Corn and soybean response to soil pH level and liming

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Soil pH and crop yield

Limestone application to raise soil pH is needed when the pH is too acidic to allow for optimum crop growth and yield. Some Iowa soils are naturally acidic, and others become acidic over time mainly due to sustained N application for corn with urea or ammonium-based products that acidify soils during the microbial transformation of ammonium to nitrate (nitrification). Soil pH decreases as the acidity increases because the pH measurement expresses acidity as the negative logarithm of H^+ ion concentration. Alfalfa is the most sensitive crop to low pH grown in Iowa, while forage grasses are the least sensitive and corn and soybean are intermediate. Soil acidity can affect plant growth directly or indirectly by affecting the plant-availability of several nutrients, increasing levels of some elements to phytotoxic concentrations, and influencing microbial activity or other soil properties.

Soil particles have the capacity to hold exchangeable H^+ ions (often referred to as reserve acidity) in much higher concentrations that the concentrations of H^+ in the soil solution. The amount of reserve acidity depends largely on the soil pH and clay and organic matter concentrations. Soil pH is and should be used to determine whether a soil is too acidic and requires liming, but pH by itself does not indicate the quantity of active or reserve acid that needs to be neutralized and the amount of lime to apply. In Iowa and most states, the amount of lime needed to increase soil pH to a desirable level is estimated by mixing a strong buffer solution of known pH with soil and measuring the resulting pH change. Low buffer pH values indicate high reserve acidity and higher lime requirement, and research with different soils and pH values are used to determine the lime requirement to raise pH to a certain value. A few states use some indicators such as pH, texture, and/or organic matter instead of buffer pH, while a few others use buffer pH together with some of these soil properties.

Current pH and lime management guidelines for corn and soybean

The current Iowa State University (ISU) soil pH and lime application guidelines (extension publication PM 1688) have not changed in the past 30 years (Sawyer et al., 2002). For most Iowa soils, the guidelines suggest lime application for grass hay or pastures, corn or soybean, and alfalfa when soil pH is < 6.0, < 6.5, and < 6.9, respectively. A pH of 6.0 is considered sufficient for corn and soybean in regions with high-pH (calcareous) subsoil, however, although when the soil is to be limed the suggestion is to apply the amount of lime needed to raise pH to pH 6.5. These regions include the soil association areas Clarion-Nicollet-Webster in north-central Iowa (the Des Moines Lobe) and Galva-Primghar-Sac, Moody, Ida-Monona, Marshall, and Luton-Onawa-Salix in western Iowa. These guidelines were based on research conducted during the 1960s through the late 1970s using many lime application rates, mainly by ISU researchers Drs. John Hanway, John Webb, and Dr. John Pesek.

The information used to develop the guidelines is largely unpublished or was summarized in partial annual progress reports of ISU research farms or other brief reports. A summary for long-term experiments with corn and soybean on acid soils at the Moody and northeast research farms and two other short-term experiments in Crawford and Plymouth counties (Voss, 1991) showed clear responses at the extreme northwest (Moody) and northeast Iowa sites, but small and erratic responses at the western Iowa sites. Early progress reports for a long-term experiment with continuous corn established by Drs. Webb and Pesek in the early 1960s in a Webster soil having slightly acid surface soil (pH of 6.1) and calcareous subsoil at the Northern research farm showed very small or no yield response to annual small rates of lime (225 to 900 lb CCE/acre). A summary of an experiment Dr. Webb conducted with corn-soybean rotations in acid soils northwest research farm (Mallarino, 1991, unpublished) indicated moderate yield responses to lime, and a slightly higher relative response from soybean than from corn.

More recent research has shown variable corn and soybean responses to lime across Iowa soils having average pH as low as 5.3 to 5.8; which has generated questions about optimum pH values for these crops and how appropriate are the current lime application guidelines. An on-farm study conducted from 1998 to 2000 evaluated uniform and variable-rate lime application for corn and soybean in two central Iowa fields having soils with high-pH subsoil

(Bianchini and Mallarino, 2002). They found a small yield increase only for corn in one year at one field. Dr. Stanley Henning conducted long-term experiments with corn and soybean from the late 1980s to the middle 2000s at three ISU research farms. He found no yield responses at the Armstrong (southwest) research farm where soils have high-pH subsoil (Henning, 2007), small or no responses at the southeast research farm in a soil without high-pH subsoil (Henning, 2004), and large responses at the northeast research farm in a soil with no high-pH subsoil (Henning, 2001, 2004, 2008). Summaries of the most recent years of the long-term study with continuous corn and annual lime rates at the northern research farm showed small and statistically not significant yield corn response to lime (Mallarino and Rueber, 2003). A long-term experiment conducted from the middle 1990s to the middle 2000s at the northwest research farm (Kassel, 2004) evaluated different rates of lime for corn-soybean rotations managed with different tillage systems. This is a region classified as having high-pH subsoil, and they reported small to moderate yield responses from soybean but no response from corn. Results of two recent studies that compared aglime and eggshells in the northern and northwest research farms (both areas being classified as having high-pH subsoil) showed small soybean yield increases at the northwest farm but no corn yield increases at any location (Holmes et al., 2011).

