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# Use of Fly Ash as a Liming Material of Corn and Soybean Production on an Acidic Sandy Soil

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## Abstract

Fly ash (FA) produced from subbituminous coal combustion can potentially serve as a lime material for crop production in acidic soils. A five-year study was conducted to determine if FA was an effective liming material in an acid sandy soil under corn and soybean grain production. Fly ash and pelletized lime (PL) were surface applied at rates ranging from 3,200 to 6,400 and 1,416 to 5,658 kg/ha (0.5 to 2 times the recommended rate) at two sites near Brunswick, NE, respectively. At Site A, lime source additions increased soil pH by 0.7 units and decreased soil exchangeable Al by 7.3 mg/kg to a depth of 20 cm. Lime applications resulted in pH increase during the first year (2004) at the 0 to 10-cm depth, and in 2007 at the 10 to 20-cm depth. At Site B, soil pH data suggested that one or more past lime applications may have occurred. Corn and soybean grain yields were not different during each year between the control and lime source treatments at both sites. This lack of difference was likely due to soluble Al concentrations not being great enough to affect grain yield. Fly ash did not negatively affect grain yields in this study. Boron concentration (400 mg/kg) in FA were likely too low to adversely affect yields. The FA applied at rates in this study, increased pH comparable to PL and is an appropriate liming material.

## Introduction

Soil acidification can decrease yield and profitability of crop production. An estimated 25 to 30% of world soils are acidic (7). The negative effects of soil acidity on plant productivity include: Al and/or Mn toxicity; H ion toxicity; decreased bioavailability of Mg, Ca, K, P, and Mo; and inhibition of root growth (8).

In areas where conventional agricultural liming materials are either unavailable or uneconomical due to high transportation costs, locally produced alternative liming materials may serve as a valuable asset for producers with acidic soils.

In west-central Nebraska, many hectares of sandy soils have become acidic over time due to their low pH buffering capacities combined with frequent applications of ammonium-based fertilizers for crop production. Sources of conventional agricultural lime are available in eastern Nebraska, but transportation of these materials increases the costs of application. Because of this logistical problem, fly ash (FA) produced as a by-product of coal combustion from a local electrical generating facility (Gerald Gentleman Power Station, Nebraska Public Power District, Sutherland, NE) may be more cost effective for farmers in the area. The coal supplied to this station was obtained from the Power River Basin in northeast Wyoming. However, potential agricultural users have expressed concern about the accumulation of toxic levels of boron (B), molybdenum (Mo), selenium (Se), and aluminum (Al) in the soil and/or plants. These constituents are present in FA at varying concentrations and can be toxic to plants or grazing animals (1,5). Stevens and Dunn (17) showed that a single application of FA decreased cotton lint yield by 12 kg/ha for each Mg FA applied when boron was present at an equivalent rate of 3.1 to 9.2 kg/ha. However, during the second year, cotton lint yields were significantly higher for residual FA plots than the untreated check. Plank et al. (16) reported that weathered FA applied at rates of up to 29 kg B per ha did not adversely affect corn yields. Variability in chemical and physical properties of FA from different sources must be considered when assessing effects on crop yield (11).

Past research demonstrated that FA from the Nebraska Public Power District (NPPD) Gerald Gentleman power station in west central Nebraska can potentially serve as an alternative liming source without reducing corn grain yields (9,18). However, because crops differ in their sensitivity to acidic soils, there is a need for research in central and western Nebraska that addresses the agronomic effects lime source additions on soybean in cropping system with acidic soils within an economic feasible transportation distance of the Gerald Gentleman power station. Peterson and Hilgenkamp (14) demonstrated that soybeans were more responsive to lime additions than corn in an acid soil.

The positive and negative FA characteristics that affect crop growth are influenced by the composition of the parent coal, coal combustion conditions, efficiency of collection and/or filtration devices, storage and handling procedures, and climate. Concerns and questions by local agricultural producers and variability in FA composition requires site-specific evaluation of FA materials as agricultural amendments on common agricultural crops.

Pelletized lime (PL) is made by granulating finely ground dolomitic or calcitic limestone lime and is used in production agriculture (10).

This study was established to assess the agronomic suitability of FA obtained from the Gerald Gentlemen Station for use as an alternative liming material in an irrigated corn-soybean rotation production on sandy acid soils. Research objectives were to: (i) compare the effects of FA and PL on soil pH and exchangeable Al; and (ii) determine the effects of FA and PL on corn and soybean grain yields.

## Testing Fly Ash as a Liming Material

This study was conducted at two center-pivot irrigated sites in the same field over a five-year period near Brunswick, NE, on a Thurman sand (sandy, mixed, mesic Udorthentic Haplustoll) under a corn-soybean rotation. In a given year, half of the field and one site was planted to soybeans and the other half and the other site to corn. The soil at both sites had an average pH of 4.8 (1: soil:water) and a buffer pH of 6.7 in the surface 30 cm.

