Economic Comparison between high resolution and conventional soil sampling using the example of the soil pH

Tobias Leithold, Peter Wagner

Martin-Luther-University Halle-Wittenberg, Agribusiness and Farm Management Group, 06120 Halle (Saale)
tobias.leithold@landw.uni-halle.de, peter.wagner@landw.uni-halle.de

ABSTRACT

Since the introduction of the Veris Mobile Sensor Platform (MSP) pH Manager it has become possible to sample fields for soil pH with a sampling density of more than 15 samples ha^{-1}. With this, the density of information increases greatly and small-scale pH heterogeneities can be recorded that remained undiscovered in conventional sampling methods. The optimal distribution of lime leads less to a saving of fertiliser but instead to the expectation of positive agronomic effects, such as an increase in yield. In three fields a comparison was made between high resolution and conventional soil sampling. In this the expected agronomic effects were simulated from results from other trials for a rotation period of six years. The economic evaluation of the comparison shows that a potential of ca. 20 € ha^{-1} y^{-1} remains through the much higher density of information using the Veris-MSP.

Keywords: Veris, Precision Farming, economic comparison, soil pH, Germany

1. INTRODUCTION

An important basis for lime fertilisation is the recording of soil pH. Several studies have shown that the soil pH can vary greatly on a small scale (Bianchini and Mallarino, 2002; Lauzon et al. 2005). Only with the development of a sensor from the company Veris (Kansas, USA) has it become possible to determine the soil pH cheaply in a much higher sampling density than with the time and cost intensive laboratory method. Both methods differ in their measurement principles and the results of the pH sensor must be fitted to the results of the laboratory method. A suitable algorithm for the calibration of the on-the-go recorded data has been evaluated and presented by the authors (Leithold et al., 2012).

With the high resolution soil pH map it is possible to undertake sub-field specific lime fertilisation of a field in order to create a uniform optimal soil pH. In contrast to this, lime fertilisation using conventional sampling methods would lead to sub-fields being over- and under-supplied. The expected agronomic effects were evaluated for a simulated trial period of six years.

T. Leithold, P.Wagner. "Economic Comparison between high resolution and conventional soil sampling using the example of the soil pH". EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013. The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of the Internation Commission of Agricultural and Biosystems Engineering (CIGR) and of the EFITA association, and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process by CIGR editorial committees; therefore, they are not to be presented as refereed publications.

2. MATERIALS AND METHODS

The investigation of high resolution soil sampling was carried out using the Veris-MSP pH Manager on three fields (see table 1). The measurement principle is based on the removal of a soil sample, which is then analysed online through two pH sensitive electrodes within a few seconds to obtain the soil pH (Lund et al., 2004).

Table 1. Description of location

Site	1	2	3
Size (ha)	45.31	28.08	116.27
longitude/latitude	11.046278/51.775511	12.467478/50.764906	11.948912/51.619575
Textural class (FAO, 2006)	Silt loam	Sandy loam	Silt loam
Date of soil sampling	16.9.2011	24.7.2011	20.9.2011
Crop 2011	Winter wheat	Winter barley	Winter wheat

Conventional soil sampling in fixed 1-ha and 5-ha grids as well as according to homogeneous apparent electrical soil conductivity zones (EC), was simulated in ArcGIS (Esri, 2009). The interpolated soil pH maps (according to the pH sensor) serve as the basis of the simulated soil sampling. The apparent electrical conductivity of the soil was recorded with a recorded frequency of 1 Hz during the soil pH measurements by the Veris-MSP. After determination of the sampling line 15 individual probes were simulated and combined as a mixed sample. The results from this using the procedure with the pH sensor or the conventional procedure were compared using the four parameters described below:

- Costs of soil sampling

This includes the costs for taking and analysing the soil samples. Furthermore, this also includes the costs for the procurement and preparation of the data of the apparent electrical conductivity of the soil.

