SOIL pH AND LIME MANAGEMENT FOR CORN AND SOYBEAN: AN ONGOING ON-FARM PROJECT

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Introduction

Soil acidity can affect plant growth directly and indirectly by affecting the plant-availability of nutrients, levels of phytotoxic elements, microbial activity, and other soil properties. Soils may become acidic in the long term as a result of several natural processes. In the short term, however, soil acidity develops mainly due to application of N fertilizers or manure, primarily those having high concentrations of ammonium or urea because nitrification releases hydrogen (H) ions. Soil pH decreases as the acidity increases because pH expresses acidity as the negative logarithm of concentration (activity) of H^+ ions. Soils have a capacity to hold H^+ ions (often referred to as reserve acidity) with the magnitude depending largely on the clay and organic matter content, i.e. the cation exchange capacity. Soil pH is used to determine whether or not to lime a soil, but does not indicate the quantity of acid that needs to be neutralized. Direct determination (titration) of soil acidity seldom is used, and instead a buffer pH test is used to determine lime rate requirement. Buffer solutions are designed to have a large capacity to resist change in pH. Therefore, the amount of lime needed to increase soil pH to a desirable level can be estimated by mixing a buffer solution of known pH with soil and measuring the resulting pH change. Low buffer-pH values indicate high reserve acidity and large lime requirement.

In Iowa, as in many Midwestern states, the Shoemaker-McLean-Pratt (SMP) buffer is used to estimate the lime requirement of soils (Shoemaker et al., 1961; Watson and Brown, 1998). Buffers used in other states are original or modified versions of Woodruff (Woodruff, 1948; Watson and Brown, 1998), Adams-Evans (Adams and Evans, 1962), or Mehlich (Mehlich, 1976) methods. Solutions used in these buffers were developed before federal laws regulated disposal of hazardous waste due to ignitability, corrosivity, reactivity, or toxicity. Chemicals in this category are p-nitrophenol and potassium chromate in the SMP buffer and barium chloride in the Mehlich buffer. Work has been done recently to develop alternative buffers for determining lime needs without using these hazardous chemicals. Hoskins (2005) and Wolf and Beegle (2005) modified the Mehlich buffer by replacing barium chloride with calcium chloride. A disadvantage of the modified Mehlich buffer is a shelf life of only a few weeks. Sikora (2006) replaced potassium chromate and p-nitrophenol in the original SMP method with 2-(Nmorpholino) ethanesulfonic acid monohydrate (MES) and imidazole. He compared the two buffers for many soil samples from Kentucky and other regions. He concluded that the modified buffer produced the same buffer pH value as the SMP buffer and had good stability over 150 days. Godsey et al. (2007) evaluated the SMP and modified Mehlich buffers in Kansas soils with laboratory soil incubations and field limestone application. They reported that buffer pH values were significantly lower for the modified Mehlich buffer, and that with local calibration this method would predict lime requirement better than the SMP buffer.

Iowa State University (ISU) recommendations (Sawyer et al., 2002) suggest lime applications for grass hay or pastures, corn or soybean, and alfalfa when soil pH is < 6.0, < 6.5, and < 6.9, respectively. However, a pH of 6.0 is considered sufficient for corn and soybean for soil series with free carbonates at a shallow depth. Research to update these recommendations is needed because of changes in production practices and yield levels since the original supporting research was conducted. Also, a few recent field trials confirmed the need for lime in strongly acid soils, but results from other trials, mainly in soils with calcareous subsoil, suggested pH values lower than currently recommended might be sufficient for corn and soybean. Therefore, an on-farm long-term project was initiated in 2007 to assess within-field soil pH variability, evaluate alternative (to the SMP) buffer pH methods, and measure corn and soybean response to lime application. This report summarizes second-year results.

Materials and Methods

Ten replicated trial sites were established in Iowa farmer fields. Five sites were established in 2007 and five in 2008. Five more trials were established in 2009 but no results can be shared at this time. The project used dense soil sampling and precision agriculture technologies based on replicated lime treatments applied to long strips. Custom applicator equipment, yield monitors, GPS, and GIS are used for lime application and data management and analysis. Treatments are no lime or a uniform lime rate of 3 ton/acre of effective calcium carbonate equivalent (ECCE). Each treatment was replicated three to five times. The CCE application rate applied ranged from 3.7 to 5.9 ton/acre across fields due to differences in limestone fineness. Table 1 summarizes site information. The trials will be evaluated for at least 4 years. Results are available for the first year from ten sites and the second year from five sites. Nine fields were managed with chisel-plow/disk tillage and one with no-tillage.