Liming materials included PL and dry FA. A no lime application treatment was included as a control. The FA was obtained from the Nebraska Public Power District, Gerald Gentleman Power Station in Sutherland, NE. Selected constituents in the FA are presented in Table 1. The PL was obtained from Weeping Water, NE.

Table 1. Selected total constituent content and lime quality of fly ash (FA) from the Gerald Gentleman Power Station and pelletized lime (PL). Values are reported on a 100% dry matter basis.

| **Constituent** (unit) | **FA** | **PL** |
|---|---|---|
| CCE (%) | 42 | 95 |
| Aluminum (%) | 7.95 | 0.045 |
| Arsenic (mg/kg) | 7.5 | 31 |
| Boron (mg/kg) | 400 | 27 |
| Calcium (%) | 18.8 | 35.0 |
| Copper (mg/kg) | 213 | 3.1 |
| Iron (%) | 3.7 | 0.15 |
| Magnesium (%) | 3.0 | 0.27 |
| Manganese (mg/kg) | 252 | 224 |
| Molybdenum (mg/kg) | 3.6 | 13 |
| Phosphorus (%) | 0.16 | 0.06 |
| Potassium (%) | 0.18 | 0.38 |
| Selenium (mg/kg) | 36 | 35 |
| Zinc (mg/kg) | 100 | 50 |

The recommended lime material application rate was determined based on the Woodruff buffer method and converted to the same effective calcium carbonate rate based on the Effective Calcium Carbonate Equivalent (ECCE) of the liming material (19). The ECCE was 42% for the FA and 95% for the PL. The application rates of the lime materials are shown in Table 2. The lime materials were applied in a single application to the plots (4.6 m by 15.2 m) using a drop spreader (6500 Series, Gandy Company, Owatonna, MN) in the spring of 2004. Lime material (including the control) and rate treatments were replicated four times in a randomized block design for each experimental site. No-tillage was used annually to provide sufficient residue cover to decrease wind erosion. The lime materials received minimal incorporation during planting.

Table 2. Lime source [control, fly ash (FA), and pelletized lime (PL)] application rates for Sites A and B.

| **Site** | **Lime source**[x] | **Application rate of lime source**[y] (kg/ha) |
|---|---|---|
| A | Control | 0 |
| | FA (×0.5) | 3200 |
| | FA (×1) | 6400 |
| | PL (×1) | 2829 |
| | PL (×2) | 5658 |
| B | Control | 0 |
| | FA (×0.5) | 3200 |
| | FA (×1) | 6400 |
| | PL (×0.5) | 1416 |
| | PL (×1) | 2829 |

[x] Number in parenthesis was the fraction of the recommended lime rate.

[y] Lime recommendation to raise soil pH to 6.5 based on Woodruff buffer pH test of 6.4. Recommended lime rate = 2688 kg (100% effective calcium carbonate equivalency)/ha.
Example calculation: FA (×1) = 2688 kg/ha/0.42 = 6400 kg/ha.

Nutrient management at all sites was based on the producer's fertilizer management practices. Corn was planted in 0.76-m rows and soybeans was planted using a drill (25 cm) in the spring of each year (except in 2007 when soybeans were planted in 0.76-m rows). Each research site was planted to either corn or soybeans and was rotated each year.

Soil samples were collected from each experimental unit in Sites A and B prior to lime source applications in the spring of 2004 and in the spring of 2005, 2007, and 2008. Eight sub-samples were taken from each experimental unit and composited into one sample per experimental unit for depths of 0 to 10, 10 to 20, and 20 to 30 cm. The soil samples were analyzed for pH using a 1:1 volume ratio of soil to water. The soil samples taken in 2008 from Site A were analyzed for total elements and exchangeable Al. Total elements were determined using ICP-OES following microwave-assisted digestion of a 10-g sample aliquot with 4 ml of concentrated $HNO_3$, 2 ml concentrated HCl, and 2 ml of 30% (v/v) $H_2O_2$. Exchangeable Al was determined using ICP-OES following extraction with 1N KCl (2).

In the fall of each year corn from two 6-m rows in each plot was hand harvested and corn grain yields were determined for each treatment at all sites. Soybean grain yield was determined by harvesting one 13.7-m row in 2007 and an area of 8.5 $m^2$ in 2004, 2005, 2006, and 2008 from each plot with a plot combine. In 2006, a large percentage of the soybeans at Site A were accidentally harvested by the producer. Therefore the grain yield data was not collected.

The irrigation water from the well supplying both sites had a $CaCO_3$ concentration of 65 mg/liter. The amount of $CaCO_3$ applied in irrigation water in 2004, 2005, 2006, 2007, and 2008 was approximately 125, 112, 90, 260, and 242 kg/ha (total = 829 kg/ha), respectively.

Analysis of variance for grain yield and soil pH was conducted using a split plot in time and space model in Statistix 8 (2003, Analytical Software, Tallahassee, FL). Lime source and lime rate combinations were treated as separate lime treatments in the analysis. Analysis of variance for exchangeable Al from the 2008 soil samples was conducted for each year separately using the Completely Randomized Design Model from Statistix 8. The least significant difference (LSD) method was used for mean separations. Significance was determined at the a = 0.05 probability level for all statistical analysis. All data was tested for assumptions of ANOVA. Data not conforming to the assumptions were log transformed prior to analysis. Data is reported in non-transformed form.