- Incorrectly allocated liming costs

The incorrectly allocated liming costs can be calculated as the difference between the optimally distributed liming application map according to the pH sensor and the liming application map of the conventional method. The decision rules of the VDLUFA are used (von Wulffen et al., 2007) in order to create the liming application maps. The over-fertilised amount of lime is multiplied by the lime price and gives the incorrectly allocated lime costs.

- Exploitation of the phosphate effect

Kerschberger (1987) developed a rule of thumb from long-term lime fertilisation trials; this describes the interaction between the soil pH and the phosphate solubility available to plants in the soil. This describes that with an increase in the soil pH of one pH unit,

phosphate solubility increases by 1 mg P per 100 g of soil. In order to obtain a comparable increase of the phosphate content with mineral fertilisation, a fertilisation of 100 kg P ha^{-1} would be necessary. The rule of thumb is only true for the suboptimal soil pH area, which is dependent on the soil texture and the humus content.
Due to the different density of information of the sampling methods investigated different results can occur in the spatial distribution of the soil pH. As a result, the liming application maps differ so that the expected soil pH development in the fertilisation planning period proceeds differently according to the sampling method. The following assumptions are made for this:

- Fertilisation period: 6 years
- Complete conversion of the lime fertiliser: 2 years
- Annual pH-change through external influences such as soil acidification, acidifying fertiliser, nutrient removal: - 0.1 pH-units (Rowell, 1997)
- Price of lime: 21.33 € CaO^{-1} t^{-1} (AMI, 2010 – 2013)
- Price of phosphate: 434.22 € P^{-1} t^{-1} (AMI, 2010 – 2013)

Figure 1 shows the temporal course of the soil pH with liming or with no liming.

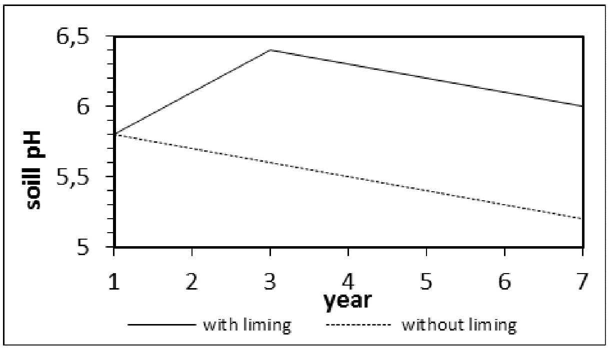

Figure 1. Temporal development of the pH value with/without influence of liming

- The expected effects on yield

Due to suboptimal soil pH yield depressions must be expected. It is also known that crops have different lime requirements. A differentiation is made between high- and low- lime demanding crops (Schilling, 2000). The literature analysis of long-term lime fertilisation trials leads to no clear yield-soil pH relationships within the high and low lime demanding crops. There are trials with less strong effects on yield (Cifu et al., 2004, Merbach et al., 1999, Pagani et al., 2009) as well as trials with a strong effect on yield (Cifu et al., 2004, Liu et al., 2004). For such a kind of imprecise defined variables a calculation of different scenarios is appropriate, which spans an expected range for the economic evaluation from a worst case scenario up to a best case scenario. In figure 2 the dotted lines show the boundaries of the worst case and best case scenarios.

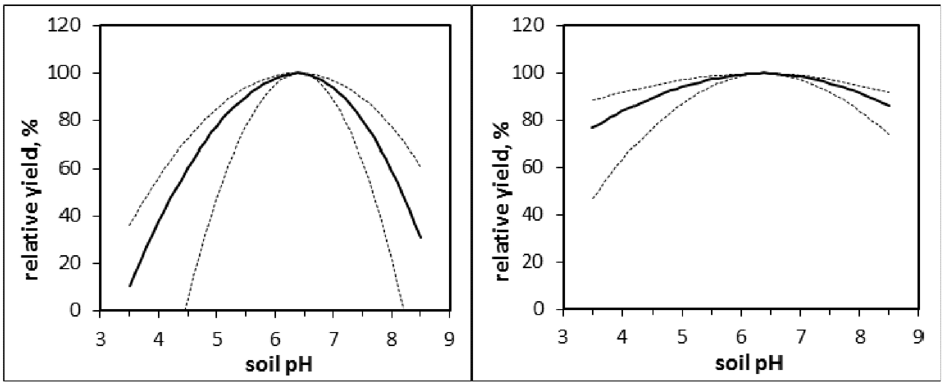

Figure 2. Average expected relative yield and boundaries of the relative yields for high lime demanding (left) and low lime demanding (right) crops according to soil pH