In recent years, questions also have been raised by laboratories about buffer pH methods to determine lime requirement that do not include chemicals classified as hazardous by EPA. The method that has been used in Iowa and most Corn Belt states for decades (Shoemaker-McLean-Pratt, or SMP buffer) includes such chemicals, and makes the test for lime requirement more expensive due to EPA disposal regulations. Therefore, there is interest in comparing new buffer pH methods in Iowa soils, such as the Mehlich and Sikora buffer methods because they do not include hazardous chemicals, but no research has been conducted in Iowa to evaluate these methods. The Mehlich buffer pH method should not be confused with the Mehlich-3 extractant used for phosphorus (P), potassium (K), and other nutrients.

Objectives of new research

An on-farm research project was initiated in 2007 with corn and soybean to address several of the questions indicated above. The objectives were to (1) study within-field soil pH and buffer pH variability, (2) compare the new buffer pH methods Mehlich, Sikora, and the the currently used SMP method for estimating lime requirement, and (3) study the variation of crop response to lime within fields and re-evaluate soil pH values currently considered optimum for corn and soybean in some important Iowa soils.

Summary of procedures for on-farm strip trials

Fourteen strip trials were established staggered over three years to avoid applying lime the same year in all trials. The first crop year was 2007 with five trials, 2008 with five other trials, and 2009 with four trials. All trials will be evaluated across four years. Therefore, the trials currently have been evaluated four, three, and two years for the trials established in 2007, 2008, and 2009, respectively. Results for yield and soil pH for the 2011 crop year were not available when this article went to print, and results for the last year of four trials will not be available until late fall 2012.

Two aglime treatments were no aglime and 3 ton of Effective Calcium Carbonate Equivalent (ECCE)/acre applied only once before the first corn or soybean crop. Most fields were managed with corn-soybean rotations, but some farmers planted two years of corn in a few fields. The treatments were replicated 4 to 5 times with the only exception of one narrow and long field where only two replications fit when borders were excluded. The trials were in Boone, Cedar, Crawford, Greene, Jasper, O'Brien, Pottawattamie, Ringgold, Story, and Union counties. Management practices other than lime application were those used by each farmer. Nine fields were managed with chisel-plow/disk tillage, four with no-till, and one with strip-till. The trials were conducted using precision agriculture technologies such as yield monitors, GPS, and GIS.

Soil samples were collected from a 0- to 6-inch depth in tilled fields and from depths of 0-3 and 3-6 inches in the no-till fields using a dense grid-sampling approach. Composite samples (12 cores) were collected before applying lime from cells 0.3 to 0.5 acres in size (19 to 48 initial samples per field). Soil samples also were collected after crop harvest of each year from the limed and non-limed portions of each initial grid cell. All initial soil samples were analyzed for pH and by the SMP, Mehlich, and Sikora buffer pH methods. All post-harvest soil samples were analyzed for pH to measure soil pH change due to the lime application and differences between limed and non-limed treatments over time.

The yield monitors were calibrated by weighing grain harvested along combine passes outside the experimental areas, and the monitors recorded yield and grain moisture values at one-second intervals. The yield monitor spatial accuracy was checked in several field locations with a hand-held GPS receiver with differential signal correction. In two years of one trial, grain was harvested by hand from sections delimited by each grid soil sampling cell along each strip because the farmer did not have a yield monitor. The grain yield and moisture records were imported into ArcGIS software for processing. Data were unaffected by borders because at least 60 feet at each strip end were harvested but not used and at least two crop rows on each side of a strip border were not used. Any data affected by common yield monitor problems (such as unexpected combine stops or waterways) were deleted. ArcGIS software was used to calculate averages for areas defined by each treatment strip, and also for field areas defined by each strip intersecting soil series polygons of digitized soils survey maps, grid soil sampling cells, and field areas with initial soil pH testing within several defined pH ranges.