## Site A Soil pH and Exchangeable Al

Analysis of variance main effects for lime source ($P > F = 0.006$), year ($P > F = <0.001$), and soil depth ($P > F = 0.01$) main effects on pH and all two-way interactions on soil were significant. There were some slight differences in the rate of pH increase over time between treatments which lead to the significant lime source × year interaction (Fig. 1). Averaged over all soil depths, soil pH increased over time for all lime source treatments to a greater degree than the control after the lime sources were applied (Fig. 1). The slight increase in soil pH over time for the control was likely due to lime additions in the irrigation water. Data indicates that lime effects on soil pH are reaching the 10 to 20-cm depth; averaged over all lime source treatments (excluding the control), the soil pH increased over time at the 0 to 10 cm and 10 to 20 cm depths (Fig. 2). There was no change in soil pH at the 20 to 30-cm depth over time. Lime applications resulted in pH increase during the first year (2004) at the 0 to 10-cm depth, and in 2007 at the 10 to 20-cm depth. At the 0 to 10-cm depth, soil pH continued to increase four years after lime source applications. In 2008, the soil pH reached 6.7 in the 0 to 10-cm depth. At the 10 to 20-cm depth, soil pH increased two years after lime source applications to a pH of approximately 5.4. For all lime sources the greatest change in pH (lime source treatment – control) at a depth of 0 to 10 cm occurred during the first year after lime application (Fig. 3). The increase in soil pH averaged 1.0 from 2005 to 2008 for all lime sources at the 0 to 10-cm depth. All lime sources also increased pH over time at the 10 to 20-cm depth (0.6 pH units) (Fig. 3). Averaged over all study years, soil pH decreased as soil depth increased for all treatments. Figure 4 only shows the control, FA (×1), and PL (×1) treatments data because there were no differences among the rates within each lime source (at the 0 to 10 soil depth, the soil pH was in the order PL1 = PL2 > FA0.5 = FA1 > control).

