VALIDATION OF ON-THE-GO SOIL PH-MEASUREMENTS – PRIMARY RESULTS FROM GERMANY

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ABSTRACT

Soil pH has a huge impact on nutrient availability in soil and on plant growth in general. As soil pH decreases under most farming conditions over time, application of lime is a standard activity for most farmers. However, in-field variability for soil pH could not be considered because reliable spatial information has hardly been available. The required density of soil pH measurements could not be achieved by manual soil sampling due to time constraints and analysis costs for the vast number of samples.

A fully automated on-the-go soil pH mapping system (Veris MSP) has been developed during the last years and tested under US farming conditions, but data on the performance under German soil and weather conditions were not available. This on-the-go pH sensing system was adapted to German farm technology and validated on fields with varying soil types and soil texture belonging to the experimental farm of the University of Applied Sciences Osnabrueck and on several fields from nearby farmers.

Based on the Kriging method the measured pH values were interpolated to generate pH maps for individual fields. Additionally, soil samples were collected manually and analysed in the lab to validate the accuracy of the pH sensor data. The relationship between Veris MSP and lab data was assessed by regression analysis.

A sampling density of 40 - 90 samples per hectare was realized depending on speed (6 - 10 km/h) and spacing between passes (7.5 - 15 m) in the field. The difference between minimum and maximum pH for individual fields was usually higher than one pH unit. The correlation coefficient between pH sensor and lab data ranged from 0.36 to 0.79 for individual fields. Based on the Veris MSP data spatial variability of soil pH was determined. In combination with additional soil data (e.g. soil texture) these maps offer opportunities for management adaptations (especially for lime application).

Keywords: in-field variability, on-the-go sensing, soil pH mapping, Veris MSP

INTRODUCTION

During the next decades land area available for food production per person will decline substantially: world population will expand to about 9 Billion people (UN, 2004), while arable land is projected to increase only by about 7.2 % (Zhang et al., 2006). It is therefore essential to enable crops to fully utilize their yield potential thereby increasing food production per unit area.

Soil pH can be seen as one of the most important soil chemical parameters. It is well-known that for most crops a nearly neutral (silt or clay soils) to slightly acid (sandy soils) soil environment is optimal. However, due to leaching, soil respiration by microbes and plant roots, root excretion of organic acids and input of acidifying substances from the atmosphere ("acid rain") or farm inputs (e.g. N fertilizers) under most farming conditions a decrease in soil pH occurs over time. As a result in many arable soils pH is not appropriate for optimal plant growth leading to a general stress situation for plants (e.g. reduced root growth, uptake of non-desirable elements). Furthermore nutrient availability might be decreased, e.g. phosphate, an essential plant nutrient, might react with iron and/or aluminum oxides to non plant available compounds at low soil pH.

Application of lime is therefore a standard activity for most farmers to raise soil pH to a level mainly depending on soil type and crop to be grown. In general liming is done uniformly for a given field, although it has been shown that within a field variability for soil pH might be considerable even at small scale (e.g. Bianchini and Mallarino, 2002; McBratney and Pringle, 1997). In-field heterogenity of crop growth due to varying chemical and physical soil properties (e.g. texture, water holding capacity, pH, nutrient status) requires spatial adaptation of farming activities (e.g. soil tillage, fertilizer application rates) to ensure optimal plant growth conditions in different parts of a field (e.g. Olfs 2009). As a consequence it can be expected to improve crop production and economic result as well as to reduce environmental impacts. However, up to now reliable spatial information on soil pH was hardly available, because the required density of pH measurements could not be achieved by manual soil sampling due to time constraints and analysis costs for the vast number of samples.

As an alternative an automated system for mapping soil pH was developed (Viscarra Rossel and McBratney, 1997; Adamchuk et al., 1999). Based on this prototype and further technical adjustments the on-the-go soil pH mapping system Veris MSP is provided by Veris Technologies Inc. (Salina, KS, USA) since 2003. This pH sensor has been extensively validated under US farming conditions (Lund et al. 2005). However, before this pH sensing unit can be recommended for farm advisory application in Germany data on the performance under German soil, climate, and farming conditions have to be evaluated.

