International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July
Ref: C0377

Variable rate lime application based on on-line visible and near infrared (vis-NIR) spectroscopy measurement of soil properties in a Danish field

Boyan Kuang[1], Yucel Tekin, Toby Waine, Abdul. M. Mouazen,*

1. Department of Environmental Science and Technology, Cranfield University, Cranfield, MK43 0AL, UK. 2. Vocational School of Technical Sciences, Uludag University, Bursa, Turke

E-mail: b.kuang@cranfield.ac.uk

Abstract

In Denmark recommendations for variable rate lime application is made based on laboratory analyses of organic carbon (OC), pH and clay content (CC). It is done based on one soil sample per hectare, which ignores spatial variation in soil properties at a finer scale. This paper aims to use an on-line visible and near infrared (vis-NIR) spectroscopy sensor to map, with high sampling resolution within field variation in OC, pH and CC in one field of 18 ha in Denmark. It is assumed that this high sampling resolution data will lead to refining the recommendation map of lime for improved adjustment of soil acidity at lower cost. After the on-line measurement of soil spectra, a previously developed calibration models of OC, pH and CC were upgraded with new samples from the Danish field to predict spatial variations and generate comparison and full-point maps using ArcGIS software. Based on on-line predations, lime recommendation was calculated using an algorithm from the Danish Centre of agriculture (DCA). To evaluate the outcome of the on-line measurement based variable rate (OVR) lime approach, as compared to traditional uniform rate (UR) and (TVR) the field was divided equally into 9 plots, which represent three replicates of the three applications. Cost-benefit analysis was carried out based on input (amount of lime applied) – output (barely yield) calculations of the 9 plots.
Results showed that the on-line measurement accuracy ranged between good to very good with coefficient of determination (R^2) of 0.71 for OC, 0.76 for pH and 0.72 for CC, root mean square error of prediction (RMSEP) of 1.48% for OC, 0.13 for pH and 1.05% for CC, and ratio of prediction deviation (RPD) of 1.93 for OC, 2.08 for pH and 1.98 for CC. It was found that OVR treatments consumed the largest amount of lime of 37 t for the entire field and the UR consumed the smallest amount of 25.3 t for entire field. This was attributed to the fact that the on-line sensor provided a more detailed lime recommendation map, reflecting a better characterisation of within field variability. There was only slightly better yield response for OVR (7.57 t/ha and 136.3 t/field) method over UR (7.51 t/ha and 135.2 t/field) and TVR (7.44 t/ha and 134 t/field) methods, indicating no agronomic response. Therefore, the cost-benefit analysis showed no significantly economic benefit (£2.5 / ha) for VRn liming, after one year experiment, which suggests the need for a longer-term experiment to allow the crop response to take place, due to pH buffering. A further on-line measurement is needed to explore changes in within field variation in soil acidity, as compared to the original variation.

Keywords: Variable rate liming; vis-NIR, on-line sensor; Danish field

Introduction

Maintaining the optimum pH level in the topsoil in all parts of the field is important to achieve optimum yields and consistent quality. Not correcting soil acidity can cause large yield losses, but over-use of lime is wasteful and costly and can create problems with the availability of some micronutrients (RB209, DEFRA, 2009). Traditionally, uniform rate (UR) liming is widely used to regulate the soil pH level and to achieve the optimal crop nutrients uptake and yield response (Coventry et al., 1997; Moody et al., 1995). The UR liming is recommended based on one average sample per field. This low sampling rate ignores the spatial variation of soil pH within a field. Thus, over-rate and under-rate applications were likely to occur when a UR liming was adopted. Under-rate in some part of a field can cause insufficient nutriments uptake by crop, whereas over-rate could result in waste of lime and also in increased disease pressure (Huber and Wilhelm, 1988; Kurtzweil et al., 2002). Therefore, lime has to be managed variably.

Recognising the potential agronomic and economic benefit of variable lime application (VR), variable rate liming has become more attractive for researchers in last decades (Bongiovanni and Lowenberg-Deboer, 2000, Johnson et al., 2010). Some VR liming experiments, based on limited number of soil samples have shown explicit agronomic or economic improvement over traditional UR method. However, the overall performance of VR lime application exhibited rather diverse conclusions due to the complication of lime effect toward crop uptake of other nutrients, or to the lake of detailed description of soil acidity variation in a desired fine scale. The VR lime application studies suggest that to date, most VR lime applications were based on grid zone sampling and topsoil pH analysis of few samples per ha. Therefore, over-rate and under-rate lime application could be applied on none sampled areas (Viscarra Rossel and Mcbrateney, 2000). Therefore, proximal soil sensors are needed to map spatial variation in soil acidity at high sampling resolution, to enable a precise application of lime.

