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On-the-go measurements of pH in tropical soil

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Abstract. *The objective of this study was to assess the performance of a mobile sensor platform with ion-selective antimony electrodes (ISE) to determine pH on-the-go in a Brazilian tropical soil. The field experiments were carried out in a Cambisol in Piracicaba-SP, Brazil. To create pH variability, increasing doses (0, 1, 3, 5, 7 and 9 Mg ha^{-1}) of lime were added on the experimental plots (25 x 10 m) one year before the data acquisitions. To estimate soil pH levels we used a Mobile Sensor Platform (MSP - Veris Technologies, Salina, USA) with two ISE. In each plot, six on-the-go acquisitions were performed. Soil samples were collected at each of this acquisition points and sent to a laboratory for soil pH determination using two methods: H_2O solution and $CaCl_2$ 0,01 M solution. The analysis of pH data showed that treatments were effective to create variability in soil pH, with a minimum pH of 5.6 and maximum of 7.4 determined in H_2O solution. The average pH was higher in ISE determinations (6.87) and decreased using H_2O (6.53) and $CaCl_2$ (5.92) methods. The correlation between the readings taken on-the-go and in the laboratory were 0.90 and 0.91 using H_2O and $CaCl_2$ methods, respectively. These results revealed a great potential of using a MSP to estimate soil pH in Brazilian soils. Despite the good correlation coefficients, it is necessary to account for the difference between on-the-go and lab results before using the data to recommend variable rate lime applications.*

Keywords. *Ion selective electrodes, mobile sensor platform, proximal soil sensing*

Introduction

Soil pH is a feature that directly affects the availability of nutrients for plants, influencing the yield potential of crops. Most Brazilian soils have medium to high acidity, thus, liming is a key to maximizing the efficiency of fertilizers (Alcarde et al., 1991).

In recent decades, the precision agriculture techniques aided by geostatistical tools have increased the understanding of the spatial variability of soil chemical and physical attributes. The variability of soil attributes are controlled by factors of soil formation such as climate, landscape, parent material and vegetation being affected by the intensification of land use and management practices (Mallarino & Wittry, 2004).

Cherubin et al. (2014) studied the spatial dependence of soil pH of 30 production fields, which were sampled using square grid schemes of 100, 142 and 173 m. The authors concluded that the sample densities used were not efficient to characterize the spatial variability of pH, which may compromise the accuracy of liming requirements for variable rates.

On the other hand, increasing the sample density to efficiently characterize the soil spatial distribution leads to an increase in cost, making the technique uneconomical. In this regard, in recent years there have been proposals of equipment capable of sensing the soil in real time with high sample density (Adamchuck et al., 2004; Gebbers & Adamchuck, 2010). One of these equipment aims to map the soil pH in the field using ion selective electrodes mounted on a mobile platform pulled by a tractor or pickup (Adamchuck et al., 2005).

Satisfactory results of soil pH mapping using this platform were observed in studies from United States (Adamchuck et al., 2005) and Germany (Schirrmann et al., 2011). Although the technique have higher uncertainty in the readings compared to those performed in the laboratory with prepared soil samples (dried, ground and sieved), high sampling density is able to compensate such effects and improve liming requirements for variable rate (Schirrmann et al ., 2011).

The lime requirements are governed by different methods in each Brazilian region. The most usual one uses bases saturation and cation exchange capacity (CEC) to define the exact requirements. Previous studies using 6,083 soil samples from Mato Grosso state showed good relation (r^2: 0.82/RMSE: 5,2%) between soil pH and bases saturation (Trevisan et al., 2014). Such relation could permit estimating soil bases saturation from pH values derived from ISE.

Even though good results have been observed in soils from temperate climates, the knowledge about the performance of these electrodes in Brazilian tropical soils is still incipient. In this sense, the objective of this study was to evaluate the performance of a mobile sensor platform with ion-selective antimony electrodes to determine pH on-the-go in a Brazilian tropical soil.

Material and Methods

The study was conducted in the southeast region of Brazil, in the municipality of Piracicaba, state of São Paulo. The experimental area is located at coordinates 22°41'57.24" S and 47°38'33.33" W.