The following crop rotation is assumed for all trial fields for the scenario calculations:

Sugar beet – winter wheat – winter barley – canola – winter rye – summer barley.

The expected yields and product prices of the crops are shown in table 2.

Table 2. Expected yield and product prices considering the locational characteristics

	Expected yield ($t\ ha^{-1}$) site		Product prize (€ t^{-1})
crops	1[1]	2[1], 3[1]	Average price (3 years)
Summer barley	5.00	6.50	19.89[2]
Winter barley	6.50	8.50	15.69[2]
Canola	3.80	4.50	34.94[2]
Winter rye	7.00	9.00	19.17[2]
Winter wheat	7.00	8.50	18.45[2]
Sugar beet	60.00	70.0	4.40[3,4,5]

Sources: [1] Personal interviews with farm manager, [2]Hamm et al. (2013), [3]Beil (2010), [4]Beil (2011), [5]Beil (2012)

For the economic evaluation the soil sampling costs and the incorrectly allocated liming costs can be seen as **costs**. The exploitation of the phosphate effect and the expected yield depressions do not show any costs, but should be interpreted as **lost income**. The farm manager expects a yield from the crops sown that cannot be realised, however, due to the suboptimal soil pH distribution.

3. RESULTS

With an increasing sampling density the information density of the "true" spatial soil pH distribution increases. Even within a 1-ha grid considerable soil pH differences can be observed through the much higher sampling density of the pH sensor. The comparison of the resulting lime application maps of the sampling procedure shows that ca. 12 –

26 % of the lime fertiliser used could have been saved or better distributed on other places within the fields. According to the sampling methods investigated, an over- or under-fertilisation of lime occurred on ca. 70 % of the site area (table 3).

Table 3. General results of the sampling methods investigated

	site	Veris-MSP	1-ha-grid	5-ha-grid	EC-grid
Sampling density ($n\ ha^{-1}$)	1	15.80	0.84	0.22	0.53
	2	21.41	1.18	0.21	0.50
	3	14.62	1.01	0.23	0.46
Soil pH pH_{MEAN} (pH_{MIN} – pH_{MAX})	1	6.45 (4.99-7.25)	6.48 (5.28-7.17)	6.43 (5.82-6.88)	6.45 (5.51-7.08)
	2	5.57 (4.23-6.38)	5.63 (5.30-6.20)	5.58 (5.41-5.85)	5.67 (5.46-5.90)
	3	5.99 (4.81-7.53)	5.99 (5.25-7.01)	6.01 (5.65-6.80)	5.99 (5.37-7.11)
Recommended amount of lime (CaO t)	1	62.13	46.49	50.11	50.97
	2	46.39	43.61	47.72	37.40
	3	365.14	361.33	337.29	368.34
Over-fertilised lime (CaO t)	1	0.00	7.67	16.32	14.14
	2	0.00	8.4	12.18	6.02
	3	0.00	57.28	57.19	66.16

The results of the economic evaluation according to the four criteria are shown in fig. 3. All values are based on the annual costs or the annual lost income of the sampling methods.