On-line soil sensors offer the technology needed to increase the sampling rate at lower cost. Adamchuk et al. (1999) developed a vehicle based automated ion-selective electrodes (ISEs) sampling system for measuring soil pH, whose accuracy was evaluated in a latter study (Asamchuck, 2007), reporting an overall error of less than 0.3 pH. Author did not attempt to implement and evaluate the economic and agronomic impacts of VR lime application. Furthermore, in Denmark recommendations for VR lime application is made based on one samples per ha analysed in the laboratory for organic carbon (OC), pH and clay content (CC), ignoring spatial variation in soil properties at a finer scale. This means that not only pH is needed for lime recommendation, but also OC and CC. Basically, clay soils require a larger amount of lime than sandy soils to reach the same acidity level. High OC soils should also receive less lime than low OC soils, as the decomposition of soil organic matter itself could increase the soil pH level (Tonona et al., 2010). Therefore, detailed information about pH, OC and CC are pre-requisition for precise VR lime application, which necessitates the need for a different proximal soil sensing technology than ISEs. The aim of this paper is to develop and implement on-line based variable rate (OVR) lime recommendations based on on-line vis-NIR measurement of soil pH, OC and CC. The OVR-partial least squares regression (PLSR) and OVR-artificial neural network (ANN) recommendations will be compared by simulation, and the one that would consume the smallest lime will be evaluated further for crop response and economic return, as compared to traditional variable rate (TVR) and UR lime applications.

Materials and methods

2.1 Experimental site

A 18 ha experimental field (56°22'21.15"N, 9°33'47.03"E) located in Vindumovergaard Farm, Viborg, Denmark was used in this work. The field was drilled with spring barley in spring 2013, with the intention to establish lime application experiment to regulate the soil acidity. The soil texture in the field can be classified as sandy loam according to the United State Department of Agriculture (USDA) texture classification system.

2.2 On-line measurement

The on-line measurement system designed and developed by Mouazen (2006) was used (Fig. 1). Detailed information about the system can be found in Kuang and Mouazen (2013).

Figure 1: On-line visible and near (vis-NIR) soil sensor (Mouazen, 2006)

Blocks of 230 m by 800 m were planned in the field. Each measured line was 600 to 800 m long with 20 m intervals between adjacent transects. The travel speed of the tractor was around 2 km/h and the measurement depth was set at 15 cm. A total of 132 samples were collected during the on-line measurement. They were collected from the bottom of the trench and the sampling positions were carefully recorded. Each soil sample was equally divided into two parts, with one part used to carry out the laboratory reference measurement of soil OC, pH and CC and the other used for optical scanning. Calibration models of OC, pH and CC were developed with PLSR and ANN, using the calibration set. These models were validated using a validation set. The laboratory reference measurement of soil OC, pH and CC was based on relevant British Standards.

2.3 Lime recommendation

Lime recommendations were calculated using OC, pH and CC as input data (Table 1), based on a recommendation algorithm available at the Danish Knowledge Centre of Agriculture. Firstly, the recommendation for the UR application was calculated based on one average measured value of 20 samples of OC, pH and CC by laboratory methods (Table 1). The TVR recommendation was calculated based on 20 laboratory measured soil OC, pH and CC values of those 20 samples. This is about one sample per ha, which is the rate used by most precision farming services. The new OVR recommendations were calculated based on input data on OC, pH and CC obtained for 12580 points with the on-line vis-NIR sensor.

Lime application maps were developed for TVR and OVR based on the calculated lime recommendation rate. ArcGIS 10 (ESRI, USA) software was used to generate the TVR lime recommendation map, using inverse distance weighing (IDW) interpolation method. The reason why IDW was implemented for the TVR recommendation only was the limited number of points (e.g. 20 measurements of soil samples) used in the interpolation. To produce the OVR maps with a much larger number of sampling points (12580), Vesper 1.6 software, developed by Australian Centre for Precision Agriculture, was used to develop semivariogram models for OVR-PLSR and OVR-ANN recommendations. Based on semivariogram parameters and kriging interpolation method, ArcGIS 10 (ESRI, USA) was used to produce the vis-NIR based lime recommendation maps.