Soil samples were collected from a 6-inch depth before applying lime using a dense grid sampling approach (0-3 and 3-6 inches for no-till fields), by which one 12-core composite sample was collected from cells ranging from 0.3 to 0.5 acres depending on the field strip size. Post-harvest soil samples were collected each fall from limed soil sampling cells after one corn or soybean crop and were analyzed for pH to calculate the change from initial pH due to lime application. Soil pH and SMP buffer pH were measured on collected soil samples using methods recommended for the North Central Region (Watson and Brown, 1998). The Sikora buffer pH was measured as suggested by Sikora (2006) and the modified Mehlich buffer pH was measured as suggested by Hoskins (2005). The soil:water:buffer ratio was 1:1:2 for the SMP method and 1:1:1 for Sikora and Mehlich methods. Buffer solution pH is 7.5 for SMP, 7.7 for Sikora, and 6.6 for modified Mehlich. The pH and buffer pH results from initial soil samples (before applying lime) as expected showed large within-field variation for both measurements. Therefore, the soil-test data from each sample cell were used to compare buffer pH methods within and across fields.

Grain yield was harvested with farm combines equipped with impact flow-rate yield monitors and differential GPS receivers. A sensor located in the grain augers measured grain moisture, and yield was adjusted to moisture contents of 15.5 % for corn and 13.0 % for soybean. Yield data used for the study were unaffected by borders because experimental areas were away from field borders and data from combine passes that included border rows between strips were not used. Yield monitor data were imported into ArcGIS, analyzed for common yield monitor problems

(Mallarino et al., 2000) such as effects of waterways or unplanned combine stops, and affected data were deleted. Relative yield responses to lime application were calculated for small areas defined by the length of the soil sampling cells along crop rows and the width of the combine passes for each strip.

Summary of Findings

Very large soil pH and yield response variability along the long strips confirmed the value of using dense soil sampling, yield monitors, and GPS for this on-farm research using strip trials. The within-field variability of initial soil pH and organic matter for cells sampled along the strips was large in all fields (Table 1). Study of only average soil pH and buffer pH values for each site would have resulted in a much lower range of values and likely misleading conclusions regarding crop response to lime application and field area requiring liming. The first-year crop yield responses from the sampling cells (ten sites) indicated a high probability of a response to lime application for soil pH < 6.0 and a smaller response for pH 6.0 to 6.5 (Fig. 1). The magnitude of these one-year yield responses was small, but previous research has demonstrated a larger long-term impact of lime application over time. Fig. 2 shows relative yield response in the first and second years after applying lime for the set of five sites for which second-year results are available. Those results indicate no consistent differences for yield responses between the first and second years, and confirm the importance of evaluating yield response for several years after applying lime.

Average lime application effects on soil pH for each field are shown in Fig. 3. Application of 3 ton ECCE/acre increased pH by 0.5 to 1.5 units across the ten trials. The additional pH increase during the second year (available only for the first five trials at this time) was only 0 to 0.4 pH unit. This indicates additional pH correction beyond one year of lime reaction with the soil.

The buffer pH values for the Sikora and Mehlich buffer methods correlated well with the currently used SMP method within and across the ten sites (Fig. 4). The coefficients of determination across all samples was high for all relationships ($r^2 = 0.84$ to 0.95), being lowest between SMP and Mehlich and highest between Sikora and Mehlich. We expected that the highest correlation would be between the SMP and Sikora methods. Analyses of results by field or for each soil series included in the study (the two most dominant soil series at each site are listed in Table 1) did not show important deviations from the general relationship (data not shown). The data and statistical analysis of relationships for the SMP and Sikora methods indicated that buffer pH means did not differ significantly and that the slope of the regression line did not differ from 1.0 ($P \leq 0.05$). A similar result was found in research with soils of other regions (Sikora, 2005; Peters and Laboski, 2007). In spite of a good correlation for the Mehlich method, the results showed that the buffer pH values for this method were significantly lower than for the SMP and Sikora methods, which is a consequence of the type of buffer used. This difference also was found with other soils of the Midwest (Godsay et al., 2007; Peters and Laboski, 2007), although the difference varied greatly across states. This confirms the need for local calibrations when using buffer pH methods to determine lime requirements.