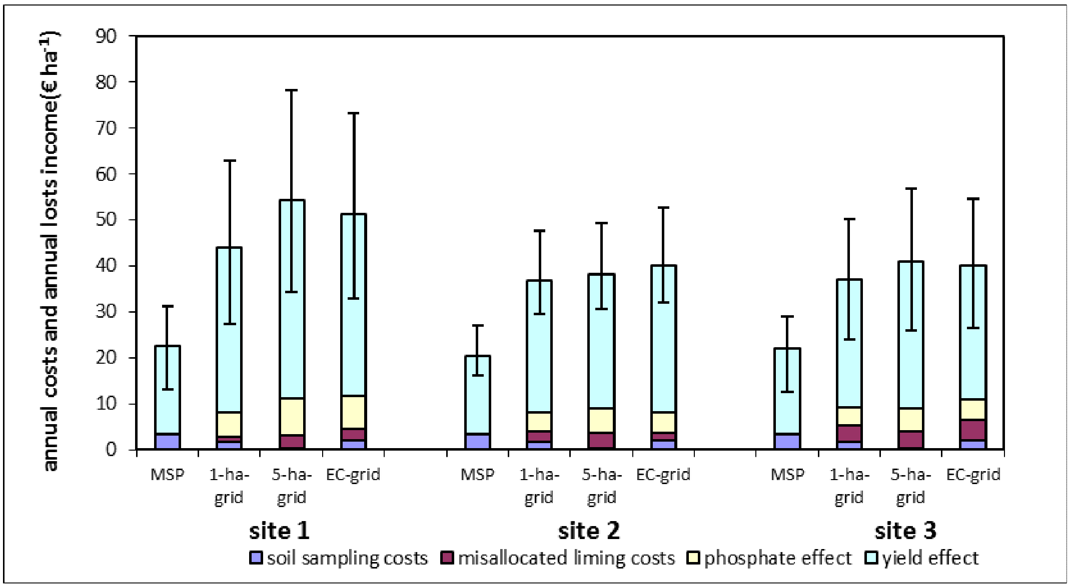

Figure 3. Annual costs and annual lost income of the sampling methods (bars of the yield depression portray the worst case and best case scenarios respectively).

C0201
T. Leithold, P. Wagner. “Economic Comparison between high resolution and conventional soil sampling using the example of the soil pH”. EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Turin, Italy, 24-27 June 2013.

The highest soil sampling costs can be shown for the pH sensor, which, however, turn out to be very low with an annual sum of 3.33 € ha^{-1}. Through the optimal distribution of lime no areas are supplied with too much or too little lime, so that no misallocated lime costs occur. Similarly the phosphate effect is completely exploited through the optimal lime distribution and no mineral compensatory fertilisation is necessary, unlike in the other sampling methods. Despite the optimally distributed amount of lime, yield depressions must be expected for the pH sensor. The reasons for this are, on the one hand, a poor lime supply at the date of soil sampling, which was first remedied after two years through the complete implementation of the lime fertilisation. On the other hand, falling soil pH are to be expected through natural soil acidification and through other soil acidifying factors, which can lead to sub-optimal soil pH in the simulated investigation period of six years. The average annual expected yield depression amounts to about 17 to 19 € ha^{-1} y^{-1} for the pH sensor. Overall, the sum of the annual costs and the lost income amounts to 20 € ha^{-1} y^{-1} to 23 € ha^{-1} y^{-1} for the pH sensor for all the locations.
Small scale soil pH heterogeneities are not detected through the low sampling density of conventional sampling methods. Despite lower annual soil sampling costs (0.38 € ha^{-1} y^{-1} to 2.18 € ha^{-1} y^{-1}) the negative effects of the lower sampling density prevail. The largest proportion is borne by the average expected yield depressions with ca. 73 % to 82 % or 31 € ha^{-1} y^{-1} to 35 € ha^{-1} y^{-1}. Annual sums of between 1 € ha^{-1} y^{-1} to 5 € ha^{-1} y^{-1} occur for the incorrectly allocated liming costs, whilst the lost incomes of the phosphate effect lie between 4 € ha^{-1} y^{-1} and 8 € ha^{-1} y^{-1}.
No positive economic effects can be achieved with the approach of delineating homogeneous apparent electrical soil conductivity zones for nutrient homogenous zones compared to the fixed grids.
The economic comparison between the high resolution soil sampling with the pH sensor and the conventional sampling method leads to an annual total potential of 17 € ha^{-1} y^{-1} to 22 € ha^{-1} y^{-1} for the use of the Veris MSP.