2.4 Lime application and yield

After comparison between lime consumption based on PLSR and ANN methods, it became clear that the latter recommendation would consume 4.9 t more lime per field, without changing the spatial distribution of lime application. This was one of the reasons why the OVR lime recommendation based PLSR was only adopted in the experimental plots. Therefore, three lime application methods were implemented, namely, UR, TVR and OVR-PLSR (Fig 2). The field was divided equally into 11 plots and the three liming treatments

were randomly allocated for those plots. Four UR, three TVR and four OVR plots were implemented (Fig. 2). Two plots were excluded from the cost-benefit analysis.
Spring barley was sowed on 3rd March, 2013 and the lime was applied in the field on 24th April, 2013. The yield was harvested on 22nd August, 2013, using a MF 9280 (Massey Fergusson, UK) combine harvester with 7.35 meter head. A basic input-output cost-benefit analysis was made to compare the three treatments in three replicates. The input included the amount of lime used, whereas the output was the yield response measured with the combine harvester, as explained before. Single factor analysis of variance (ANOVA) method was used to investigate if there was significant yield deference between OVR-PLSR, UR and TVR methods due to deferent lime applications using Excel 2010 (Microsoft, USA).

Figure 2: Experimental plots of uniform rate (UR) (red), traditional variable rate (TVR) (yellow) and new variable rate (OVR) (green) lime applications.

Results and Discussion

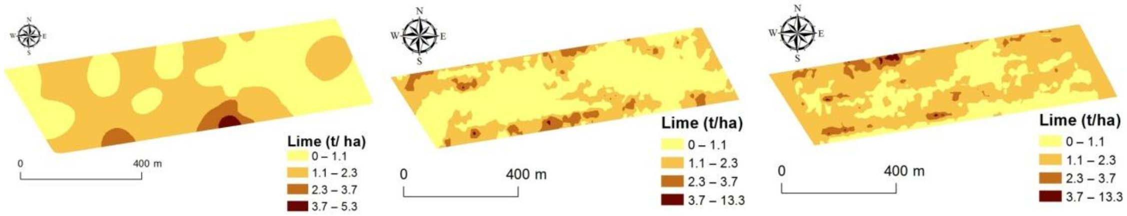
3.1 Measurement accuracy and lime application rate

Results showed that the on-line measurement accuracy ranged between good to very good with coefficient of determination (R^2) of 0.71 for OC, 0.76 for pH and 0.72 for CC, root mean square error of prediction (RMSEP) of 1.48% for OC, 0.13 for pH and 1.05% for CC, and ratio of prediction deviation (RPD) of 1.93 for OC, 2.08 for pH and 1.98 for CC.

Table 1. Virtual and actual lime requirement per individual plot, as compared to the actual yield. Calculated lime requirements were made for uniform rate (UR), traditional variable rate (TVR) and on-line variable rate (OVR) with partial least squares regression (PLSR) and artificial neural network (ANN) predictions.

Plot	**Virtual**		**Actual**		
	PLSR (t)	**ANN (t)**	**TVR (t)**	**Lime (t)**	**Yield (t /ha)**
UR1	2.9	3.9	5.4	2.1	7.88
OVR1	4.6	3.3	0.9	4.6	8.16
TVR1	1.6	2.3	2.7	2.7	8.02
UR2	2.3	2.2	4.3	2.1	8
OVR2	1.9	2.5	0.8	1.9	7.72
TVR2	1.5	2.3	1.8	1.8	7.12
UR3	1.4	1.5	0.9	2.1	7.22
OVR3	1.5	3.2	1	1.5	7.47
TVR3	3.7	5.5	1.7	1.7	7.09
UR4	3	2.4	1.8	2.1	6.93
OVR4	3.5	3.3	1	3.5	7.04
	26.8	31.7	21.8	21.5	

The calculated lime rate for the UR application is 1.40 t/ha. Higher OVR lime recommendations were calculated with with ANN than with PLSR (Table 1). It is clear that OVR-ANN method would consume 9.9, 6.5 and 4.9 t more lime product for the entire field area, as compared to the TVR, UR and OVR-PLSR methods, respectively. The larger amount of lime recommended by ANN method can be attributed to the higher predicted values of pH with ANN, as compared to PLSR models. In addition, it can be visually observed in Fig. (3b) that the area with low OC (<1.5%) in ANN based on-line full-point map is much larger than that of the PLSR based map (Fig. 3a). Low soil OC zones requires more lime to be applied to reduce the soil pH than the high soil OC zones (Tonona et al. 2010), which explains why the PLSR method would require less lime product than ANN. It is also important to mention that in spite of the fact that ANN provides more accurate predictions of OC, pH and CC, it is easier to automate the PLSR-based OVR lime application than ANN, which will enable sensor-based OVR lime application in the future.