Study of relationships between buffer pH values by the three methods and initial soil pH showed a significant relationship for all methods ($r^2 = 0.56$ to 0.61), although the slope of the regression lines was significantly different for 2007 and 2008 (not shown). Adding organic matter as a second variable to the equation relating soil pH and buffer pH did not result in a statistically significant improvement for any buffer method, which as in contrast to findings for Wisconsin soils based on incubations (Peters and Laboski, 2007). In fact, and contrary to expectations, we found a very poor (r^2 = 0.05 to 0.16) and statistically non-significant relationship between buffer pH values and soil organic matter across all fields (not shown). Moreover, the soil pH change due to the 3 ton ECCE/acre was negatively correlated with with initial pH (r^2 = 0.44) but was very poorly related to soil organic matter (r^2 = 0.14). This result might be explained by large effects of soil texture variation (texture has not been measured yet) and relatively small variation of organic matter levels in these soils (Table 1).

The research (treatments) used in this study did not allow for field calibrations of lime requirement equations for the buffer pH methods because only one limestone rate was applied in all fields. Also, the available post-lime pH data at this time are only for the first and second year for some trials. Previous research has shown that agricultural limestone often continues raising soil pH two to three years after being applied. A field calibration study is needed for the Mehlich buffer and also to confirm equations for the SMP and Sikora methods. A study with this objective was started this year using conventional field plots and various rates of lime.

Preliminary Conclusions

Firm conclusions and economic analyses will be possible only after results from at least three years of these field sites are available. The preliminary results suggested, however, that corn and soybean have a high probability of significant yield response to lime application for soil pH < 6.0 and a small response for pH 6.0 to 6.5. Comparison of first-year pH change from application of a single limestone rate indicated that SMP, Sikora, and Mehlich buffer methods would be similarly effective at estimating lime requirement of Iowa soils. Because the SMP and Sikora buffer pH values were essentially the same, current calibrations and recommendations for the SMP method can also be used for the Sikora method. An advantage of the Sikora buffer method is that it does not include hazardous chemicals. Use of the Mehlich buffer to estimate lime requirements would require new field calibrations, which could not be determined with the treatments used. The study will continue by evaluating more years of the ongoing strip trials and by conducting multi-rate trials to improve the calibration of buffer pH methods.

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Table 1. Summary of site characteristics and the mean and range of soil sample results for grid sample points in the replicated strips.

			Dominant soil series					Limestone
Site	year	County	First	Second	n†	pH (range)	OM‡ (range)	application§
							%	
1	2007	Jasper	Clarion	-	32	6.0 (5.6-7.3)	3.3 (2.2-4.4)	May 18 2007
2	2007	Story	Webster	Nicollet	40	6.0 (5.7-7.2)	4.4 (2.7-7.2)	May 25 2007
3	2007	Boone	Canisteo	Nicollet	36	5.2 (4.8-6.0)	3.8 (2.6-5.2)	Nov 14 2006
4	2007	Greene	Canisteo	Okoboji	32	6.5 (5.1-8.1	5.2 (3.6-7.8)	Oct 28 2006
5	2007	Boone	Talcot	Dickman	40	5.0 (4.6-5.8)	3.3 (1.2-4.7)	Jan 27 2007
6	2008	Cedar	Dinsdale	Muscatine	36	5.5 (5.2-6.7)	3.4 (2.3-3.8	May 12 2008
7	2008	O'Brien	Primghar	Galva	36	5.5 (5.2-6.0)	5.2 (4.5-5.7)	Nov 9 2007
8	2008	O'Brien	Galva	-	36	5.9 (5.2-6.7)	4.9 (4.5-6.0)	Nov 9 2007
9	2008	O'Brien	Marcus	Primghar	36	5.7 (5.5-6.1)	6.9 (5.3-9.2)	Apr 15 2008
10	2008	Union	Sharpsburg	Clarinda	19	5.6 (4.8-6.2)	4.0 (3.4-4.7)	Apr 28 2008

† n, number of samples (grid cells).
‡ OM, organic matter.
§ The limestone was incorporated by chisel-plow/disk or disk tillage at Sites 1 through 9 but was not incorporated at Site 10 (a no-till field).