Within-field initial soil pH and buffer pH variation

Data in Table 1 show that there was substantial initial soil pH variation and only slightly lower SMP buffer pH variability within each trial. The pH variability was especially high at Fields 1, 2, 4, 6, 8 and 10, where differences between the pH range was as high as 1.4 to 3.0 pH units. Variability of buffer pH was relatively lower than for pH, and was higher at Fields 1, 4, and 10. Other descriptive statistics for each soil series at each field (not shown) also showed substantial pH and buffer pH variation. These results confirm the value of dense soil sampling, GIS, and GPS for field-scale on-farm research and also for soil sampling and testing for production agriculture as shown in previous sampling or on-farm lime studies (Bianchini and Mallarino, 2002; Mallarino and Wittry, 2000, 2001, 2004; Mallarino and Wittry, 2004). Use of average values even for the smallest experimental areas at each field (6 to 16 acres) would result in misleading conclusions concerning pH levels and lime requirements. For example, the within-field variation in pH and buffer pH values for Fields 4 and 6 would result in limestone applications (to raise pH to 6.5 according to current ISU guidelines) ranging from zero to about 4 tons ECCE/acre. Use of the average pH and buffer pH values for the experimental areas, however, no lime would be recommended for Field 4 (because the average pH was 6.5) and about 1.5 tons ECCE/acre for Field 6.

Comparison of buffer pH methods to estimate lime requirements

The buffer pH values for the Sikora and Mehlich methods were linearly related with the currently used SMP method across all fields (Fig. 1). The correlation was good for all methods, but was lowest between SMP and Mehlich and highest between Sikora and Mehlich. This was an interesting result since we expected that the highest correlation would be between the SMP and Sikora methods because the Sikora method was originally developed to mimic the SMP method. The intercept and slope of the regression line between Sikora and SMP buffer pH values were not statistically different from 0 and 1, respectively, which indicates that both methods gave statistically similar results. However, the Mehlich buffer pH methods resulted in significantly lower values than the SMP and Sikora methods (intercept and slope were lower than 0 and 1, respectively). The average differences between SMP and Sikora for each field were small (-0.07 to 0.17 pH units, on average 0.07 unit) but differences between SMP and Mehlich were much larger (0.53 to 0.84 pH units, on average 0.67 pH unit). Results of correlations between each buffer method and the soil pH change one year after lime application showed no clear differences between the three methods (not shown). The results indicate that the current equations for lime requirement for the SMP method can be used for Sikora, but the differences for Mehlich indicate it could be a good method but needs further research concerning its calibration to estimate lime requirement.

Lime application effect on soil pH

Figure 2 shows the average effect of applying 3 ton of ECCE/acre on soil pH change for each field over time. Because the start of the trials was staggered across three years, at this time we do not have soil pH data for the same number of years for all trials. The lime effect at increasing soil pH varied greatly across fields, but was greater for the first year after liming. The pH increases for samples taken after the first crop after liming ranged from 0.5 to 1.5 units across fields, and the additional increase after the second crop ranged from 0 to 0.5 pH units. After that, soil pH remained about the same or there were small increases or decreases. More years of information for the newer trials are needed to better analyze soil pH changes over time.

In the four trials managed with no-till, one year after lime application there was a significant increase of soil pH in the top 3-inch depth and also in the second 3-inch soil depth (Fig. 3). The first-year increase for a depth of 0-3 inches ranged from 0.97 to 1.94 pH units across the fields, whereas the increase for a depth of 3-6 inches ranged from 0.22 to 1.42. These results suggest significantly more movement of lime through the shallow topsoil layers than usually assumed in Iowa. Two years after lime application the pH increase remained significant for the top 0-3 inch soil layer, but at the 3-6 inch layer the increase remained only for the Union County field. The greater decrease for the second depth might be explained by small limestone movement and more acidity in that soil layer from nitrification of ammonium from anhydrous ammonia applied to corn (in all fields corn was the second crop anhydrous ammonia was injected).

Crop response to lime according to soil pH

The average crop yield response across the entire length of the strips does not represent well the responses for within-field areas with significantly different soils and soil pH values. Therefore, data for each field are not shown in this summary article, and we emphasize presentation and discussion of yield responses in relation to initial soil pH for all data combined from the first year to the most recent available results (for the 2010 crop year). Also, analyses by field or soil series within each field (not shown) indicated no consistent or statistically significant differences between the relative magnitude of corn and soybean yield responses to lime application.

Therefore, Fig. 4 summarizes results of GIS analyses by showing the relative response to lime across the two crops, fields, and years after liming (43 site-years) for different initial soil pH ranges. It must be remembered that at this time we have data for four, three, and two years for sets of trials established in 2007, 2008, and 2009, respectively. The responses are expressed as relative values to be able to put together data for corn and soybean and also to combine data from fields or field areas having different yield levels. There was a large corn and soybean yield response for pH ranges up to pH 5.9, a smaller and barely significant response for the pH ranges from 6.0 to 6.9, and a small yield decrease for higher pH values. Results for each field indicated inconsistent change in the magnitude of yield responses to lime over time. This inconsistency also is shown in Fig. 5, which summarizes relative responses for each year after lime application across fields and for different soil pH ranges. The relative magnitude of yield responses decreased after the 2nd year for the most acid pH range for reasons not understood at this time (yield increases were large and the pH of non-limed soil remained very acid over time), but remained about the same and increased or decreased slightly for the other pH ranges.