The soil is classified as Cambisol (WRB-FAO, 2015). An experimental field with dimensions of 50 x 30 m was used to create soil variability of pH (figure 1). The field was subdivided into six plots (25 x 10 m) and different levels of lime (0, 1, 3, 5, 7 and 9 Mg ha^{-1}) with relative neutralizing value of 70% were added to each plot.

The system used in this study is from Veris Technologies (Salina, Kansas, USA). The mobile sensor platform (MSP) uses two principles of sensing to collect high-density soil data: electrical and electrochemical. In this study, we used data collected by the electrochemical sensors. Two electrodes working with a soil sampler performed the soil data acquisitions (Figure 1).

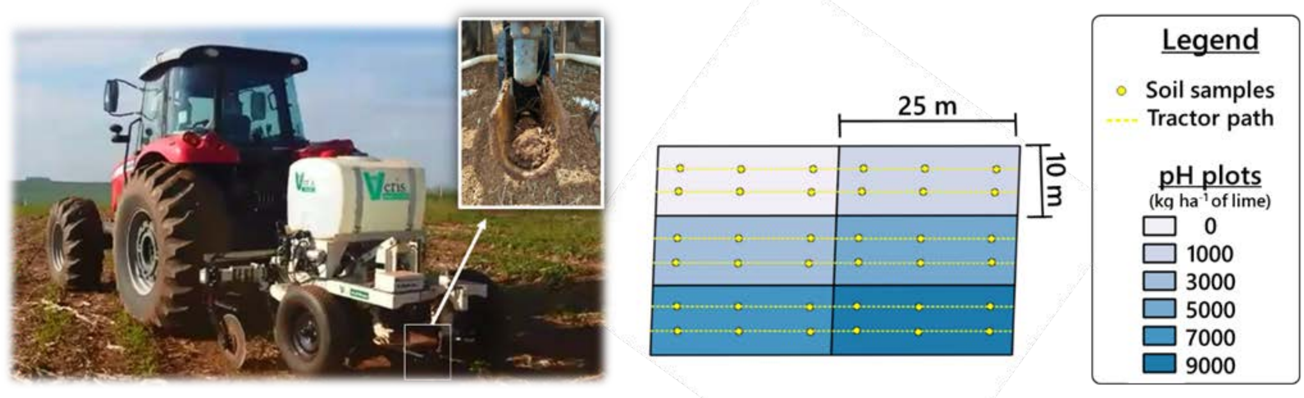

Figure 1. Mobile sensor platform in the field with close look in the sampler system (left) and the plots where the acquisitions were performed (right).

The ion selective antimony electrodes (ISE) determine instantaneous soil pH in the soil sample collected by the sampler shank. Each new sample is collected at approximately 20 seconds interval so the spatial density depends on the speed and the swath widths. In this study the tractor speed was around 0.4 m s^{-1} with 3 m swath widths inside each experimental plot (Figure 1). Using this configuration, six acquisitions of pH were taken in each plot, making a total of 36 samples in the experimental field.

Soil samples were collected exactly in the same points where the ISE performed the acquisitions. The samples were sent to the laboratory of soil analysis from the University of São Paulo and soil pH was determined using two methods: H_2O solution and $CaCl_2$ 0,01 M solution.

The statistical procedures consisted of descriptive statistics, correlation analysis between on-the-go and laboratories readings and linear regression analysis, assuming that laboratory readings represents the reference values. The quality of prediction was expressed by the mean absolute error (MAE).

Results and Discussion

The descriptive statistics showed that the average values of pH collected in the field were higher than that determined in laboratory (Table 1). As expected, the average of pH determined using $CaCl_2$ method was lower than the H_2O method, which occurs because this method can measure also weaker acids contained in soil. The standard deviation of laboratory and on-the-go measurements were similar, demonstrating practically the same amplitude independently of the method used.

Table 1. Descriptive statistics and correlation coefficient of pH determined on-the-go and in-lab using H_2O and $CaCl_2$ methods.

Method	Mean	Min.	Max.	Median	SD	Correlation coefficient	
						pH on-the-go (MSP)	pH Lab. (H_2O)
pH on-the-go (MSP)	6.87	6.00	7.70	7.05	0.52		
pH Lab (H_2O)	6.53	5.60	7.40	6.70	0.54	0.90	
pH Lab. ($CaCl_2$)	5.92	4.90	6.80	6.15	0.60	0.91	0.98

In Figure 2A we can visualize the soil pH as a function of limestone added to each treatment, each point in the graph represents the average of six samples. The pH determination method using $CaCl_2$ had lower results, followed by the method of water and on-the-go determinations.