4. DISCUSSION

Adamchuk et al. (2004), Ericksen (2004) and Olfs et al. (2012) report on the positive economic effects of the use of the Veris-MSP, the economic potential of which lies in a region of between 5 to 10 € ha^{-1} y^{-1}. The economic evaluation of the named working groups is based on the soil sampling costs, the liming costs and the expected increase in yield. The interaction between the soil pH and phosphate availability was not taken into account.
The results presented are based on a model in which the yield is only dependent on the soil pH. It is known, however, that on the one hand the yield is dependent on several factors and that interactions between the factors must be taken into account. On the other hand, interactions do not only exist between the soil pH and phosphate availability, but also between the soil pH and other pH dependent nutrient availabilities, e.g. Cu, Zn and Mn (Rengel, 2002). Thus the presented simulated economic evaluation shows a result range which, taking into account other complimentary effects, for instance in micro-nutrient fertilisation, could lead to a higher economic potential.

Targeted soil sampling on the basis of homogenous zones according to the apparent electrical conductivity of the soil (Corwin and Plant, 2005) does not provide an alternative on the trial fields under investigation in comparison to the conventional fixed grid. The higher sampling density of the fixed 1-ha grid leads to a much higher gain in information than the EC grid.

5. CONCLUSIONS

With the Veris-MSP the economic advantages of precision farming technology can be shown using the example of the soil pH. Characteristic is a much higher density of information which is able to reveal small-scale soil pH heterogeneities. The profitability of a higher density of information is not shown so much through the savings in fertiliser but rather the improvement of efficiency is to be expected through increased yield and a better utilisation of the interaction between the soil pH and phosphate availability.

6. ACKNOWLEDGEMENTS

The project was funded by the Federal Ministry for Economics and Technology.

7. REFERENCES

Adamchuk, V.I., M.T. Morgan and J.M. Lowenberg-DeBoer. 2004. A Model for Agro-Economic Analysis of Soil pH Mapping. *Precision Agriculture* 5 (2): 111-129.

Ami (Agrarmarkt Informations-Gesellschaft mbH). 2010 – 2013. Märkte und Preise. *Bauernzeitung* 51 – 54 (different issues). (In German).

Beil, C., 2010: Geschäftsbericht für das Geschäftsjahr 2010 des Ringes Fränkischer Zuckerrübenanbauer e.V. Eigenverlag, Eibelstadt. (In German).

Beil, C., 2011: Geschäftsbericht für das Geschäftsjahr 2011 des Ringes Fränkischer Zuckerrübenanbauer e.V. Eigenverlag, Eibelstadt. (In German).

Beil, C., 2012: Geschäftsbericht für das Geschäftsjahr 2012 des Ringes Fränkischer Zuckerrübenanbauer e.V. Eigenverlag, Eibelstadt. (In German).

Bianchini, A.A. and A.P. Mallarino. 2002. Soil-Sampling Alternatives and Variable-Rate Liming for a Soybean-Corn Rotation. *Agronomy* 94 (6): 1355 – 1366.

Cifu, M., L. Xiaonan, C. Zhihong, H. Zhengyi and M. Wanzhu. 2004. Long-term effects of lime application on soil acidity and crop yields on a red soil in Central Zhejiang. *Plant and Soil* 265 (1-2): 101-109.

Corwin, D.L. and R.E. Plant. 2005. Applications of apparent soil electrical conductivity in precision agriculture. *Computers and Electronics in Agriculture* 46 (1): 1-10.

Ericksen, B. 2004. Field Experience Validates On-The-Go Soil pH Sensor. *Purdue Top Farmer Crop Workshop Newsletter*, 1-4.