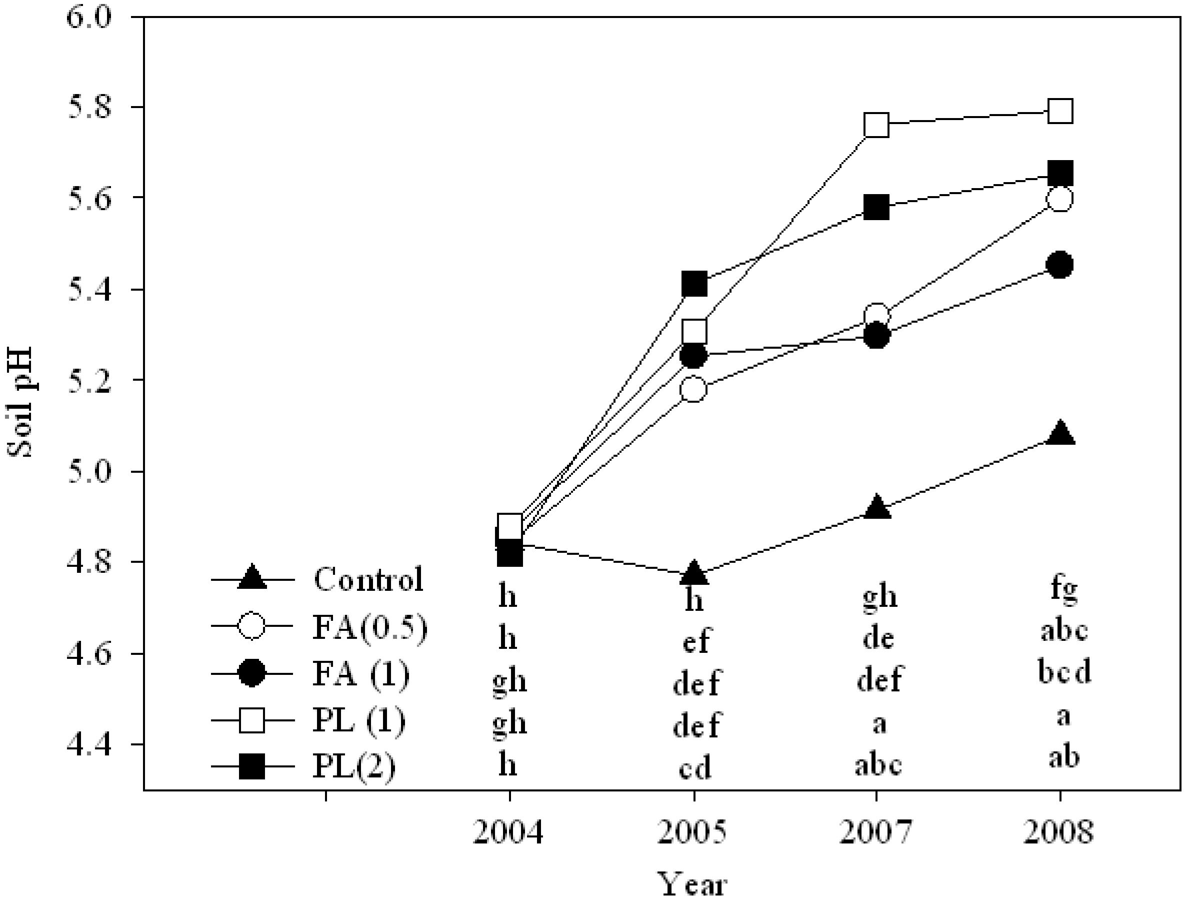

Fig. 1. Relationship between soil pH (average of all depths) and year for lime sources at Site A (lime × year interaction). Points with same letter are not significantly different. Letters from top to bottom correspond to treatments in the legend from top to bottom. Mean separations are based on LSD (*P* = 0.05).

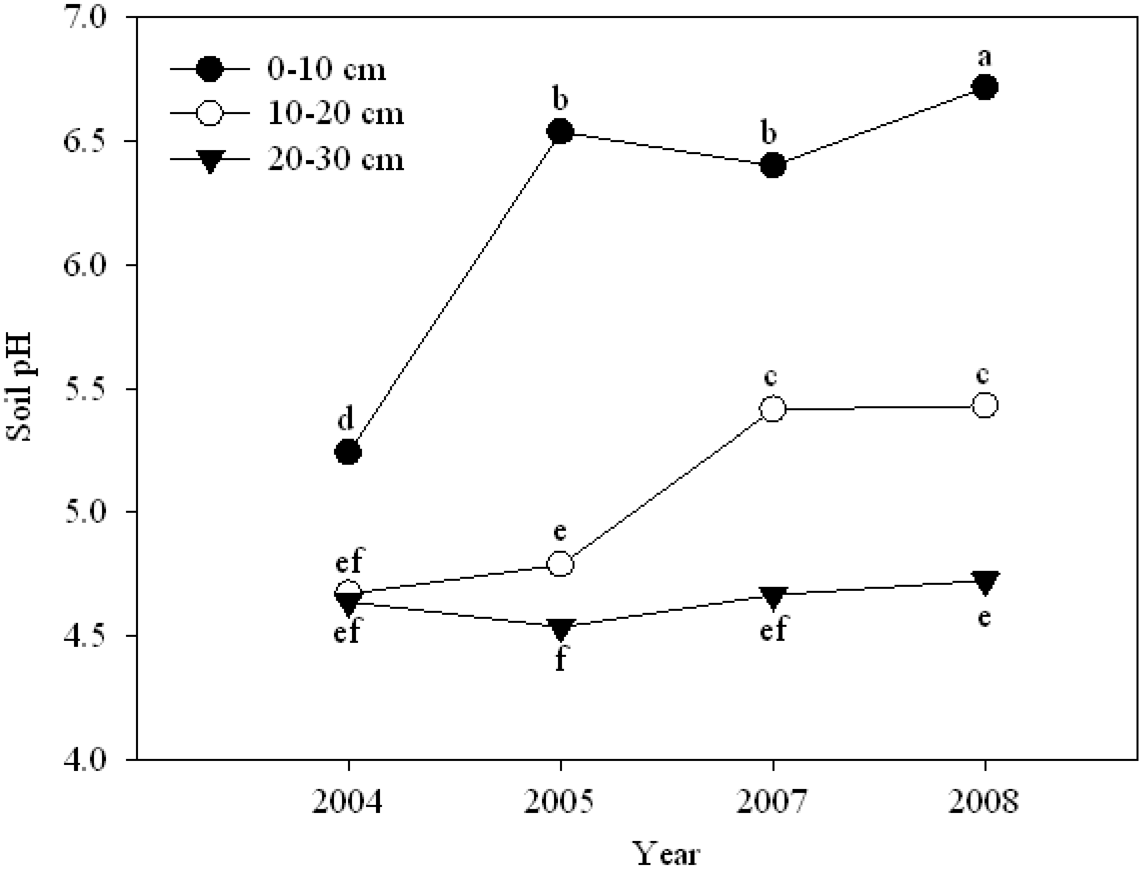

Fig. 2. Relationship between soil pH and year for each soil depth at Site A (year × soil depth interaction). Data points are averaged over lime treatments (not including the control). Points with same letter are not significantly different based on LSD (*P* = 0.05).