MATERIALS AND METHODS

The Veris MSP was adapted to German farm technology and equipped with two ion-selective antimony electrodes. For online pH measurement the soil surface is cleared from crop residue and loose soil is compacted by a firming wheel (Fig. 1). The hydraulic cylinder forces the sampler shoe into the soil (ca. 8 - 10 cm) creating a soil core which flows through the sampling shoe. The shoe with the soil core is raised against two antimony pH electrodes and the pH readings are compared for a period of maximum 30 seconds. If the difference between the two readings is smaller than 0.5 pH units, the average value is stored on a compact flash card together with the data for the georeferenced position. Otherwise the measurement is rejected. The next measurement cycle starts using demineralized water (electric conductivity < 12 mS cm^{-1}) to clean the electrodes. The entire sampling process is controlled with an external electronic control module. Before the pH sensing system is used the pH electrodes are calibrated with standard buffer solutions (pH 4 and pH 7). For our experimental test series a sampling density of 40 - 90 samples per hectare was realized depending on speed (6 - 8 km/h) and spacing between passes (7.5 - 15 m).

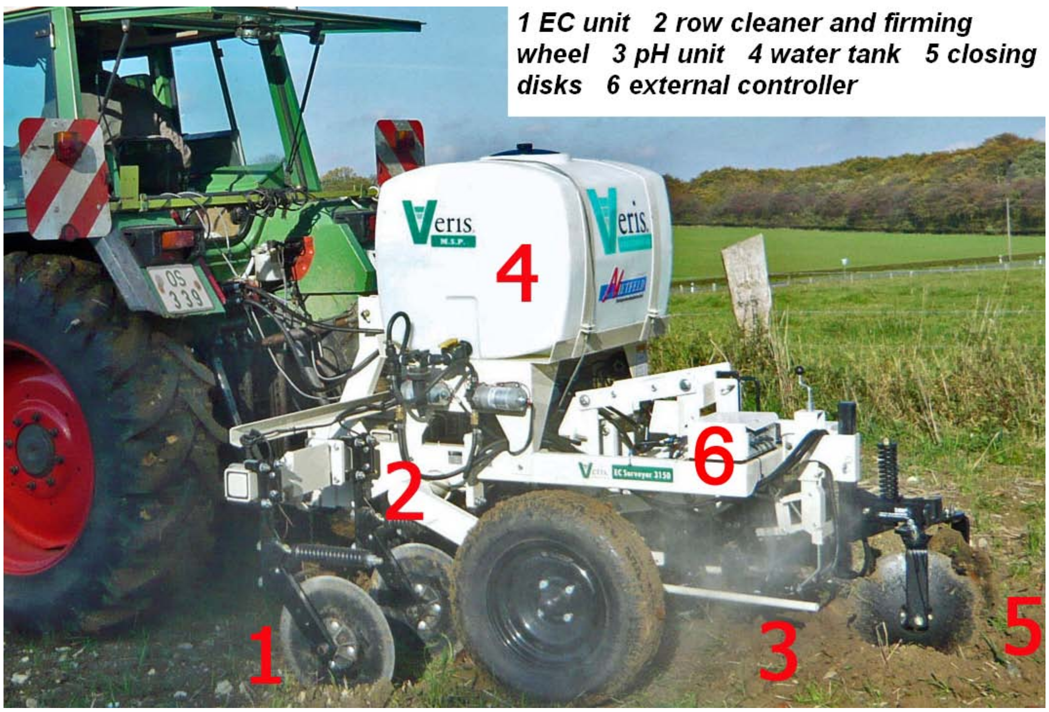

Figure 1. Set-up of the Veris MSP online pH mapping system

Additionally, on selected fields soil samples from the upper soil layer (0 - 30 cm) were collected manually using an auger in a 15 x 60 m grid (each sample consisted of 3 - 5 individual soil cores). The soil was homogenized, air dried and sieved using a 2 mm sieve. Soil pH was analysed in the lab using the German standard procedure, i.e. addition of 0.01 molar $CaCl_2$ solution at a ratio of 1 : 2.5 and pH measurement after 2 hours reaction time using a glass-membrane ion-selective electrode (VDLUFA, 1991).

Field tests were conducted on fields in north-western Germany belonging to the experimental farm of the University of Applied Sciences Osnabrueck (52°19' N; 8°02' E) and on several fields from nearby farmers with varying soil types and soil texture (Tab. 1). On field "Haster Esch" 3 consecutive Veris MSP measurements were performed to check the influence of organic manure application and soil tillage on Veris MSP pH readings. The first pH measurement was done on 10-04-2010. Farm yard manure application followed by soil tillage was done 5 days later. On 16-04-2010 the second Veris MSP pH measurement was conducted. Five days later slurry was applied and incorporated into the soil followed by a third pH measurement the next day.