Figure 6 shows the relative grain yield response for each pH range separately by the major Iowa soil association areas classified as having low or high subsoil pH. Results for fields with high-pH subsoil showed a very large yield increase with liming in soils with very acid surface soil (pH < 5.0), smaller but still significant increases up to pH 5.9, no significant or consistent increases from pH 6.0 to 6.9, and yield decreases for higher pH values. On the other hand, yield increases due to lime application across fields in areas with low subsoil pH were large up to pH 5.9, smaller but still significant up to pH 6.4, and there was no significant increases for higher pH values. These preliminary results (we still have to study of trials being harvested at this time and those planned for next year) strongly confirm the importance of considering subsoil information for lime recommendations in Iowa.

No economic analysis of yield responses to lime application was conducted because not all four years were evaluated for each trial, and a reliable analysis cannot be conducted because only one lime application rate was used. However, the relative responses (percentages of yield) and standard errors indicated in Figs. 3, 4, and 5 allow readers to approximately estimate the importance of responses for different pH ranges and adapt the percentage increases to their usual yield levels, always changing crop prices, and limestone prices that vary about three fold across different Iowa regions.

Summary and preliminary conclusions

Conclusions about lime application effects on soil pH over time and yield should be considered preliminary because we still have to study results for this crop year and next year. However, the results of available data from many fields and years showed the following important results that are unlikely to change.

The SMP and Sikora buffer pH values were essentially the same, so current calibrations to estimate lime requirement in Iowa based on the SMP method also can be used for Sikora. An advantage of the Sikora method is that it does not include hazardous chemicals. The Mehlich buffer method could perform as well as the other methods, but requires field calibrations and new equations before it can be used to calculate amounts of lime to be applied. These calibrations could not be developed with the methods used in this study. Based on these results and ISU suggestions, the Iowa Department of Agriculture and Land Stewardship (IDALS) Soil-Test Certification program has authorized laboratories operating in Iowa to use the Sikora method as an alternative to the currently used SMP method.

Large within-field soil pH and buffer pH variability in most fields confirms previous on-farm research with soil sampling methods or lime application results that site-specific lime management is necessary for most Iowa soils. Dense grid soil sampling or soil sampling zones delineated by using several sources of information obtainable with precision agriculture tools should be used to improve the assessment of soil pH and lime requirement and to optimize use of variable-rate application technology.

The yield responses in relation to different pH ranges suggest that pH 6.5 is sufficient for corn and soybean in areas without high-pH (calcareous) subsoil but pH 6.0 is sufficient in areas with high-pH subsoil. These preliminary results support the current guidelines in ISU Extension publication PM 1688 concerning pH values considered sufficient for these crops. However, the preliminary results do not fully support the current suggestion to apply lime to all acidic soils to raise pH to pH 6.5, even those without high-pH subsoil.

Results from this year and next year will allow for confirmation or adjustment of these preliminary conclusions and future updates of ISU soil pH and lime management guidelines.

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Tables and figures

Table 1. Field locations, characteristics, and lime application dates for 14 on-farm replicated strip trials.

Field	Year	County	Till †	Dominant Soils	N‡	Soil pH §	SMP Buffer pH §	Organic Matter (%)	Liming Date
1	2007	Jasper	ST	Clarion	32	6.0 (5.6-7.3)	6.7 (6.4-7.2)	3.3 (2.2-4.4)	5/18/07
2	2007	Story	CD	Webster, Nicolet, Clarion	40	6.0 (5.7-7.2)	6.5 (6.3-7.1)	4.4 (2.7-7.2)	5/25/07
3	2007	Boone	CD	Canisteo, Nicollet, Clarion	36	5.2 (4.8-6.0)	6.4 (6.1-6.8)	3.8 (2.6-5.2)	11/14/06
4	2007	Greene	CD	Canisteo, Okoboji	32	6.5 (5.1-8.1)	6.8 (6.1-7.4	5.2 (3.6-7.8)	10/28/06
5	2007	Boone	CD	Talcot, Dickman, Clarion	40	5.0 (4.6-5.8)	6.4 (6.1-6.9)	3.3 (1.2-4.7)	1/27/07
6	2008	Cedar	CD	Dinsdale Muscatine	40	5.5 (5.2-6.7)	6.5 (6.3-7.0)	3.4 (2.3-3.8	5/12/08
7	2008	O'Brien	CD	Primghar, Galva	36	5.5 (5.2-6.0)	6.2 (6.0-6.5)	5.2 (4.5-5.7)	11/9/07
8	2008	O'Brien	CD	Galva	36	5.9 (5.2-6.7)	6.6 (6.3-6.9)	4.9 (4.5-6.0)	11/9/07
9	2008	O'Brien	CD	Marcus, Prighmar, Galva	36	5.7 (5.5-6.1)	6.3 (6.1-6.6)	6.9 (5.3-9.2)	4/15/08
10	2008	Union	NT	Sharpsburg, Clarinda	19	5.6 (4.8-6.2)	6.4 (5.9-6.8)	4.0 (3.4-4.7)	4/28/08
11	2009	Ringgold	NT	Nira	36	5.7 (5.3-6.2)	6.5 (6.3-6.9)	4.5 (2.9-5.7)	12/12/08
12	2009	Pottawattamie	NT	Marshall	36	5.2 (5.1-5.6)	6.2 (5.9-6.5)	3.8 (3.4-4.5)	1/9/09
13	2009	Pottawattamie	CD	Marshall	36	5.4 (5.2-5.6)	6.2 (6.1-6.8)	4.1 (3.7-4.5)	1/9/09
14	2009	Crawford	NT	Marshall, Judson	48	5.3 (5.1-5.8)	6.4 (6.2-6.8)	4.0 (3.2-5.0)	2/23/09

