Soil & Tillage Research 155 (2016) 471–477

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

On-line visible and near infrared spectroscopy for in-field phosphorous management

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ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 3 April 2015
Accepted 6 April 2015

Keywords:
On-line measurement
Soil phosphorous
Variable rate application
vis–NIR spectroscopy

ABSTRACT

Current methods of phosphorous (P) management based on conventional soil sampling of one sample per ha followed by laboratory analysis are tedious, time consuming, expensive and does not allow exploring spatial variation in P at a desired fine spatial scale. Visible and near infrared (vis–NIR) spectroscopy has proven to be a robust, quick and relatively cost effective tool to measure key soil properties with appreciable accuracy. This paper aims at utilising high spatial resolution P data generated with an on-line vis–NIR spectroscopy sensor for site specific management of P_2O_5 fertiliser for enhanced uniformity of P spatial distribution across the field, which is hoped to optimise and homogenise crop growth and yield. On-line measurement was carried out for three successive years of 2011, 2012 and 2013 after crop harvest in a 21 ha field in Duck end farm, Bedfordshire, the UK. Variable rate (VR) P was only applied in year 2 after crop harvest, where the field was divided into 4 P-index zones. Indexes 0 and 1 received 140 kg ha^{-1} and 70 kg ha^{-1} P_2O_5, respectively, whereas indexes 2 and 3 received no P_2O_5 fertiliser. The purpose of this VR P application was to attempt unifying the entire field to index 2, which is considered the optimal P level for cereal crops. Results showed that the on-line measurement accuracy of P was acceptable with coefficient of determination (R^2), root mean square error of prediction (RMSEP) and residual prediction deviation (RPD) of 0.60, 0.60 mg 100 g^{-1} and 1.5, respectively. However, accuracy was larger with soil samples scanned under laboratory non-mobile conditions with R^2, RMSEP and RPD of 0.75, 0.51 mg 100 g^{-1} and 1.8, respectively. The VR application of P_2O_5 after crop harvest in year 2 improved the uniformity of the spatial distribution of P, measured in year 3 with the on-line soil sensor. The number of zones of P-index was decreased from 4 indexes before P_2O_5 VR application to a uniform P index e.g. index 2. The coefficient of variation (CV) of P in the field was reduced from 26% in 2011, and 25% in 2012, to 16% in 2013. The on-line measured P map of year 3 showed significant improvement in the uniformity of P spatial distribution across the field, comparing to previous years. It was concluded that the on-line vis–NIR soil sensor is an effective tool to manage and minimise within field variation in P in arable crops. However, a further study is needed that should include more fields with different soil types in order to generalise the results achieved in the current work.

1. Introduction

Soil available phosphorous (P) is an essential element for crop roots, seeds and canopy development. Phosphorous deficiency is considered to be one of the major limitations of crop production particularly in low-input agriculture systems around the world (Raghothama, 2005). It is estimated that 5.7 billion hectares of land worldwide is deficient in P for achieving optimal crop production (Batjes, 1997). Although the shortage of P in many parts of the world negatively affect crop growth and yield, excess application of manure has become a significant sources of soil and water pollution in the developed countries, particularly in areas with high rates of run off and soil erodability (Sharpley et al., 2001). However, agriculture and environmental impacts of P starts at within- or sub-field scale, where input is applied homogenously by the majority of farmers worldwide. Even farmers adopting precision farming technologies for variable rate (VR) applications of fertilisers do not manage smaller field units than 1 ha, over which one average sample is considered as representative of the underlying variability. Therefore, within field management of P should be targeted at fine spatial resolution, so that management at larger scales could be achieved. In order to fulfil this

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http://dx.doi.org/10.1016/j.still.2015.04.003
0167-1987/

requirement, proximal soil sensors that quantify and map P spatial distribution are key success, as they produce >1000 samples per ha (Kuang and Mouazen, 2013).

Recent review report by Kuang et al. (2012) discussed the potential implementation of different technologies adopted for proximal soil sensing in agriculture. The review revealed that the majority of these technologies can be successfully implemented for mapping the spatial variability, with limited capability in isolating and quantifying sources of the variability. Among different techniques discussed the visible and near infrared (vis–NIR) spectroscopy was concluded to be the most successful technique to achieve this goal, particularly for field applications under both mobile and non-mobile measurement conditions. However, authors have indicated that the use of this technology should be made with a particular attention to the fact that users should distinguish between directly and indirectly spectrally active properties. This is true, as soil properties with direct spectral responses in the near infrared (NIR) range are generally measured with higher accuracy than those with indirect spectral responses (Stenberg et al., 2010; Kuang et al., 2012). Properties with direct spectra responses are moisture content, organic carbon, clay mineralogy and perhaps total nitrogen, whereas the remaining soil properties are classified under the indirect spectral response group, among which P is a good example. In spite of the fact that P has no direct spectral response in the NIR range, literature showed some successful cases (e.g. Bogrekci and Lee, 2005; Maleki et al., 2006; Mouazen et al., 2009). The main conclusion by these studies is that when P is successfully measured with vis–NIR spectroscopy, this is more likely to be through co-variation with other soil properties that have direct spectral responses e.g. moisture, clay or organic carbon. Field experience also demonstrated relationship between soil colour and P. So far, there is no clear explanation of the successful cases.

