectra as that used for calibration model development. The on-the-go collected spectra after spectra pre-treatment were used to predict MC, TN, and OC using the calibration models developed in advance The chemical analysis values of the manually collected samples were compared with the on-the-go predicted concentration values in the same positions. Table 2 summarises the results of model accuracy and on-the-go validation results. 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 almost 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 the prediction performance for TN, OC and MC is very good to excellent performance (Table 2).

Table2. Calibration and field validation results of the on-the-go measurement in 5 fields in European farms

		OC			TN			MC		
Validation		RMSEP	RPD	SD	RMSEP	RPD	SD	RMSEP	RPD	SD
	CZ	0.07	2.33	0.164	0.007	2.52	0.019	0.72	3.16	2.34
	DK(1)	0.05	2.38	0.12	0.004	2.47	0.012	0.37	3.25	1.25
	DK(2)	0.1	2.28	0.23	0.008	2.35	0.021	0.32	3.96	1.28
	UK(1)	0.09	2.29	0.22	0.009	2.18	0.02	0.68	3.06	2.09
	UK(2)	0.09	2.38	0.23	0.008	2.31	0.02	0.59	3.25	1.92
Model		0.104	2.89	0.3	0.009	2.93	0.026	1.05	4.32	4.53

Using ArcGIS 10 (ESRI, USA) mapping software, maps for the selected soil properties were developed. Figure 1 compares maps between on-the-go and laboratory measured MC, TN and OC, taken in field2 in the Danish farm as an example. The inverse distance weighting (IDW) method was used for the spatial interpolation. In order to allow for useful comparisons between reference and on-the-go measured maps, the same number of classes (seven classes) was considered for all maps. A comparison between maps of measured and predicted soil properties investigated shows large similar. The determination coefficient R^2 between Laboratory measured and on-the-go predicted soil properties were 0.78, 0.75, 0.84 for TN, OC and MC respectively.
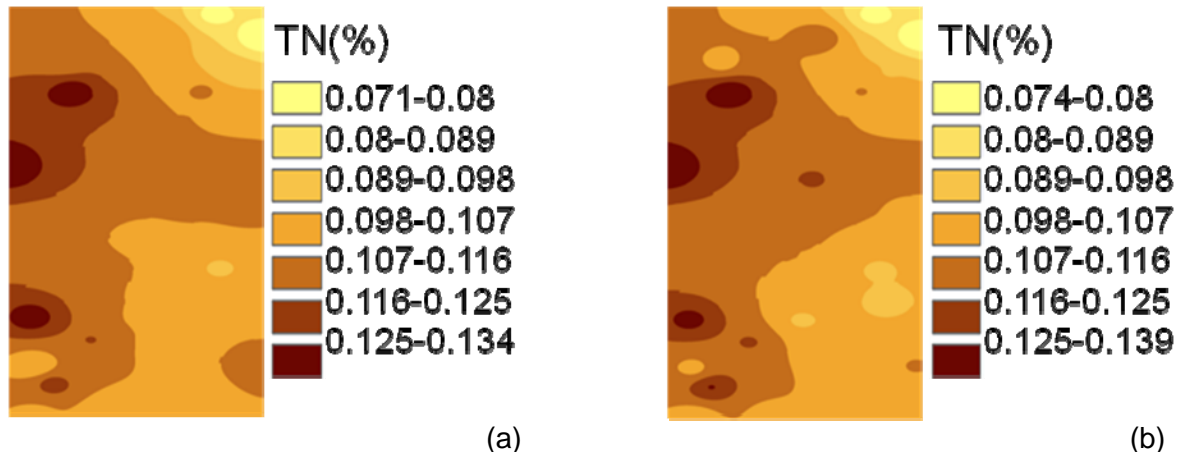
Figure1. Comparison between laboratory (a) and on-the-go (b) measured total nitrogen (TN) maps in field 2 in the Danish farm

Conclusions

This paper reports on the performance of an automatic data collection of soil properties at farm scale using a Vis-NIR on-the-go measurement system. The results reported in this study allow the following conclusions to be drawn:

1- The on-the-go measurement system is robust that enables collection of data on several soil properties, simultaneously.

2- This system enables the collection of large data points per field (around 3000 readings). The large number of points will open new possibilities for the management of soil-water-plant system, which was not achievable so far.

3- The accuracy of on-the-go measured OC, TN and MC was classified as very good to excellent prediction performance with RPD values range between 2.18 and 3.96.

Further work is being undertaken to improve the prediction accuracy of the system, which should account for the effect of MC and texture on the result obtained.

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