† Tillage: ST, strip tillage; CD, chisel/disk; NT, no-till. ‡ N, number of initial soil samples. § Average and range of values.

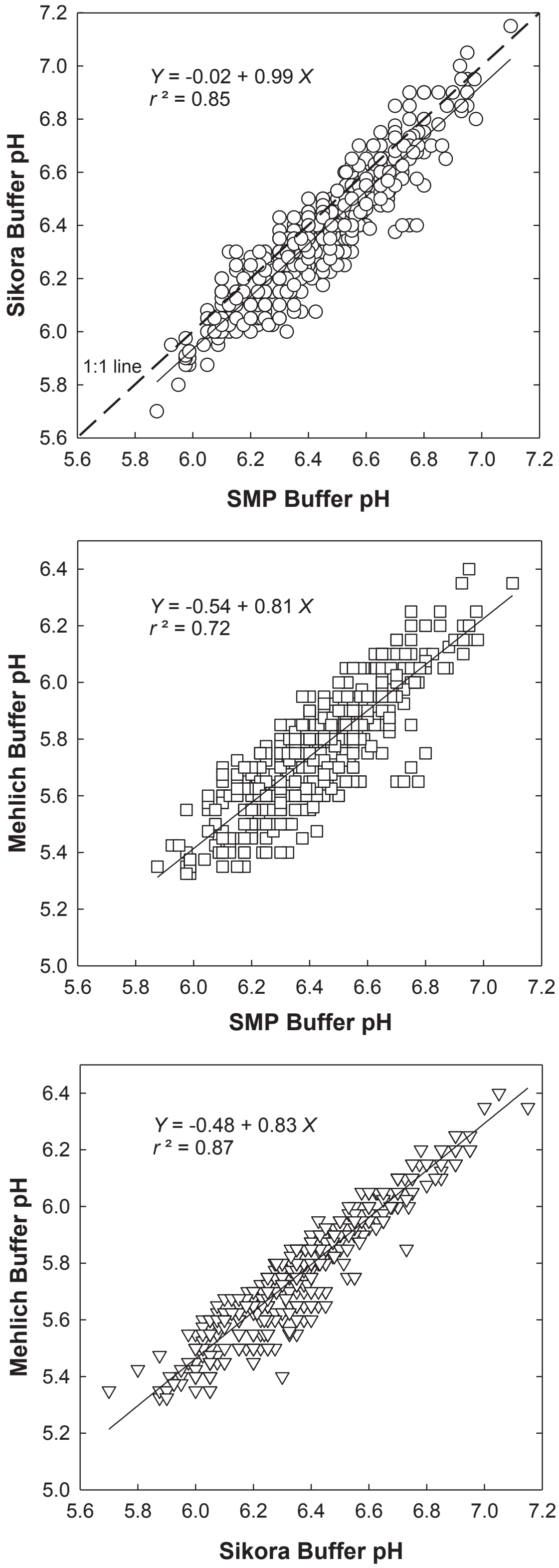

Figure 1. Relationship between buffer pH measured with the SMP, Sikora, and Mehlich methods for all soil samples collected from 14 field trials before lime application.