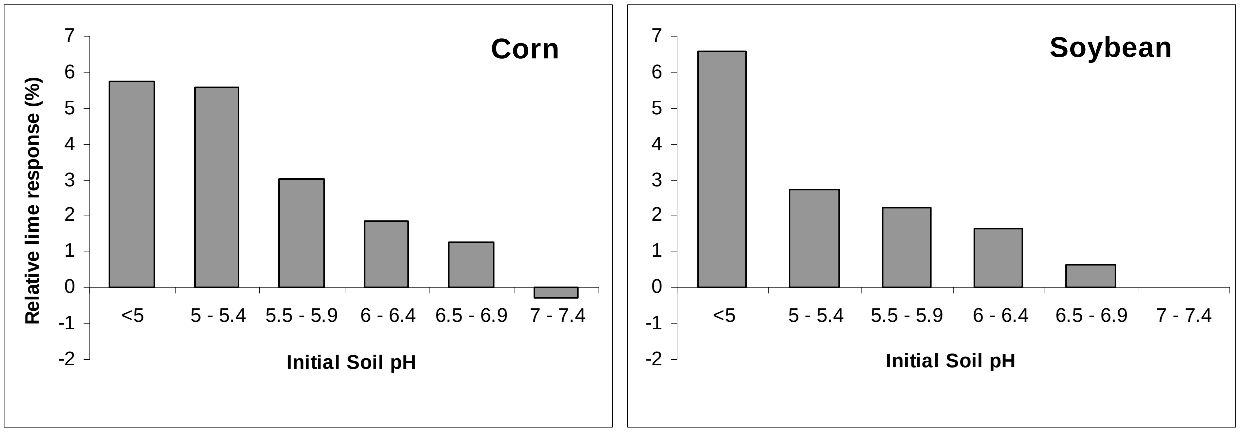

Fig. 1. Grain yield response (relative to no-lime control) of corn and soybean to 3 ton ECCE/acre for several soil pH ranges, 2007 and 2008.

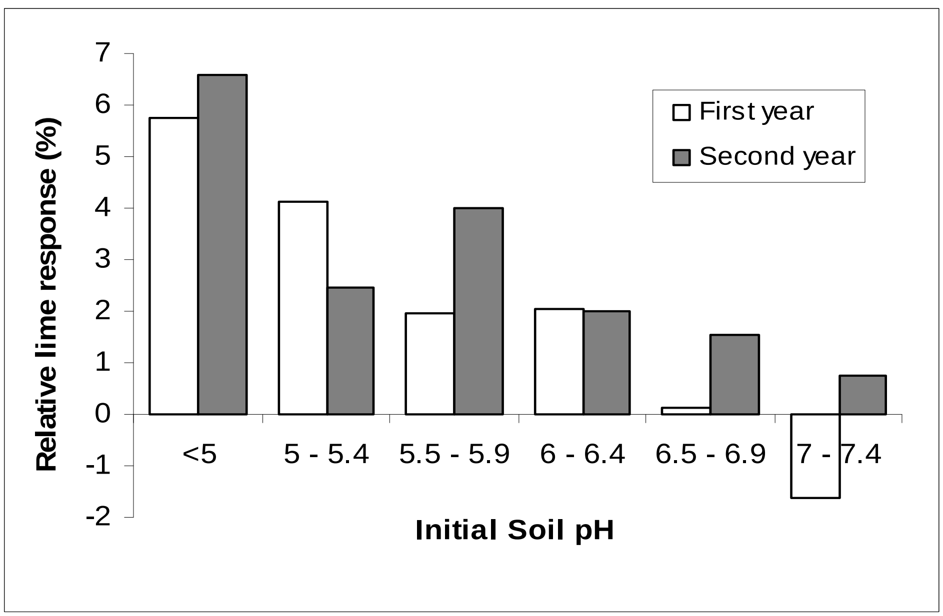

Fig. 2. Grain yield response (relative to no-lime control) of corn and soybean to 3 ton ECCE/acre for several soil pH ranges in the first (2007) and second year (2008) for sites 1 to 5.