Based on the Kriging method (Isaak and Srinivastava, 1989) pH values were interpolated to generate pH maps for individual fields using the open source GIS software "OpenJUMP" (Kielhorn and Trautz, 2009). The relationship between Veris MSP and lab data was assessed by regression analysis using the Veris MSP pH value closest to the core sampling site.

Table 1. Soil characteristics of the study sites and selected pH data

		Haster Esch	Muehlental I+II	Rolixmann I+II	Riemann Hof	Grosse Luebker	Klusacker	Sudendey	Lechtingen I+II+III
soil texture [a]		lS-tL	S	hlS	hlS	hlS	lS-sL	lS	lS
field size [ha]		3.2	2.5	7.1	3.3	5.8	6.3	1.9	5.9
Veris MSP	**n**	126	173	428	156	240	255	169	350
	pH min.	5.8	4.3	5.9	5.5	4.9	4.9	5.4	5.3
	pH max.	7.3	6.9	6.6	7.1	7.1	7.6	7.1	7.2
	Δ pH	1.5	2.6	0.7	1.6	2.2	2.7	1.7	1.9
	IQR_{50} [b]	6.3-6.5	5.1-5.8	6.1-6.3	6.1-6.6	5.9-6.6	6.6-6.9	6.1-6.3	6.0-6.7
	IPR_{90} [c]	6.1-6.9	4.8-6.4	6.0-6.4	5.8-6.8	5.6-6.9	5.9-7.2	5.9-6.5	5.6-7.0
manual	**n**	39		49		74			74
	pH min.	5.6		5.0		3.7			4.7
	pH max.	7.3		6.2		6.3			7.3
	Δ pH	1.7		1.2		2.6			2.6
	IQR_{50}	5.8-6.2		5.4-5.7		4.5-5.8			5.0-6.9
	IPR_{90}	5.7-7.0		5.1-5.8		4.0-6.2			4.8-7.2
r^2 (Veris MSP/manual)		0.51		0.36		0.58			0.79

[a] according to German soil classification: lS = loamy sand; S = sand; hlS = humic loamy sand; sL = sandy loam
[b] Interquartil range 25 – 75 %
[c] Interpercentil range 5 – 95 %

RESULTS AND DISCUSSION

On each of the fields of this series a considerable soil pH range (i.e. minimum versus maximum pH) was determined (Veris MSP: 0.7 - 2.7 pH units; manual: 1.2 - 2.6 pH units; Tab. 1). Based on the calculation of the interquartil ranges (IQR_{50};

i.e. pH range for 25 % above and below the median) and the interpercentil ranges (IPR_{90}; i.e. pH range for all samples without the 5 % lowest and 5 % highest values) it is obvious that in-field variability of soil pH for the fields of this study is relevant to be considered for management adaptations. A typical example is shown in figure 2 for field “Klusacker”: the pH ranges from 4.9 to 7.6 (Veris MSP pH data) and even at small-scale variation in soil pH is detectable providing evidence that a high sampling density is required to derive reliable lime application maps.

