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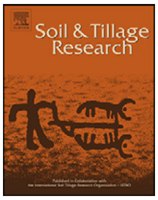

Effect of spiking strategy and ratio on calibration of on-line visible and near infrared soil sensor for measurement in European farms

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ABSTRACT

A previously developed on-line visible and near infrared (vis–NIR) spectroscopy-based soil measurement system was implemented for the measurement of soil organic carbon (OC), total nitrogen (TN) and moisture content (MC) in three fields at three European farms. The on-line sensor platform was coupled with a mobile, fibre type, vis–NIR spectrophotometer (AgroSpec from tec5 Technology for Spectroscopy, Germany), with a measurement range of 305–2200 nm, to acquire soil spectra in diffuse reflectance mode. A general calibration set of 425 soil samples, spiked with different number of spectra from the three validation fields were used to establish calibration models for the studied soil properties using partial least squares (PLS) regression analysis. Different spiking strategies and spiking ratios were investigated and results revealed that the best prediction accuracy was obtained after 20% spiking ratio with samples whose spectra were measured in the laboratory. Evaluated by the values of residual prediction deviation (RPD), which is the ratio of standard deviation to root mean square error of prediction (RMSEP), the accuracy of the on-line measurement was classified as excellent for MC (RPD = 2.76–3.96), good to very good for OC (RPD = 1.88–2.38) and good to excellent for TN (RPD = 1.96–2.52). Reducing the number of samples used for spiking resulted in deteriorating the prediction accuracy, although 1–2 samples per ha were found to provide good predictions. There was a distinguishable spatial similarity between the on-line and laboratory measured maps for all studied properties, although the full-data point maps provided more detailed information about the spatial variation. This confirms that the on-line vis–NIR soil sensor provides correct and detailed information about soil OC, TN and MC at high sampling resolutions.

1. Introduction

One of the strategies used in precision agriculture (PA) is to minimize the production costs through enhanced efficiency, which can increase profits and conserve the environment. It is proved that PA is an environmental friendly strategy, in which farmers can vary the use of inputs to respond to variable soil and crop conditions within a field (Srinivasan, 2006). Conventional determination of soil spatial variability usually involves manual soil sampling, sample pre-treatment, laboratory reference analyses and mapping. This procedure is very expensive, time consuming and provides scattered measurement points. Therefore, the development of a fast, robust, cost effective and environmental friendly detecting method of the soil spatial variability is a preliminary task for the implementation of PA.

Visible and near infrared (vis–NIR) spectroscopy became recently a proven technique for fast, cost effective and high resolution data collection on soil properties (Viscarra Rossel and McBratney, 1998; Shepherd and Walsh, 2002; Mouazen et al., 2010; Stenberg et al., 2010). In comparison to non-mobile analysis, there is considerably less literature available about on-line vis–NIR spectroscopy analysis of soil properties. Generally, both the laboratory and in situ non-mobile vis–NIR methods provide better accuracy than the on-line method (Kuang et al., 2012). This might be attributed to other factors influencing the latter method only, such as noise associated with tractor vibration, sensor-to-soil distance variation (Mouazen et al., 2009), stones and plant debris and difficulties of matching the position of soil samples collected for validation with corresponding spectra collected from the same position (Mouazen et al., 2007). A review on the current status of on-line vis–NIR measurement systems confirms that only three systems are available today (Shibusawa et al., 2001; Mouazen et al., 2005; Christy, 2008). The beginning of these systems dates back to 1991, when Shonk et al. (1991) developed a system to measure soil organic matter (SOM) and moisture content (MC), which utilised a single wavelength (660 nm) of light, reporting a determination coefficient (R^2) of 0.83 for SOM. Shibusawa et al. (2001) developed an on-line vis–NIR (400–1700 nm) sensor to

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predict organic carbon (OC), MC, pH and NO_3-N. Although this system is highly technically instrumented, it is rather expensive. Christy (2008) developed a prototype soil reflectance mapping unit equipped with a vis–NIR spectrophotometer, which is commercially available in the market today. The sapphire glass of the optical probe makes direct contact with soil and stones. They have reported that OC can be successfully measured with a root mean square error of prediction (RMSEP) of 3.0 g kg^{-1} in a high OC variability area (standard deviation = 5.1 g kg^{-1} and range = 3.0–26.3 g kg^{-1}). A simpler design to the one of Shibusawa et al. (2001) without sapphire window optical configuration was developed by Mouazen (2006). So far, the system provided variable degrees of success for the measurement of MC, total nitrogen (TN), total carbon (TC), pH and available P in different soils in Belgium and northern France (Mouazen et al., 2005, 2007, 2009). More recently, employing the on-line system developed by Christy (2008), Bricklemyer et al. (2010) reported on the on-line measurement for soil OC and clay content. Although authors did not report quantitative estimation of accuracy for OC, they calculated a standard error of prediction (SEP) of 3.4 g kg^{-1} and a ratio of prediction deviation (RPD) value of 1.4 for clay content. Using the same system, coupled with topography and aerial photograph data, Munoz and Kravchenko (2011) reported low to moderate accuracy of soil OC measurement with R^2 and RMSEP ranged from 0.44 to 0.66 and from 1.41 to 1.51 g kg^{-1}, respectively. Applying this vis–NIR system in combination with electrical conductivity (EC) and temperature sensors in a Danish field, Knadel et al. (2011) obtained moderate prediction accuracy (RMSEP = 59.4 g kg^{-1} and RPD = 2.3) for soil OC. However, the vis–NIR sensor alone only achieved a relatively low accuracy (RMSEP = 59.8 g kg^{-1}, RPD = 1.9). This brief review reveals that the existing on-line sensors do not provide sufficient accuracy and stability to recommend them for site specific application of different inputs. The variable degrees of performance of these on-line sensors might be attributed to the fluctuation in model performance, with the majority of them established for field-scale analysis (e.g. Shibusawa et al., 2001; Mouazen et al., 2005; Christy, 2008; Munoz and Kravchenko, 2011), or for regional- and country-scale analyses (e.g. Mouazen et al., 2007, 2009). Some studies suggested spiking local samples into the general calibration models can improve prediction accuracy under laboratory or in situ measurement conditions (Shepherd and Walsh, 2002; Janik et al., 2007; Waiser et al., 2007; Sankey et al., 2008; Viscarra Rossel et al., 2008; Minasny et al., 2009; Wetterlind and Stenberg, 2010; Guerrero et al., 2010). As yet, no general calibration procedure that included spiking strategy have been reported for establishing calibration models of on-line sensors, which has led to stable performance of on-line sensors, at the lowest model production cost.