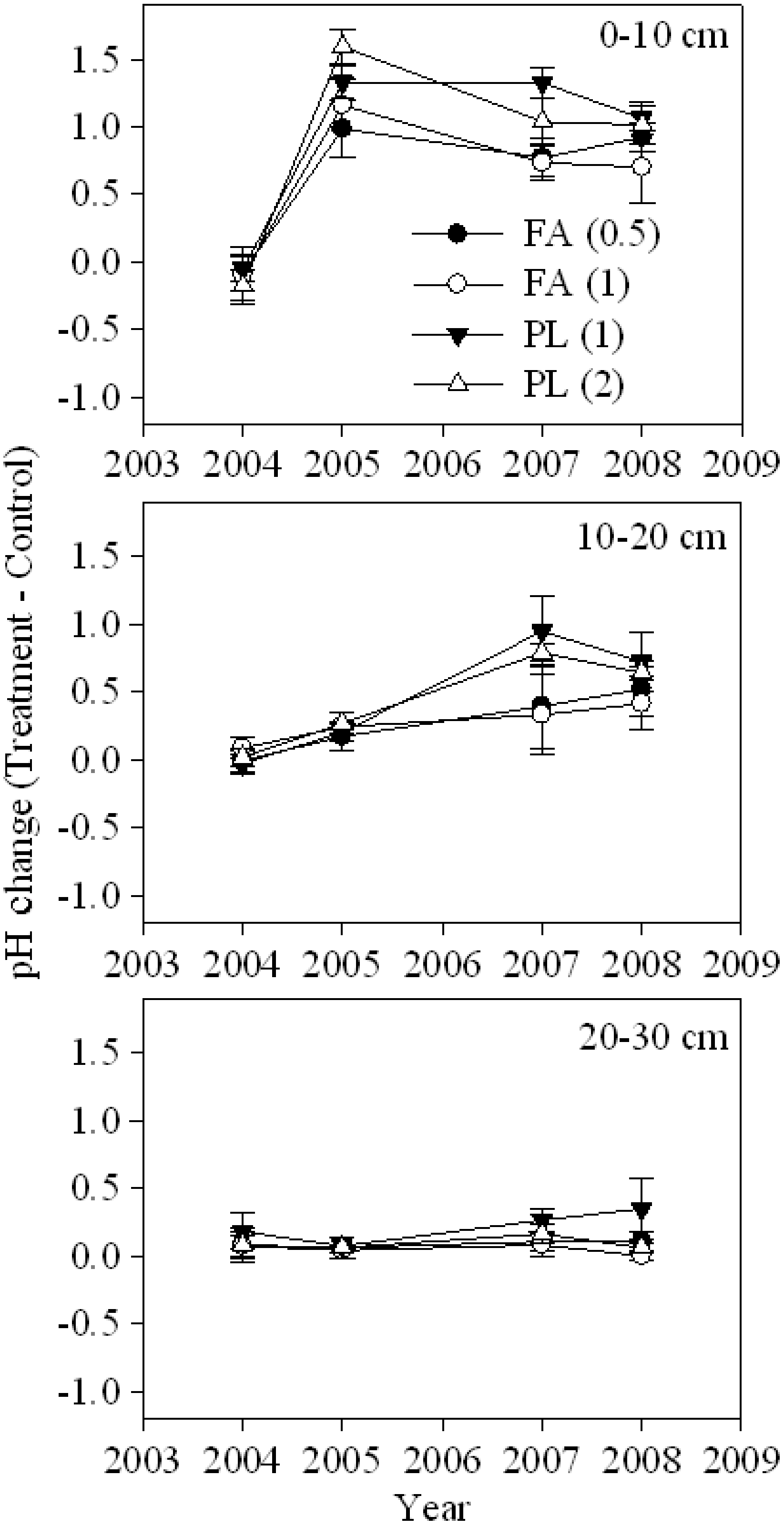

Fig. 3. Relationship between change in pH for lime source treatments (treatment – control) and year for the 0 to 10, 10 to 20, and 20 to 30-cm depths at Sites A. Error bars for each treatment mean represent the standard errors.