(a) (b) (c)

Figure 3: Lime recommedation maps based on traditional variable rate (TVR) method (a) and new variable rate method (OVR) based on partial least squars regression (PLSR) models (b) and artificial neural network (ANN) models (c)

3.2 Lime recommendation maps

Comparing the TVR lime application map (Fig 3a) with the corresponding maps of OVR based on PLSR method (Fig 3b) and ANN method (Fig 3c), revealed that more detailed spatial lime requirements could be observed for both OVR maps. Also, much higher lime amount is needed in some spots for OVR maps. This can be explained by the high sampling resolution obtained with on-line vis-NIR sensor, to enable a better detection of areas with low or high pH levels. The low sampling resolution of TVR might lead to ignoring this fine scale characterisation of within field variation not only in pH, but in OC and CC. Only limited spatial similarity could be observed at the southern edge of the field between TVR map and OVR maps, where a relatively high amount of lime was recommended by all three maps. In some parts of the field, contradictive lime recommendation was found between TVR and OVR maps, which can also be attributed to the limited number of samples (e.g. 1 sample/ha), used for the former approach.

A reasonable spatial similarity between OVR-PLSR and OVR-ANN lime recommendation maps can be observed (Fig. 3). This is particularly true for areas with low lime recommendation of 0 - 1.1 t/ha (Fig. 3b and c). These over-rate and under-rate lime applications expected for the majority of the field area if the UR is adopted explains why TVR lime application showed no clear economic benefit over UR approach (Johnson et al., 2010).

3.3 Economic evaluation of lime application

Examining the amount of actual lime applied per treatment, plot or per field reveals that lime consumption differs from treatment to treatment and from plot to plot (Table 1). The OVR-PLSR based approach consumes the largest amount of lime at 1.973 t/ha (Tables 2), in comparison with TVR (1.889 t/ha) and UR (1.394 t/ha), which consumed the least amount of lime. However, a small extra amount of lime (0.084 t/ha) was used for OVR, as compared to TVR. This result is in line with simulation results reported by Tekin et al. (2013). Indeed, whether or not VR liming can spare lime product depends on the variability of soil pH, sampling method and sampling resolution, hence, lime consumption tends not the main critical factor to be adopted to evaluate the success of VR lime experiment. Agronomic estimation should be considered in conjunction with cost-benefit analysis to arrive at a final evaluation for the success of a variable rate lime application. Although the lowest amount of lime was applied in this study in the UR treatments, this was distributed uniformly, which might not be the ideal practise to maintain the soil pH. The final actual spatial variability of pH is not uniform, since areas received under- or over-applications. A long term benefit of OVR should be associated with more even pH distribution across the entire field, which is expected to result after lime application.

Table 2: Comparison of lime fertiliser use and yield gain per treatment

Treatment	**Area (ha)**	**Input fertiliser (t)**	**Input fertiliser (t/ha)**	**Yield (t)**	**Yield (t/ha)**
UR	*5.952*	*8.3*	*1.394*	*44.724*	*7.512*
TVR	*4.451*	*8.41*	*1.889*	*33.145*	*7.445*
OVR-PLSR	*5.93*	*11.7*	*1.973*	*44.924*	*7.574*

UR: uniform rate lime, TVR: Traditional variable rate, OVR: New variable rate based on on-line partial least squares regression (PLSR) measurement