There is a high correlation between the field and laboratory readings, however, as visualized by Schirrmann et al. (2011), to make full use of the on-the-go measurements, it is important to establish calibration models that convert the sensor readings into pH ($CaCl_2$ or H_2O) or bases saturation which is the main input for calculating lime requirements. In this study, just one field was investigated, but other works (Adamchuk et al., 2007; Schirrmann at al., 2011) have demonstrated the deviation between pH measurements on-the-go and in laboratory is different from each field, so field-specific calibration is necessary to reduce systematic errors.

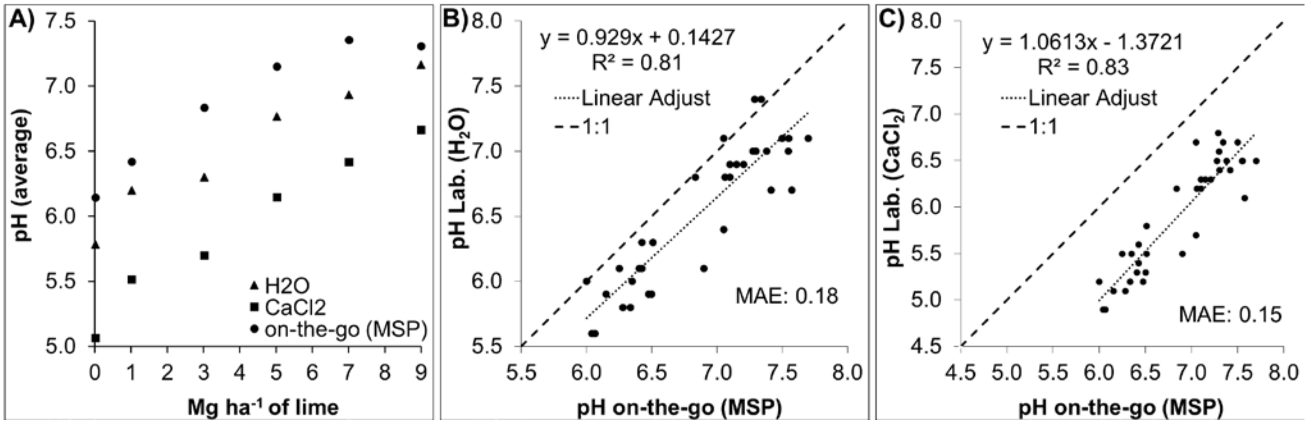

Figure 2. Relationships between applied limestone and pH determined on-the-go and in-lab using H_2O and $CaCl_2$ methods.

In this sense, linear equations were fitted to the data, which can be used to correct field acquisitions (Figure 2B and C). The linear regression coefficients between on-the-go and H_2O or $CaCl_2$ measurements were high, 0.81 and 0.83, respectively. The MAE of the estimative was low, 0.18 to H_2O method and 0.15 to $CaCl_2$. These results are comparable to the best results found in different fields investigated by Adamchuk et al. (2007) and Schirrmann et al. (2011).

In this experiment, using a linear regression to correct the data from the field was a good alternative but considering that the slope coefficient in the equations (0.93 and 1.06) were very close to 1, the correction can be made simply by just applying a shift in the on-the-go data to predict laboratory values. Adamchuk et al. (2007) suggested that applying a shifting in MSP pH measurements for the entire field is a more appealing technique than attempting to adjust values using linear regression.

Conclusion

The performance of a mobile sensor platform to estimate soil pH on-the-go was good, with coefficient of correlation between on-the-go and laboratory of 0.90 and 0.91 and mean absolute error of estimative of 0.18 and 0.15 using pH determined by H_2O and $CaCl_2$ methods, respectively. These results revealed the potential of using a MSP to estimate soil pH in Brazilian soils and a need for investigating this type of equipment in other conditions. Despite the good correlation coefficients, it is necessary to account for the difference between on-the-go and lab results before using the data to recommend variable rate lime applications.

This work is part a series of evaluations in progress using MSP in Brazilian tropical soils.

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