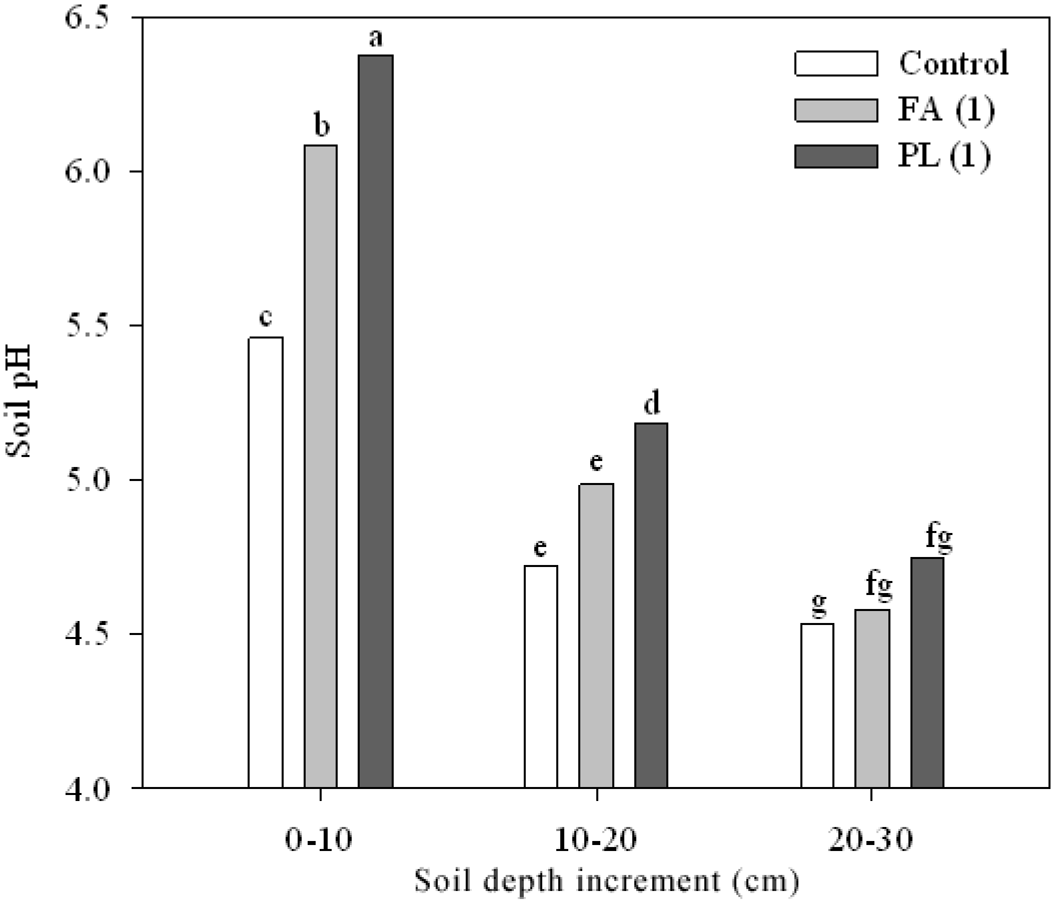

Fig. 4. Relationship between soil pH and depth for each selected lime treatments at Site A (lime × soil depth interaction). Data points are averaged over year. Bars with same letter are not significantly different based on LSD (*P* = 0.05).

Analysis of variance of main effects for lime source and soil depth on soil exchangeable Al and the two-way interaction were significant (P > F = <0.001). Soil exchangeable Al concentrations at the 0 to 10-cm soil depth were not different between the control and the FA (×0.5), FA (×1), and PL (×1) treatments (average = 0.49 mg/kg, Fig. 5). However, the PL (×2) treatment (0.08 mg Al per kg) was lower than the control (0.74 mg Al per kg). Soil exchangeable Al concentrations at the 10 to 20-cm depth for FA (×1), PL (×1), and PL (×2) treatments decreased by 42% compared to the control. There were no differences in soil exchangeable Al concentrations between lime source treatments at the 20 to 30-cm depth. Soil exchangeable Al was related to soil pH; as soil pH increased over the range of 4.3 to 7.3, exchangeable Al decreased by 99.9% at both sites and all soil depths (Fig. 6).

