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Increased sample point density in farm soil mapping by local calibration of visible and near infrared prediction models

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ABSTRACT

For use as decision support for variable rate applications in precision agriculture, the commonly used sample point density of one sample per hectare is often not enough. However, increasing the sampling density using laboratory analyses is too expensive for farmers to implement. It is therefore important to find methods for rationalisation. To this end, farm-scale visible and near infrared reflection (vis–NIR) calibrations were established on two farms in southern Sweden (Hacksta and Sjöstorp) for soil texture, soil organic matter, total N, pH and plant-available P, K and Mg. By keeping the laboratory analyses to a minimum to be used for vis–NIR calibrations and only collecting vis–NIR spectra from the vast majority of the samples, the sampling density could be increased without significantly increasing the cost. In this study 25 samples were used in the calibrations. Six different calibration sample selection methods were compared, selected from three different datasets originating from a larger context aiming at covering soil variations. Using only 25 calibration samples resulted in good predictions for clay at both farms, r^2 values of 0.81 and 0.89 and RMSEP values of 3.6 and 3.9%. Sand, soil organic matter and total nitrogen were well predicted at Hacksta ($r^2 = 0.87$, 0.90 and 0.89 and RMSEP = 3.0, 0.28 and 0.018% respectively) but 25 samples proved to be too few at the geologically divided farm Sjöstorp. For predicting pH and plant-available P, K and Mg, more than 25 calibration samples were needed at both farms, although with 75% of all reference samples (92 and 94 at Hacksta and Sjöstorp respectively) in the calibration these parameters also showed potential for building useful NIR calibrations (RPD values between 2.3 and 2.8 except for the predictions for pH at one of the farms resulting in an RPD value of 1.6). However, predictions for silt content were less reliable and the small number of calibration samples was not the limiting factor in this case. The promising results are encouraging for further development of cost-effective high resolution farm soil maps using NIR spectroscopy.

1. Introduction

Farm soil mapping is the main source of information to farmers on the plant nutrient status of their soil and provides basic data for decision-making on e.g. fertilisation and liming. In contrast to the more stable parameters such as soil texture and to some extent soil organic matter (SOM) content, the amount of plant nutrients changes due to farming practices and thus farm soil maps need to be renewed regularly. The conventional soil sampling density in Sweden and many other countries is one sample per hectare. Soil texture and SOM content are often analysed on every second or third sample or not at all. However, soil properties can vary extensively within fields (e.g. Delin and Söderström, 2003) and for reliable decision support in precision agriculture for variable rate applications, this density would not be sufficient. Soil sampling and conventional laboratory analyses are time-consuming and costly. Increasing the sampling density would simultaneously increase the cost and would thus become too expensive for farmers to implement. It is therefore important to find methods for rationalisation.

Near infrared reflectance (NIR) spectroscopy is frequently put forward as such a technique (van Vuuren et al., 2006; Viscarra Rossel et al., 2006; Wetterlind et al., 2008b; Zornoza et al., 2008). NIR is a fast non-destructive technique that only requires limited sample preparation. In addition, several properties can be determined from a single scan. A number of studies have shown the potential of NIR to predict soil texture (Chang et al., 2001; Shepherd and Walsh, 2002; Islam et al., 2003; Moron and Cozzolino, 2003; Viscarra Rossel et al., 2006) and SOM content (Dalal and Henry, 1986; Morra et al., 1991; Sudduth and Hummel, 1991; Reeves et al., 1999; Chang et al., 2001; Udelhoven et al., 2003; Wetterlind et al., 2008a). Particle size and SOM content could be considered primary properties in relation to NIR, since NIR spectra are directly influenced by combinations and overtones of fundamental vibrations for organic functional groups, particle size and surface properties (Ben-Dor and Banin, 1995b; Chang et al., 2001). Other farm soil mapping properties such as plant nutrients and pH may in some situations be predicted with NIR spectroscopy due to

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correlations to more spectrally active properties (Ben-Dor and Banin, 1995a; Chang et al., 2001). Promising results have for example been reported for prediction of e.g. pH (Malley et al., 1999; Dunn et al., 2002; van Vuuren et al., 2006), various forms of phosphorus (Malley et al., 1999; Daniel et al., 2003; Bogrekci and Lee, 2005; Maleki et al., 2006), potassium (Chang et al., 2001; van Vuuren et al., 2006; Zornoza et al., 2008) and magnesium (Malley et al., 2000; Shepherd and Walsh, 2002; van Groenigen et al., 2003; Maleki et al., 2006).

In the majority of the field-scale NIR calibrations presented in earlier studies, a substantial amount of the soil samples have been used in the calibrations, resulting in laboratory analyses on more than one sample per ha (e.g. McCarty and Reeves, 2006; Viscarra Rossel et al., 2006; He et al., 2007). However, if the vast majority of the samples are measured for their NIR spectra only and the number of reference samples with laboratory analyses is kept to a minimum for NIR calibrations and prediction of those with NIR-data only, the sampling density can be increased without significantly increasing costs. Wetterlind et al. (2008b) presented promising results from such a strategy for clay and SOM content from one of the farms included in the present study. With few calibration samples, it is crucial to cover as much of the variation as possible. Wetterlind et al. (2008b) selected calibration samples from the two different sampling strategies according to their EC_a or reflectance values from a satellite image. Another possible way, as proposed by e.g. McCarty and Reeves (2006), is to select the most spectrally diverse samples for calibration. Stenberg et al. (1995) presented a method for selecting a small subset of samples while retaining a maximum of the original variation in important soil properties using principal component analysis of the NIR spectra.