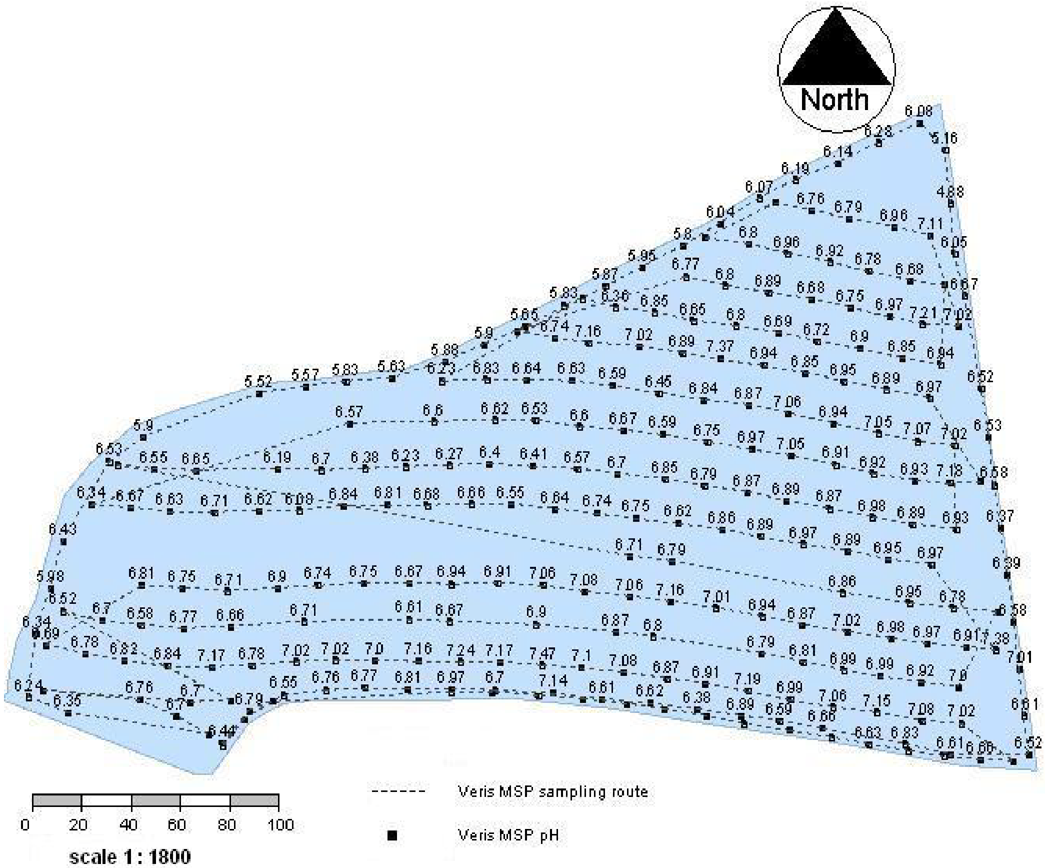

Figure 2. Spatial distribution of Veris MSP soil pH values on field “Klusacker”

To evaluate the impact of different sampling situations under practical farming conditions the Veris MSP was used 3 times on field “Haster Esch”. The spatial pattern visible in the 3 pH maps is similar. A zone with high pH values at the northern borderline of the field (pH 6.8 - 7.3) can be distinguished from a band (south-west to north-east direction) in the center of the field (pH 6.0 - 6.4).