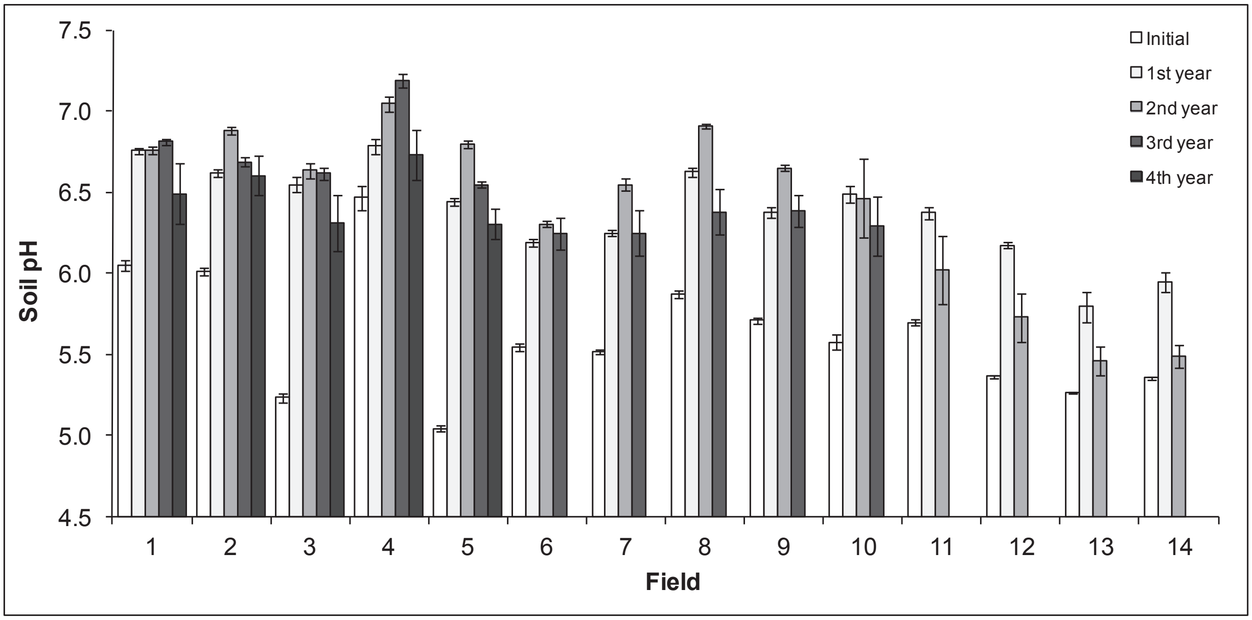

Figure 2. Initial pH values and pH over time after a single application of 3 ton ECCE/acre for 14 strip trials (vertical lines on top of bars represent standard errors).