This paper aims at reporting on a methodology for the calibration of a vis–NIR on-line measurement system (Mouazen, 2006), including spiking concept for automatic data collection of OC, TN and MC at farm scale in three European farms.

2. Materials and methods

2.1. Soil samples and laboratory analyses

A total of 425 soil samples were used as a general dataset to be used to establish calibration models for the measurement of OC, TN and MC in European soils (Table 1). They were collected from four different farms in Europe, namely Mespol Medlov, A.S. (Czech Republic, http://farmsubsidy.org/CZ), Wimex (Germany, http://www.wimex-online.de), Bramstrup Estate (Denmark, http://www.bramstrup.dk) and Silsoe Farm (The UK). Bulked samples from 16 cores were collected from the upper soil layer (0–30 cm) in the spring of 2008 (Czech Republic and Germany), spring of 2009 (Denmark) and summer of 2009 (UK) and covered diverse soil conditions (Kuang and Mouazen, 2011). A total of 128, 97 and 48 soil samples were, respectively, collected from seven fields in Mespol Medlov, A.S. farm, six fields in Bramstrup Estate farm and two fields in Silsoe farm. Further 152 soil samples were collected from four sub-areas belong to Wimex farm, with four samples from two fields at Reppichau, 50 samples from nine fields at RAG, 20 samples from ten fields at Aken and 54 samples from fifteen fields at the Wulfen farm.

Table 1
Soil samples used to establish general calibration models without spiking for organic carbon (OC), total nitrogen (TN) and moisture content (MC). Samples were collected from Mespol Medlov, A.S. farm in Czech Republic, Wimex farm in Germany, Bramstrup Estate farm in Denmark and Silsoe farm in the UK.

Country	Number of samples	Nr of fields	Sampling time
Czech Republic	128	7	2008
Germany	152	37	2008
Denmark	97	6	2009
UK	48	3	2009

Apart from these soil samples, another 113 soil samples were collected from three selected fields, where on-line measurement was carried out, namely, in Mespol Medlov, Bramstrump Estate and Silsoe farms (Table 2). These were considered as validation fields. They were collected during the on-line measurement from the bottom of trenches at a depth of 15 cm. The validation field in Silsoe farm is 500 m away from the nearest fields, where samples used for general data set were collected, whereas the validation fields in Mespol Medlov and Bramstrump Estate farms are 2.5–3 km far from the nearest fields, respectively. A principal component analysis (PCA), performed on 425 samples of general calibration dataset and 113 validation data set shows clear separation between validation samples of each individual farm from the general dataset samples (Fig. 1).

Around 200 g of soil from each sample was kept deep frozen (−18 °C) until analysis. After careful mixing, half of each sample from Czech Republic, Germany and Denmark was sent to Leibniz Centre for Agricultural Landscape Research (ZALF) in Germany for soil chemical analyses for TN and OC and the second half was sent to Cranfield University for optical measurement and data analysis. Samples collected from the UK and 113 samples collected during the on-line measurement in 2010, were subjected to both optical and chemical measurement at Cranfield University. Sample statistics of laboratory reference measurements is summarised in Table 3 for the calibration and validation datasets.

2.2. On-line measurement

The on-line measurement system designed and developed by Mouazen (2006) was used (Fig. 2) to measure three fields in the three European farms. It consists of a subsoiler, which penetrates the soil to the required depth, making a trench, whose bottom is smoothened by the downwards forces acting on the subsoiler. The optical probe is housed in a steel lens holder. This is attached to the backside of the subsoiler chisel in order to acquire soil spectral reflectance data from the smooth bottom of the trench. The

Table 2
Information about the three fields in Mespol Medlov, A.S. farm in Czech Republic, Bramstrup Estate farm in Denmark and Silsoe farm in the UK, where on-line measurement took place in 2010.

Field	Area (ha)	Crop	Sample nr	Texture type	Sand (%)	Silt (%)	Clay (%)
Czech republic	2	Wheat	48	Silt clay loam	4.86	70.58	24.56
Denmark	2	Wheat	37	Sandy loam	68.57	21.96	9.48
UK	2	Wheat	28	Clay loam	40.11	27.38	32.51