The majority of VR P fertilization is based on manual soil sampling of limited number of samples, which is successively followed by laboratory analysis of P and development of phosphate recommendations. It is obvious that this method is tedious, time consuming, expensive and does not allow exploring spatial variation in P at the desired spatial scale so as to allow successful management of P at smaller unit than one ha. Only limited work was reported on the use of proximal soil sensing for VR P application. Among these, probably the most successful example is the sensor-based VR P fertilisation reported by Maleki et al. (2008), which was based on vis–NIR real time sensing and control of P. In this study, it was found that the average P_2O_5 applied on VR plots was 28.75 kg ha^{-1}, which was 1.25 kg ha^{-1} less than the uniform rate fertilisation (30 kg ha^{-1}), recommended according to the standard soil test. An extra maize kernel yield of 336 kg ha^{-1} was recorded on the VR plots, which resulted in an overall calculated profit of about 30 per ha, by applying variable rate P_2O_5. However, this study was for sensor-based VR P application, where there was no follow up study in the year to come to conclude on the fertilisation efficiency from soil fertility (uniformity of P distribution in the field) points of view. This is particularly true for the evaluation of the resultant spatial homogeneity or heterogeneity of P obtained after the VR P application, which is expected to affect crop growth and yield.

The aim of this paper is to utilise P maps generated with an on-line vis–NIR spectroscopy sensor for site specific management of P_2O_5. The final scope was to ensure uniformity of P distribution across the field, which is hoped in the long term to optimise and homogenise crop growth and yield.

2. Materials and methods

2.1. Experimental site

The study site was a 22 ha Horn End Field at Duck End Farm, Wilstead, Bedfordshire, U.K. (latitude; 52d 05m 51s N, longitude; 0d 27m 19s W) (Fig. 1). The field is normally under annual crop rotation system of winter wheat, winter barley and winter oil-seed rape. The soil type was defined as ‘Haplic Luvisols’ (Soil Survey of England and Wales, NSRI, UK). The textures of selected soil samples indicated the presence of clay, clay loam, sandy clay loam and loam (United States Department of Agriculture (USDA) classification). The topography of the area is rather flat with an elevation that varies between 30 and 38 m, determined by differential global positioning system (DGPS) (EZ-Guide 250, Trimble, USA). The study took place over three cropping seasons (2011–2013). In year 2, the very wet winter caused standing water in the field, for which the farmer cultivate spring barley rather than the planned winter wheat.

2.2. On-line sensor and measurement

The on-line multi-sensor platform designed and developed by Mouazen (2006) was used in this study (Fig. 2). It consists of a subsoiler that penetrates the soil to the required depth, making a trench, whose bottom is smoothed due to the downwards forces acting on the subsoiler. The optical unit was attached to the backside of the subsoiler chisel to acquire soil spectra from the

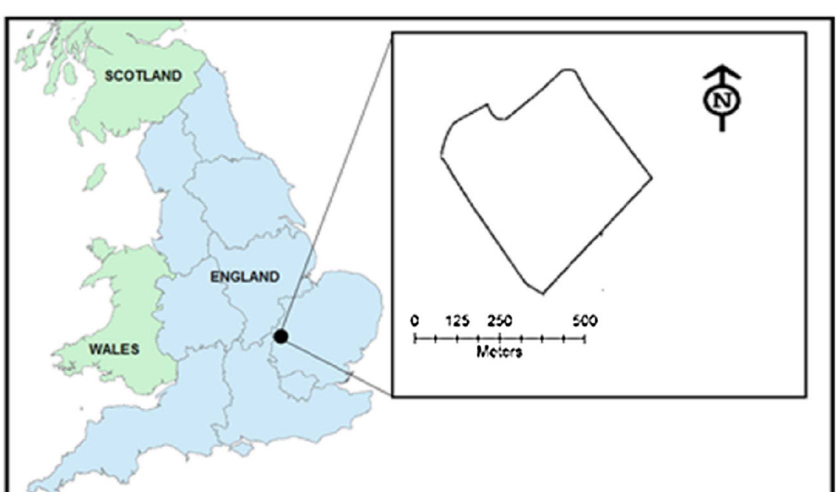

Fig. 1. Location of Duck End Farm and study Horns End Field.