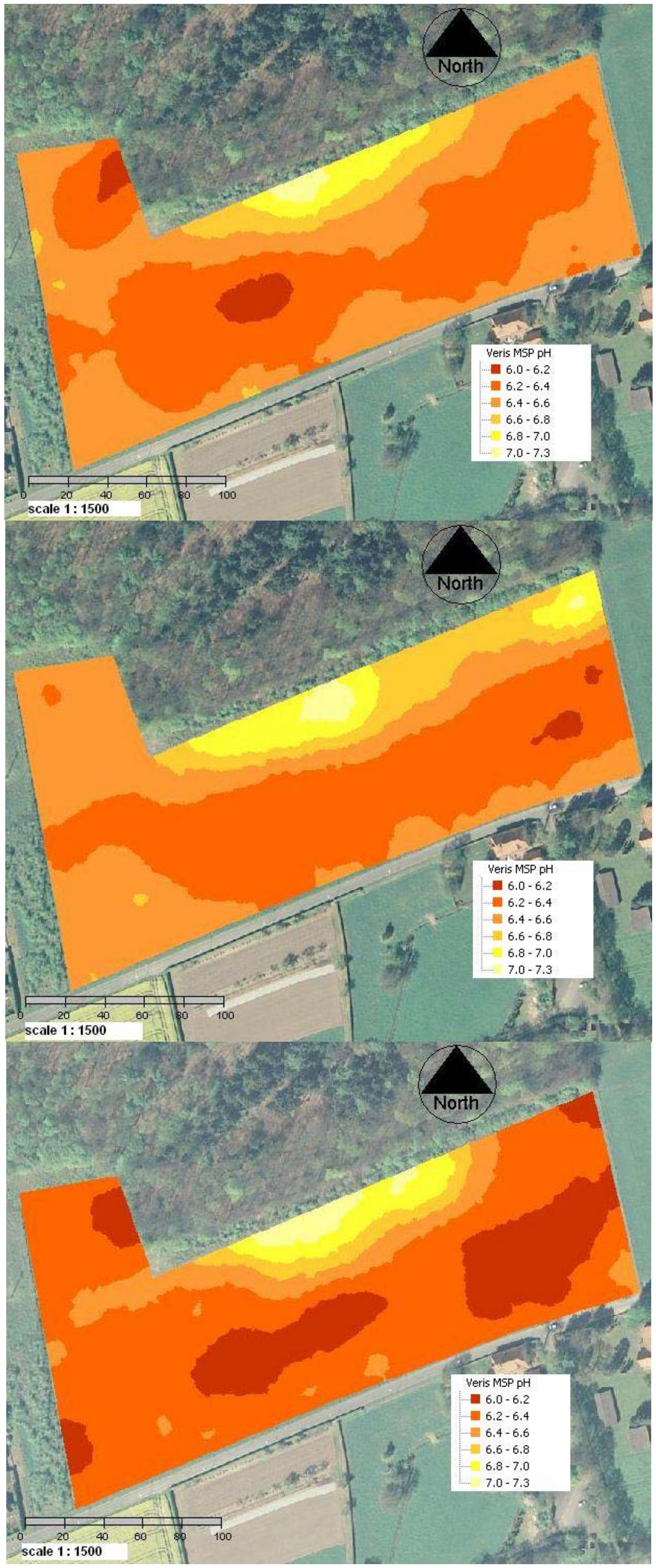

Figure 3. Soil pH maps for field "Haster Esch" (3.2 ha) based on Veris MSP data measured before (top), 1 day after farmyard manure application/soil tillage (middle) and again 5 days later following a slurry application/soil incorporation (bottom).

Comparing soil pH maps (after interpolation via Kriging) based on Veris MSP soil pH measurements with grid sampling (15 x 60 m grid) according to the German standard procedure reveals that a similar pattern of pH zones is identifiable. On the 6 ha field “Grosse Luebker” pH values are around pH 6 in the eastern part, while in the south-western section pH values are considerably lower (Fig. 4).

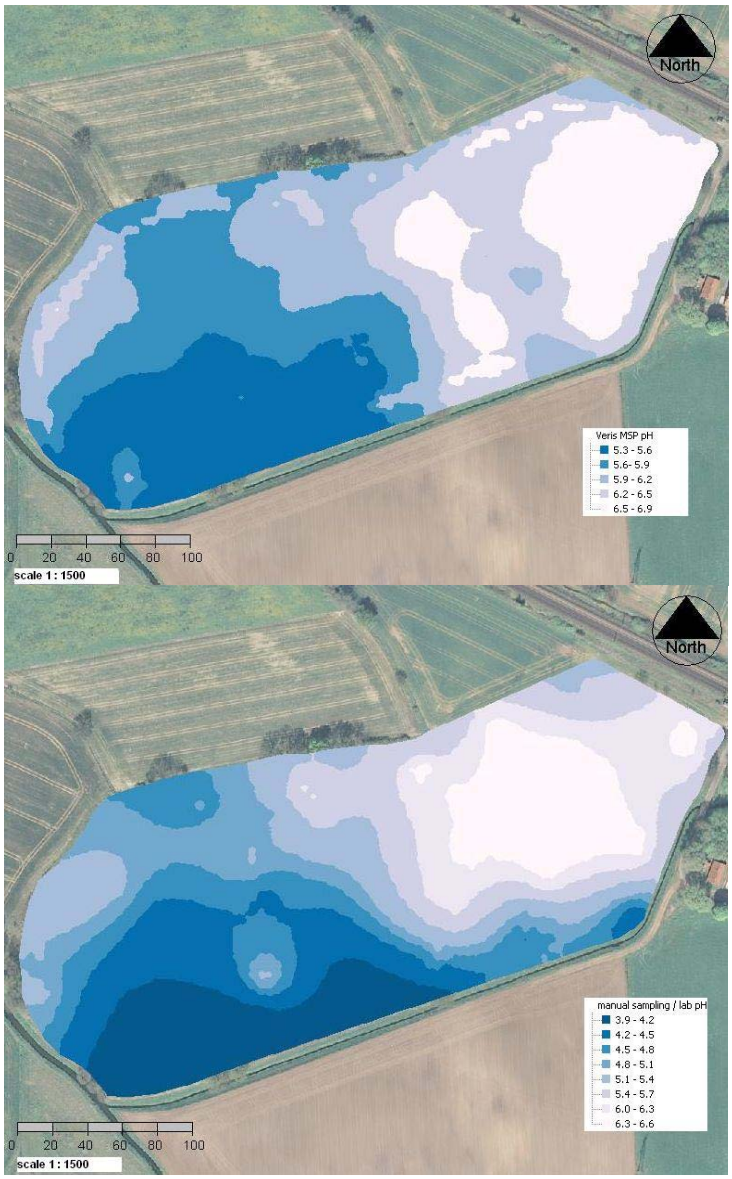

Figure 4. Comparison of soil pH maps for field “Grosse Luebker” (6 ha) based on Veris MSP data (240 measurement points; top) versus manual soil sampling (15 x 60 m grid = 74 samples; 0 - 30 cm soil layer) followed by lab analysis according to German standard procedure (bottom)

It is important to mention that the discrepancy between Veris MSP and manual sampling/lab analysis pH values is substantial especially in low pH zones.