Esri. 2009. ArcGIS Desktop 9.3.1. ESRI, Redlands, California, USA.

FAO. 2006. Guidelines for soil description, Fourth edition. Rome.

Hamm, L.-R., M. Heim, J. Weiß and G. Dorfner. 2013. Landwirtschaftliche Erzeugerpreise in Bayern – Datensammlung für die Landwirtschaftsberatung. Ed.: Bayrische Landesanstalt für Landwirtschaft. München. (in German).

Kerschberger, M. 1987. Einfluß des pH-Wertes auf den doppellaktatlöslichen P-Gehalt im Boden (DL-Methode). *Arch. F. Acker- und Pflanzenbau und Bodenkunde* 31 (5): 313-319. (In German).

Lauzon J.D., I.P. O`Halloran, D.J. Fallow, A. Peter von Bertoldi and D. Aspinall. 2005. Spatial Variability of Soil Test Phosphorus, Potassium, and pH of Ontario Soils. *Agronomy* 97 (2): 524 – 532.

Leithold, T., P. Wagner and M. Schneider, 2012: Improvement of the quality of „on-the-go" recorded soil pH. *11th International Conference on Precision Agriculture*. Indianapolis, Indiana, USA.

Liu, D.L., K.R. Helyar, M.K. Conyers, R. Fisher and G.J. Poile, 2004: Response of wheat, triticale and barley to lime application in semi-arid soils. *Field Crops Research* 90 (2-3): 287-301.

Lund, E. D., K.L. Collings, P.E. Drummond and C.D. Christy, 2004: Managing pH Variability with On-The-Go pH Mapping. *7th International Conference on Precision Agriculture*. Minneapolis, Minnesota, USA.

Merbach, W., L. Schmidt and L. Wittenmayer, 1999: Die Dauerdüngungsversuche in Halle (Saale). Teubner-Verlag, Stuttgart. Halle. (In German).

Olfs, H.-W., A. Borchert, D. Dabbelt, G. Recke and D. Trautz, 2012: Economic evaluation of a variable lime application strategy based on soil pH maps derived from on-the-go pH-measurements under German conditions. In: *11th International Conference on Precision Agriculture*. Indianapolis, Indiana, USA.

Pagani, A., A.P. Mallarino and J.E. Sawyer, 2009: Soil pH and lime management for corn and soybean: An ongoing on-farm project. In: *39th North Central Extension-Industry soil fertility Conference.* Des Moines, Iowa, USA.

Rengel, Z., 2002: Role of pH in Availability of Ions in Soil. (Ed.: Z. Rengel, 2002): *Handbook of Plant Growth – pH as the Master Variable*, 323-350.

Rowell, D.L., 1997: Bodenkunde – Untersuchungsmethoden und ihre Anwendungen. Springer-Verlag, Berlin, Heidelberg. Reading. (In German).

Schilling, G., 2000: Pflanzenernährung und Düngung. 4. Auflage, Ulmer-Verlag, Stuttgart. Halle. (In German).

Von Wulffen, U., M. Roschke and H.-E. Kape, 2007: Richtwerte für die Untersuchung und Beratung sowie zur fachlichen Umsetzung der Düngeverordnung – Gemeinsame Hinweise der Länder Brandenburg, Mecklenburg-Vorpommern und Sachsen-Anhalt zur Umsetzung der novellierten Düngeverordnung (Stand: 01.04.2007). Ed.: Landesanstalt für Landwirtschaft, Forsten und Gartenbau des Landes Sachsen-Anhalt, Landesamt für Verbraucherschutz, Landwirtschaft und Flurneuordnung – Referat Acker- und Pflanzenbau, Landwirtschaftliche Fachbehörde des Landes Mecklenburg-Vorpommern. Bernburg, Güterfelde, Rostock. (In German).

C0201

T. Leithold, P. Wagner. "Economic Comparison between high resolution and conventional soil sampling using the example of the soil pH". EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013.