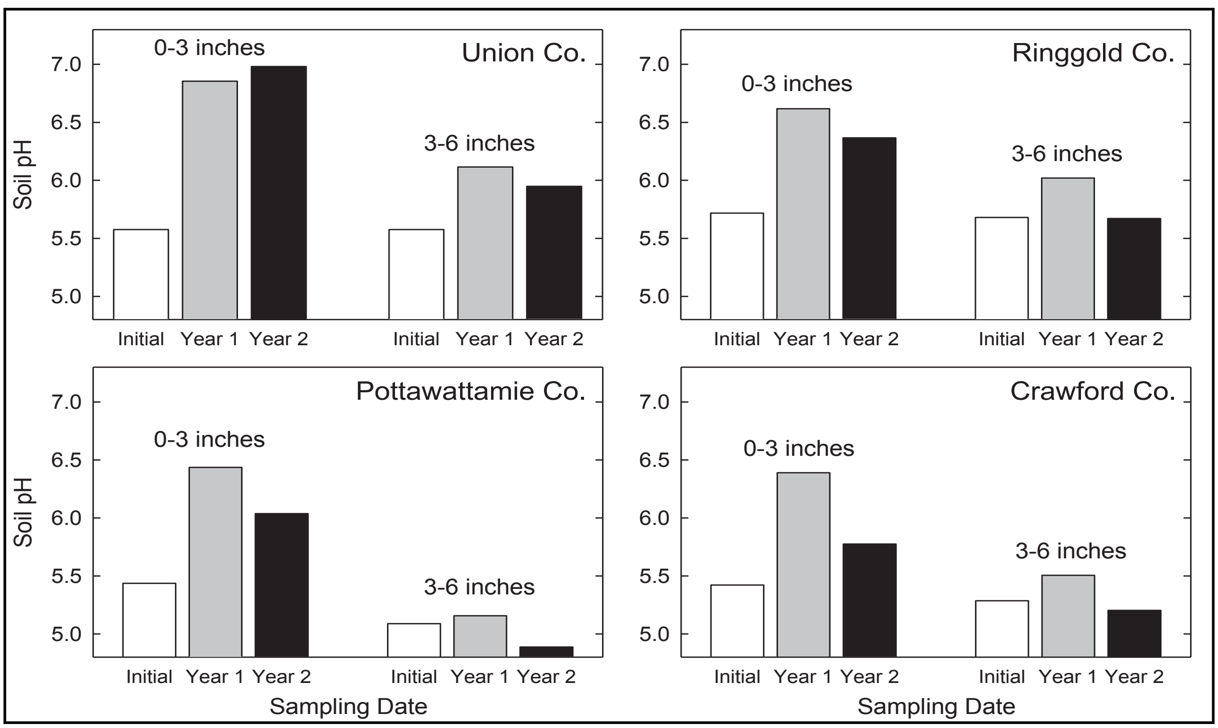

Figure 3. Effect of lime application (3 ton ECCE/acre) on soil pH for two different depths for four no-till trials one and two years after liming.

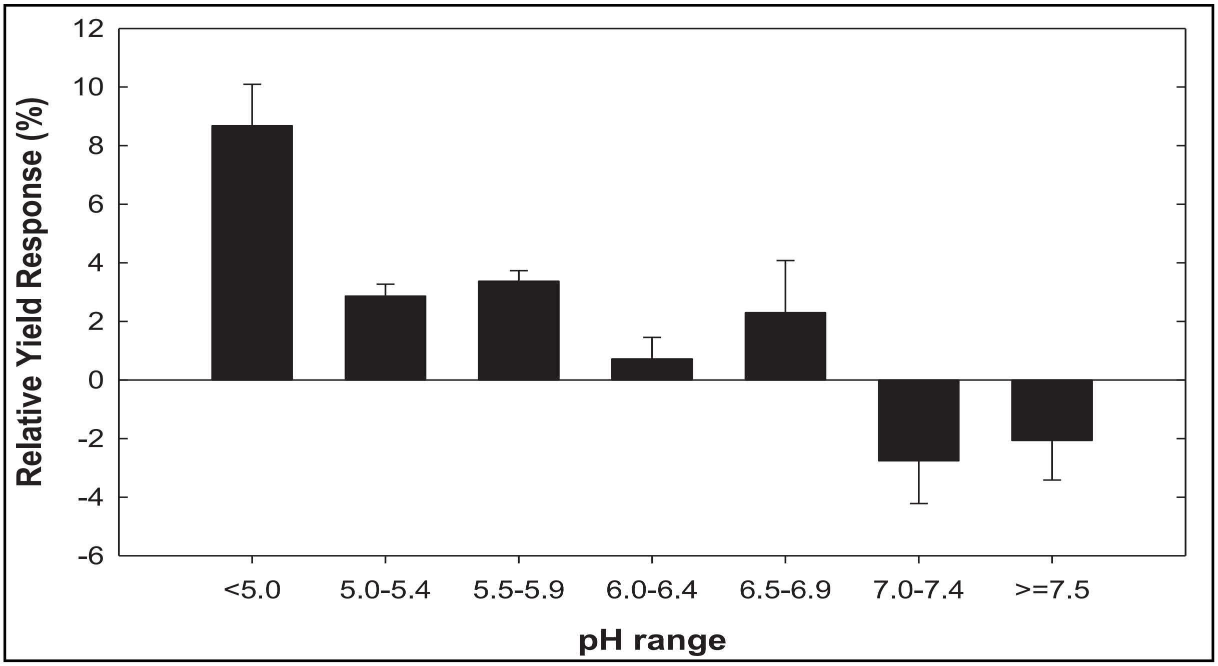

Figure 4. Relative grain yield response (combined corn and soybean) to 3 ton ECCE/acre summarized by soil pH across all strip trials and years (43 site-years). Lines represent standard errors.