The OVR-PLSR lime application results in the highest yield of 7.574 t/ha, as compared to the other two traditional lime application methods, whereas the traditional TVR method resulted in the lowest yield of all treatments of 7.445 t/ha. The ANOVA analysis of yield of OVR between UR provides a larger F value of 5.75 than the F critical (3.84), which allows the conclusion that the differences of yield between the two treatments are significant at 95% confidence (p=0.016) < 0.05 level. Similarly, the ANOVA analysis between OVR and TVR also showed a larger F value (4.17) than F critical value (3.47) which means there is significant yield difference between two treatments at 95% confidence level (p=0.04). However, there is no significant yield difference between TVR and UR at 95% confidence (p =0.23) level, as the ANOVA analysis shows larger F critical value (3.84) over F value (0.22). This is a positive point for food security, as more yield can be produced per unit area, when OVR-PLSR approach is implemented. Experience shows that lime application may not affect crop growth and yield in the first year of application hence, a longer-term experiment is needed to arrive at a satisfactorily economic evaluation for the viability of the innovative approach of OVR. Crop yield response to lime is a complex phenomenon dependent on soil characteristics and other factors. Indeed, the yield response to liming varies from crop to crop, and according to the pH level. Because of its complexity and its long term nature, few researchers have attempted to estimate crop response curves to pH, and no functions have been published so far for wheat or barley

Table 3: Margin calculated per ha, per treatment and for the entire field (virtual), for a lime fertiliser price of £10/t and spring barley selling price of £135/ton. Results are shown for UR: uniform rate lime application, TVR: Traditional method of variable rate lime application, OVR: New variable rate lime application

	Input fertilizer cost (£)	**Yield value (£)**	**Margin (£)**
Per ha			
UR	*13.9*	*1014.12*	*1000.22*
TVR	*18.8*	*1005.075*	*986.275*
OVR(PLSR)	*19.7*	*1022.49*	*1002.79*
Per treatment			
UR	*83*	*6037.74*	*6029.44*
TVR	*84.1*	*4474.575*	*4466.165*
OVR(PLSR)	*117*	*6064.74*	*6053.04*
Per field			
UR	*222.4*	*16225.92*	*16003.52*
TVR	*300.8*	*16081.2*	*15780.4*

OVR(PLSR)	*315.2*	*16359.84*	*16044.64*

The differences in yield between different treatments are reflected on differences of margin between treatments (Table 3). The OVR method provides extra margin of £2.5 per ha over the traditional UR application and £16.5 per ha over the TVR lime application, although OVR consumed the largest amount of lime (Table 3). But, the price of lime is rather low (e.g. £10/t), as compared to other artificial fertilisers. Previous reports based on different soils, crops and cost-benefit analyses arrived to diverse results. Bongiovanni and Lowenberg-Deboer (2000) reported that VR lime application based solely on agronomic recommendations could increase annual returns by $7.24 ha-1 in Indiana corn and soybean production systems. The model used by Adamchuk et al. (2004) demonstrated $6.13 per ha extra margin from using VR liming with automated soil pH mapping over VR liming based on 1 ha (2.5 acres) manual grid point sampling for the selected simulated field conditions. Wang et al. (2003) also reported economic and environmental benefits from adopting VR over UR liming, although VR liming did not result in uniform higher profit than UR methods. Compared to other VR liming studies, the current study results in a lower extra margin of £2.5 (= $4.1 per ha). However, in comparison with TVR the extra margin due to OVR lime is significantly larger of £16.5 per ha (=$27.2 per ha). This is disappointing results for farmers or current precision farming services adopting the TVR. Narrowing down the comparison to UR, it is worth indicating that the most previous studies on VR liming were based on three to four cropping seasons, which is long enough to record responses in yield to TVR liming. This implies the need for extra 2-3 more cropping seasons to be completed before fair robust conclusions on the cost-benefit analysis can be made.

Conclusions

A lime application plot experiment was carried out in 18 ha field in Denmark to compare

traditional uniform rate (UR) and variable rate (TVR) with a new variable rate (OVR) lime applications using high resolution data on soil organic carbon (OC), pH and clay content (CC), generated with an on-line visible and near infrared (vis-NIR) sensor. The on-line vis-NIR soil sensor based lime recommendation consumed considerably more lime of 3.4 and 3.3 t per field, as compare to the traditional UR and TVR methods, respectively, which was attributed to the more detailed characterisation of the key soil properties. The yield deference between OVR and UR was significant at 95% confidence ($p=0.016 < 0.05$) level and yield deference between OVR and TVR was also significant at 95% confidence level ($P=0.04$). There is no significant yield difference between TVR and UR at 95% confidence ($p=0.23>0.05$) level. The economic analysis showed that the OVR-PLSR method provided extra margins of £2.5/ha and £16.5/ha over the traditional UR and TVR lime applications, respectively. However, a longer experiment is needed to confirm the economic and agronomic benefits of the innovative OVR liming approach.