The aims of this study were to: a) further investigate the feasibility of establishing farm-scale NIR calibration models for some of the most common farm soil mapping properties in Sweden (soil texture, SOM, total C, total nitrogen, pH and ammonium acetate lactate (AL)-extractable P, K and Mg) with only 25 calibration samples in order to increase sampling density without increasing the cost; b) compare the prediction power of six calibration sample sets selected from three different sampling selection strategies. The sampling selection strategies and the calibration sample selection methods were aiming at covering as much of the soil variation as possible within all samples and within the calibration samples. For comparison, a sampling strategy and calibration sampling selection method simply using a regular grid was included.

2. Materials and methods

2.1. Sites and experimental design

The farms studied were Hacksta (59°33′N, 17°02′E), about 70 km north-west of Stockholm, and Sjöstorp (55°41′N, 13°19′E), about 20 km north-east of Malmö (Fig. 1). Crop rotations at both farms were dominated by cereals, and no farmyard manure had been applied for many years. The studied area at Hacksta covered five adjacent fields with a total area of 97 ha. The soils on this farm are dominated by glacial and postglacial clay with elements of sandy till (Möller, 1985), and vary from loam to clay with only small topographical differences. At Sjöstorp, 10 fields covering an area of 78 ha were studied. A clear borderline between two different types of glacial till soil divides this farm into an 18 ha north-eastern part and a 60 ha south-western part. The former consists of sandy till, while the latter consists of clay till with elements of chalk, changing to glacial clay close to the borderline.

The soil samples in this study were taken according to three strategies for selecting soil sample locations to capture the spatial soil variation at the farm. The three datasets were sampled according to: a), EC_a values (EC), b) reflectance values from a satellite image (SAT) or c) for comparison, a regular grid (REG). The samples were collected at a density of approximately 1.5 samples per ha resulting in about

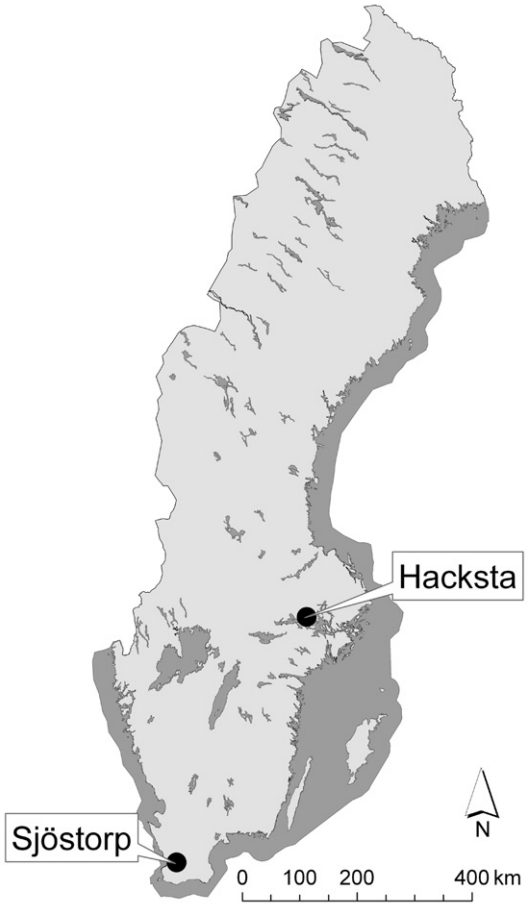

Fig. 1. The locations of the two farms.

130 samples each in the REG, EC and SAT strategies at Sjöstorp and about 150 samples each at Hacksta. The soil samples (0–20 cm depth) were taken in autumn 2005 at Hacksta and autumn 2006 at Sjöstorp. Twenty sub-samples within a radius of about 6 m were bulked to form a composite sample. The EC_a values were recorded in spring 2005 at Hacksta and in spring 2006 at Sjöstorp using EM38 (Geonics Ltd., Mississauga, Ontario, Canada). The measurements were carried out at intervals of about 10 m at Hacksta and 24 m at Sjöstorp along transects parallel to the tramlines. The satellite data used at Hacksta was the 1580–1750 nm band from a 10 m resolution SPOT 5 scene recorded on 21 March 2003. At Sjöstorp the 750–900 nm band from a 25 m resolution Landsat 7 scene recorded on 23 March 2003 was used. The satellite data were obtained from the Swedish Land Survey. The strategy for targeted sampling adopted here was a directed sampling that through an iterative procedure selects samples from an exhaustive data set (EC_a values or reflectance values from a satellite image in this case). The ultimate goal of that selection procedure was to be able to produce a map of the variable which should be as similar as possible to a map produced using all data in the exhaustive data set. An automated method was used, described by Olsson and Söderström (2003) that minimizes the differences between these maps. In addition, it fulfils some other criteria, such as fairly even spatial coverage of sites and sampling no closer than 15 m to field borders and 12 m to locations already selected. This procedure of stratified, directed sampling includes the following steps: creation of a map of the ancillary data, subdivision of the fields into 1.5 ha cells and an iterative process inserting sampling sites successively in order to reach the desired number of samples or sampling density.