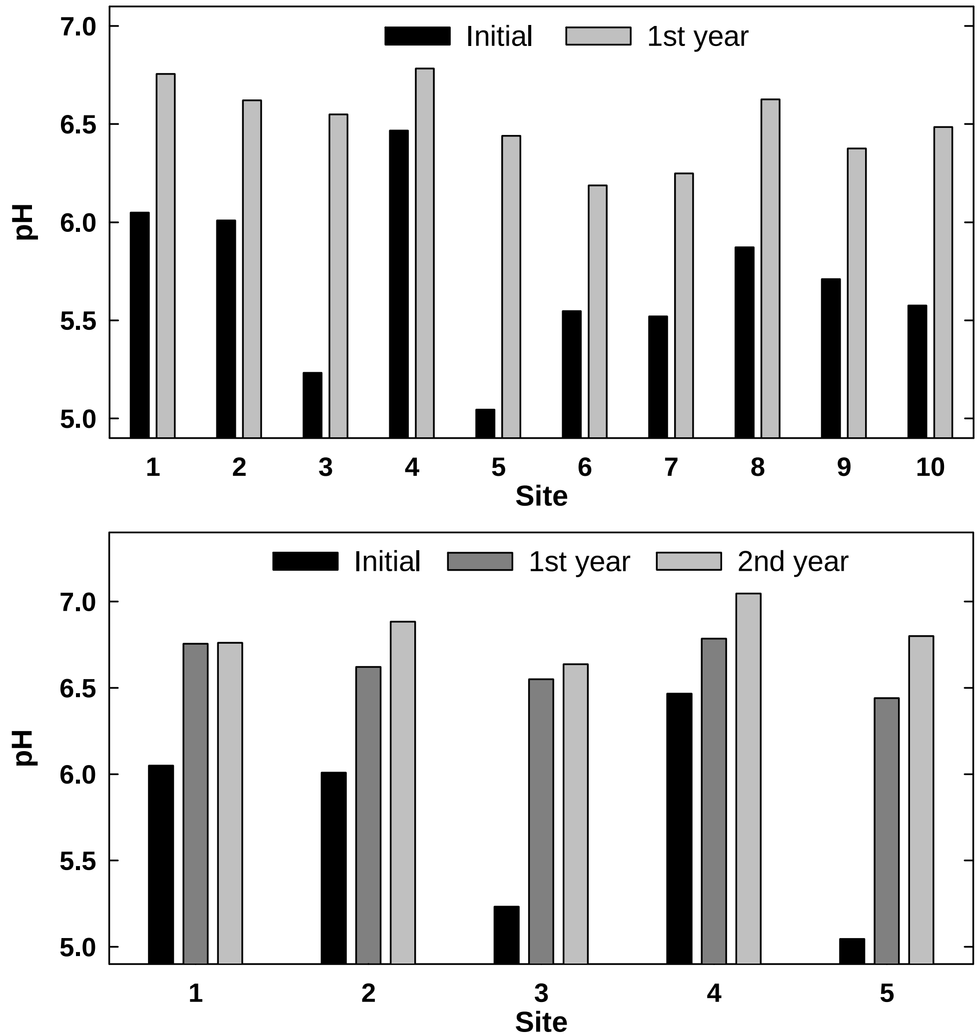

Fig. 3. Soil pH as affected by 3 ton ECCE/acre after the first crop year (average across densely sampled strips from 10 sites) and after the second crop year (from 5 sites).

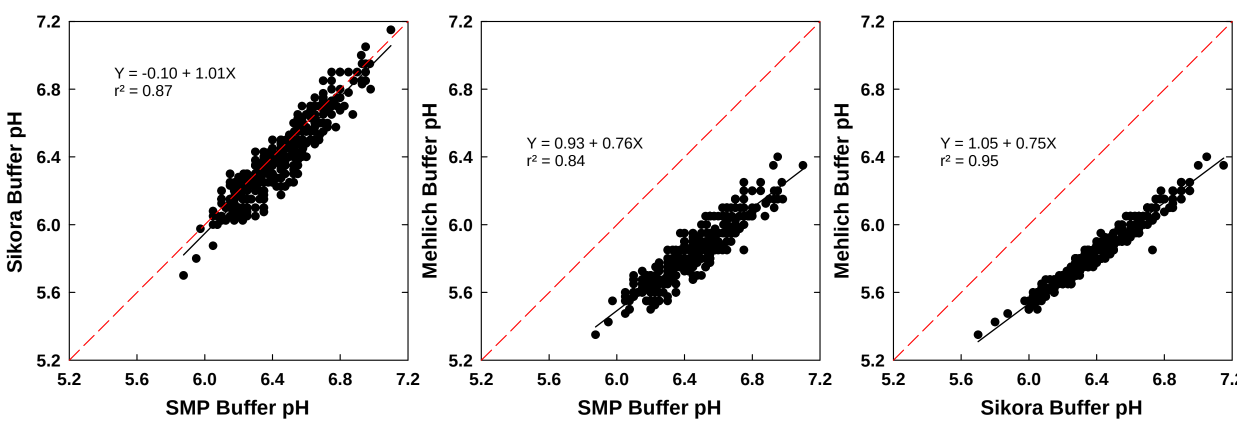

Fig. 4. Relationship between SMP, Sikora, and Mehlich buffer-pH methods for densely sampled strips in ten fields before lime application. The dashed lines show a 1:1 relationship.

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