It is true that no clear economic benefits could be achieved from adopting the new OVR of lime, as compared to the UR (£2.5/ha) only. However, the high resolution maps of OC, pH and CC measured with the on-line sensor are available to the farmers for other site specific applications, e.g. organic manure, or other soil nutrients.

Acknowledgements

The research leading to these results has received funding from the European Space Agency under the FarmingTruth project. Authors also acknowledge the knowledge Centre of Agriculture in Denmark, for providing the experimental fields and facilitating measurement.

References

Adamchuk, V.I., Morgan M.T., Ess, D.R., 1999. An automated sampling system for measuring soil pH. Trans ASAE. 42(4):885–891.

Adamchuk, V.I., Morgan M.T., Lowenberg-Deboer, J.M., 2004. A Model for Agro-Economic Analysis of Soil pH Mapping. Precision Agric .5, 111–129.

Adamchuk, V.I., Lund, E.D., Reed, T.M., Ferguson, R.B., 2007. Evaluation of an on-the-go technology for soil pH mapping. Precision Agric. 8:139–149.
Bianchini, A. A., Mallarino, A. P., 2002. Soil sampling alternatives and variable-rate liming for soybeancorn rotation. Agron J. 94, 1355–1366.

Bongiovanni, R., Lowenberg-Deboer, J., 2000. Economics of variable rate lime in Indiana. Precision Agric. 2, 55–70.

Coventry, D. R., Slattery, W. J. Burnett, V. F., Ganning G. W., 1997. Longevity of wheat yield response to lime in south-eastern Australia. Australian Journal of Experimental Agriculture. 37, 571-575

Department for Environment, Food and Rural Affairs (DEFRA, UK), Fertilizer Manual (RB209). 373. Published by TSO (The Stationery Office) and available online: www.tsoshop.co.uk. 2010. 374 (accessed on 28 November 2013).

Huber, D.M., Wilhelm, N.S., 1988. The role of manganese in resistance to plant diseases. p. 155–173. In R.D. Grahmet al. (ed.) Manganese in soils and plants. Kluwer Academic Publishers. Dorway- drecht, Netherlands.

Johnson, R. M., Richard Jr. E. P., 2010. Variable-rate lime application in Louisiana sugarcane production systems. Precision Agric. 11,464–474.

Kurtzweil, N.C.,Grau, C.R., MacGuidwin, A.E., Gaska, J.M., Kazubowski. 2002. Soil pH in relation to brown stem rot and bean cyst nematode. p. 177–185. In Proceedings of the 2002 Wisconsin Fertilizer, A glime and Pest Management Conference. 15–17, Jan.2002. Madison, WI. University of Wisconsin, Madison.

Kuang, B., Mouazen, A.M., 2013. Effect of spiking strategy and ratio on calibration of on-line visible and near infrared soil sensor for measurement in European farms. Soil & Till Res, 128, 125–136.

Moody, P. W., Aitken, R. L. Dickson, T., 1995. Diagnosis of maize yield response to lime in some weathered acidic soils. In Proceedings of the Third International Symposium on Plant-Soil Interactions at Low pH, edited by R. A. Date, N. J. Grundon, G. E.Rayment, and M. E. Probert ŽKluwer Academic Publishers, Boston, USA, 1995, pp. 537-541.

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.

Tekin, Y., Kuang, B., Mouazen, A.M., 2013. Potential of on-Line visible and near infrared spectroscopy for measurement of pH for deriving variable rate lime recommendations. Sensors, 2013. 13(8), 10177-10190.

Tonona, N., Sohic, f., Franciosod, O., Ferrarie, E., Montecchiod, D., Gioacchinid, P., Ciavattad, C., Panzacchia, P., & Powlson, P., 2010. Effect of soil pH on the chemical composition of organic matter in physically separated soil fractions in two broadleaf woodland sites at Rothamsted, UK. Eur J Soil Sci. 61, 970–979.

Viscarra Rossel, R.A., & McBratney A. B., 2000. Two-factor empirical deterministic response surface calibration model for site-specific predictions of lime requirement. Precision Agri. 2, 163-178.

Wang, D., Prato, T., Qiu, Z., Kitchen, N. R., Sudduth, K. A., 2003. Economic and environmental evaluation of variable rate nitrogen and lime application for claypan soil fields. Precision Agri. 4, 35–52.