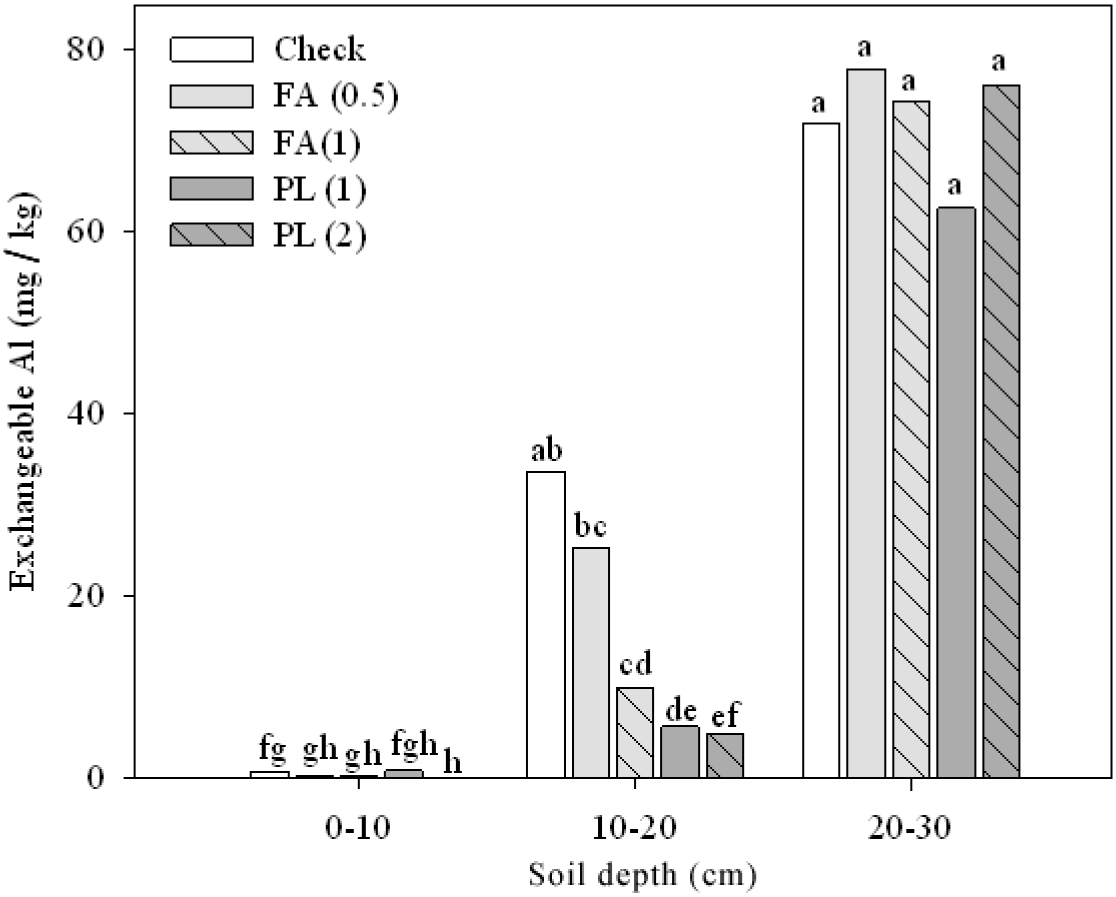

Fig. 5. Relationship between exchangeable soil Al and soil depth for each treatment at Site A (treatment × soil depth interaction) four years after lime application. Columns with same letter are not significantly different based on LSD (*P* = 0.05).

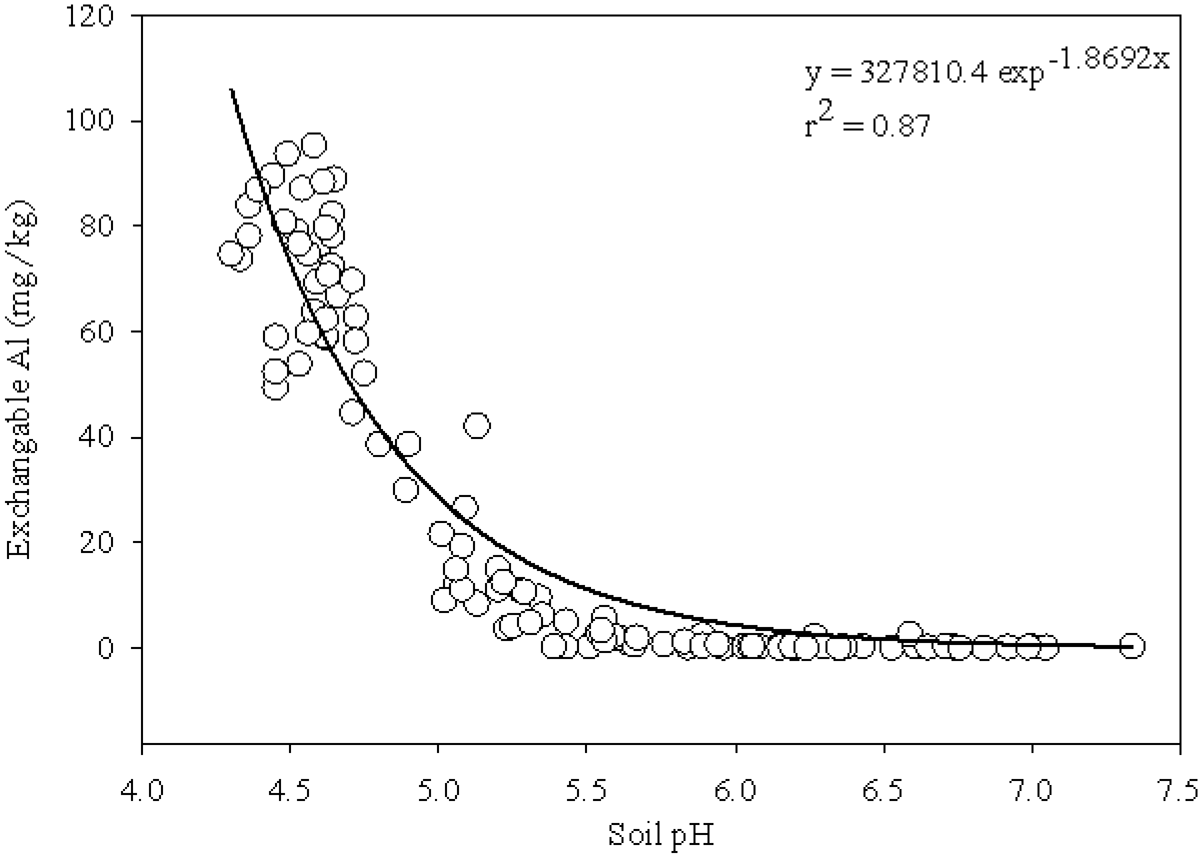

Fig. 6. Relationship between soil pH and exchangeable soil Al. Each point represents each plot from both sites and all soil depths in 2008.

These data show that lime applications in general reduced soil exchangeable Al concentrations. In addition, surface lime applications reduced soil exchangeable Al to a depth of 10 to 20 cm.

### Site B Soil pH and Exchangeable Al

At site B lime source applications had little effect on soil pH and soil Al over time. The reduced pH increase and Al decrease over time was likely a result of one or more past lime applications (*data not shown*).