This is in agreement with results presented by Staggenborg et al. (2007). It can be assumed that the prolonged reaction period under lab conditions (ca. 2 hours) and the use of a 0.01 molar $CaCl_2$ solution as extractant initiates an increased desorption of H^+ ions from binding sites at soil particles resulting in a decline of the measured pH value. Therefore the on-the-go pH determination at field scale has to be classified as a measurement of the actual pH in the soil solution (Erickson, 2004).

Regression analysis (Fig. 5) confirms that in our datasets the relationship between Veris MSP and German standard procedure pH values is somewhat lower compared to results presented by Lund (2004) for US based datasets. The coefficient of determination ranges from 0.36 to 0.79 (Fig. 5; Tab. 1) for the four investigated fields. The calculation of an overall coefficient of determination for this relationship for all four fields results in r^2=0.62.

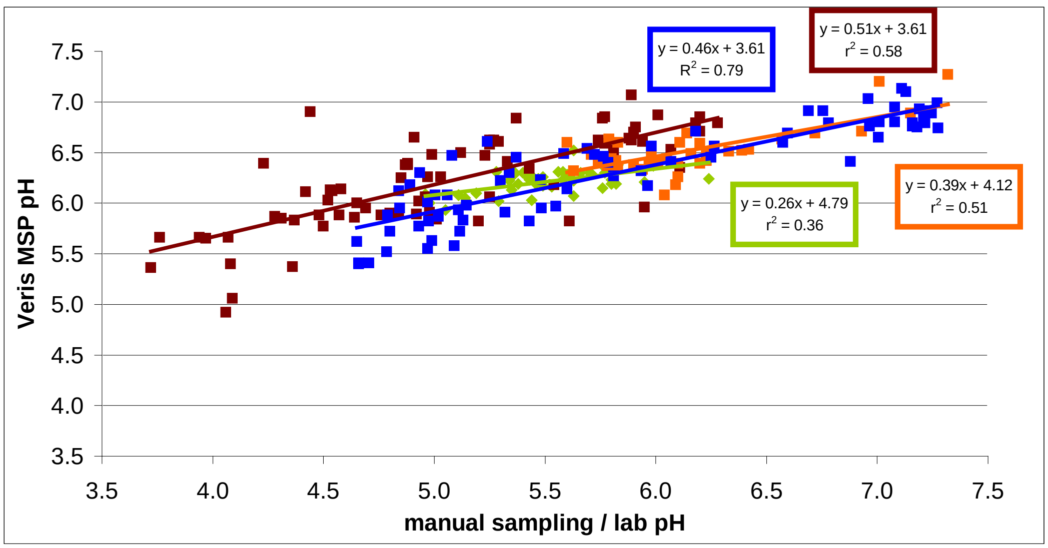

Figure 5. Relationship between soil pH based on manual soil sampling (0 - 30 cm layer) and lab analysis according to German standard procedure and Veris MSP pH values for 3 different fields (red = "Grosse Luebker"; green = "Rolixmann I+II"; orange = "Haster Esch"; blue = "Lechtingen I+II+III").

CONCLUSION

Soil pH is one of the most important soil characteristics affecting nutrient availability, soil microbial activity and plant growth. However, until recently spatial information on soil pH was hardly available. Using the soil pH mapping system Veris MSP detailed information on the in-field variability of soil pH can be obtained. Validation of Veris MSP pH values against pH values based on grid-sampled/lab analysed pH data resulted in acceptable correlation coefficients. However, at low pH values Veris MSP readings are consistently higher than lab based pH values indicating that a recalibration based on lab analysed soil samples at field level might be compulsory before a lime application map can be calculated. In proceeding field trials the Veris MSP pH mapping system will be further validated under German farming conditions (e.g. robustness of antimony electrodes; reproducibility of measurements; impact of soil conditions). Furthermore the economical return of management decisions (e.g. lime application) using on-the-go pH mapping will be compared with standard farm practice.

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