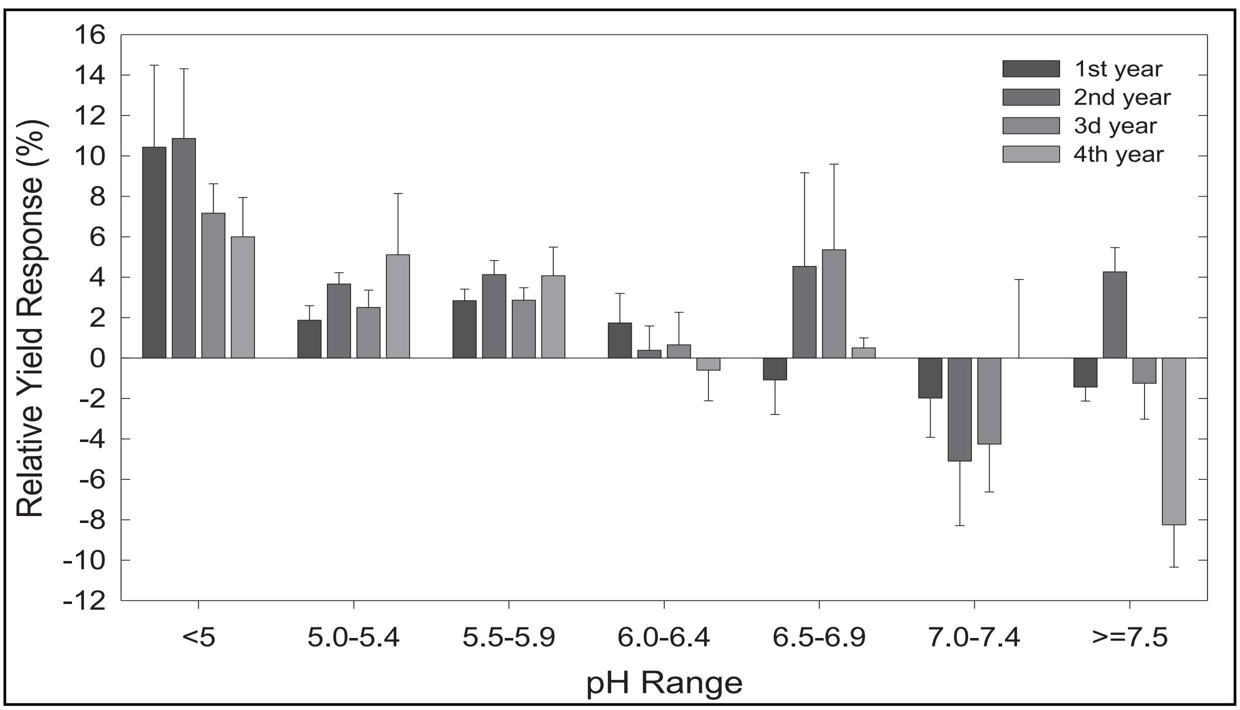

Figure 5. Relative grain yield response (combined corn and soybean) to 3 ton ECCE/acre summarized by soil pH across all strip trials for each sampling year after liming (43 site-years). Lines represent standard errors.

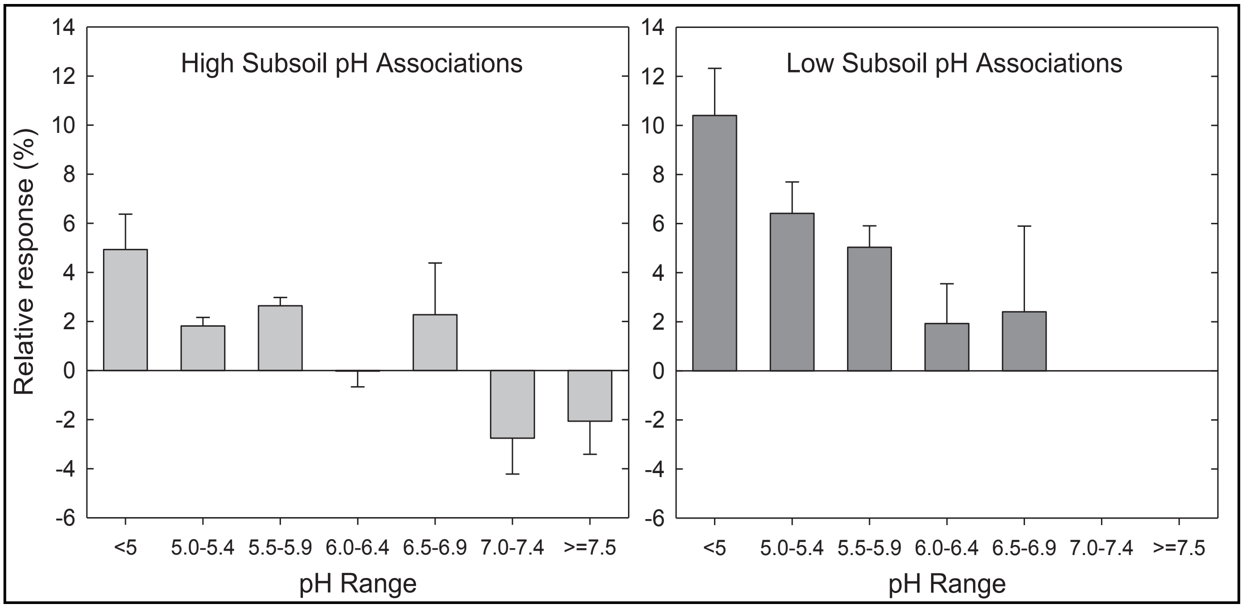

Figure 6. Relative yield response (combined for corn and soybean) to 3 ton ECCE/acre according to pH for soil associations areas with or without high-pH subsoil (lines represent standard errors).