### Corn and Soybean Yield

Lime source had no effect on corn and soybean grain yields at Site A and Site B (Table 3). At Site A, there is a trend for increased yields with lime additions compared to the control but the differences were not significant. There were differences in corn and soybean grain yield between years at Site A, and in corn yield between years at Site B (Table 3). The FA additions did not negatively affect crop grain yields during the duration of this study.

Although lime sources increased soil pH to a depth of 20 cm, this did not have an effect on corn and soybean grain yield. The lack of grain yield increase was potentially a result of one or both of the following: (i) initial soluble Al concentrations were not great enough to affect grain yields; and (ii) lime effects were limited because of surface application.

These data corroborate the results from Tarkalson et al. (18), suggesting Al and B concentrations in the FA from the Gerald Gentleman Power Station are not high enough to negatively affect crop corn and soybean grain yields. Refer to Tarkalson et al. (18) for an in-depth discussion of these issues as related to the FA from the Gerald Gentleman Power Station. The FA (×0.5) and FA (×1) application rates applied 1.3 and 2.6 kg B per ha, respectively.

Table 3. Corn and soybean yield data and analysis of variance (ANOVA) at Site A (black text) and Site B (red text).

| **Lime** | **Grain Yield by Year (SE)** | | | | |
|---|---|---|---|---|---|
| | **2004** | **2005** | **2006** | **2007** | **2008** |
| | **kg/ha** | | | | |
| | – ***Corn*** – | | | | |
| Control | 6,755 (164) | 8,500 (1283) | 7,352 (913) | 13,580 (501) | 11,148 (1004) |
| FA (0.5) | 7,117 (507) | 8,027 (780) | 7,708 (1469) | 12,925 (502) | 11,716 (1034) |
| FA (1) | 7,272 (98) | 8,838 (875) | 8,177 (938) | 13,264 (460) | 12,046 (671) |
| PL (1) | 7,131 (471) | 7,945 (942) | 8,331 (1344) | 13,497 (632) | 12,968 (747) |
| PL (2) | 7,152 (515) | 9,409 (561) | 8,287 (973) | 13,777 (295) | 12,575 (988) |
| Mean | 7,085 | 8,544 | 7,971 | | 12,090 |
| **ANOVA** | **P > F**[x] | | | | |
| Lime (L) | NS | | | | |
| Year (Y) | * | | | | |
| L × Y | NS | | | | |
| | – ***Soybean*** – | | | | |
| Control | 4,003 (83) | 3,577 (112) | --[y] | 2,279 (644) | 5,021 (257) |
| FA (0.5) | 4,055 (130) | 3,807 (266) | -- | 3,235 (178) | 4,937 (850) |
| FA (1) | 4,263 (115) | 3,708 (78) | -- | 3,408 (142) | 5,286 (239) |
| PL (1) | 4,047 (70) | 3,746 (168) | -- | 3,338 (230) | 4,801 (629) |
| PL (2) | 4,075 (114) | 3,925 (137) | -- | 3,022 (388) | 4,731 (899) |
| Mean | 4,089 | 3,753 | | 3,057 | |
| **ANOVA** | **P > F** | | | | |
| Lime (L) | NS | | | | |
| Year (Y) | * | | | | |
| L × Y | NS | | | | |

[x] NS = Not Significant, * Significant at the 0.05 probability level.

[y] Experimental error excluded use of soybean grain yield data in 2006.

## Boron, Molybdenum, and Selenium

Similar corn grain yields between the control and lime treatments at both sites suggests that B concentrations in FA was not high enough to negatively affect crop growth and grain yield. Based on their chemical compositions (Table 1), the recommended rate of FA (×1) and PL (×1) added 2.6 and 0.08 kg B per ha, respectively (Table 2). Considering these results, fly ash from the Gerald Gentleman Power Station applied at the rates used in this study is a suitable soil amendment with a low potential to negatively affect corn and soybean production.

Potentially negative effects of molybdenum (Mo) and selenium (Se) on grazing animals are a concern when applied in high amounts to soils (3). Based on past research (6,12,13,15) this one time application of FA will not likely cause Mo and Se toxicity in grazing animals.

## Conclusions

Results show that FA with properties similar to that from the Gerald Gentleman Power Station and PL are acceptable lime sources in soils with properties similar to the soil used in this study. Surface applications of the lime sources increased soil pH and decreased soil exchangeable Al concentrations to a depth of approximately 20 cm. In the top 10 cm pH was increased after one year, and by the third year the 10 to 20-cm horizon had pH increases, even under no-till. The effect of incorporation of lime materials into a greater soil volume on corn and soybean production was not addressed in this study. Corn and soybean may not have benefited from lime additions to this acidic soil due to one or possibly all of the following reasons: (i) soluble Al concentrations were not great enough to affect grain yields; (ii) lime effects were limited to the 0 to 20-cm level due to surface applications, and (iii) control treatments benefited from a yearly application of 165 kg/ha of $CaCO_3$ through the irrigation water.

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