DETERMINING ALUMINUM TOLERANCE AND CRITICAL SOIL PH FOR WINTER CANOLA IN THE SOUTHERN GREAT PLAINS

By

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CHAPTER I

INTRODUCTION

There has been a growing interest in winter canola (*Brassica napus*) production over the last five years in the southern Great Plains of the United States. However, many of the soils in these areas are acidic due to years of N-fertilizer applications. The combination of these factors has created the need to determine the pH and Al tolerance of winter canola in the region (Bohn et al., 2001; Zhang and Raun, 2006).

Canola is a broad-leaf plant in the mustard family that was originally developed from domesticated rapeseed plants (Boyles et al., 2007). Canola stands for Canadian oil low acid because of the lowered amounts of erucic acid present (<2%) whereas, traditional rapeseed contains 30-60% erucic acid (Canola Council of Canada, 2001). Through genetic improvement breeders have also been able to lower the amount of glucosinolates to less than 30 μM g^{-1} in air dried canola (Canola Council of Canada, 2001). Canola is being recommended as a rotational crop in continuous winter wheat production systems, since the overall management of canola is very similar to that of winter wheat (Boyles et al., 2006; Boyles et al., 2007). Demand for canola has been high in the United States since canola is a healthy cooking oil and has the potential for biofuel production (Boyles et al., 2007).

Historically, the Southern Great Plains has grown winter wheat which can be grown on moderately acidic soils and can even tolerant strongly acidic soils(pH <5) (Brady and Weil 2002; Zhang and Raun, 2006). Canola is believed to have less tolerance to soil acidity than wheat. According to sources for spring canola in Minnesota, spring canola has a critical soil pH, concentration in soil which below yield is decreased, of 5.5(Hansen, 1998; Havlin et al., 2005). In a study by Slattery and Conventry (1993), spring canola in Australia showed almost a 25% decrease in production at a pH of 5.5; a 40-60% decrease in production at pH around 5.0. Slattery and Conventry (1993) concluded canola tends to have higher yields as soil pH approaches neutral.

However, the increase in yield with increasing soil pH was not consistent over all the observations, since some soils there was no significant yield increase and even a decline in yield when the pH was increased to above >6.3. Mullen et al.(2006) also found, spring canola responded to application of lime (95-96% Effective Calcium Carbonate Equivalent) to strongly acidic soils (<5) by yielding 0.8 t ha^{-1} with no lime (soil pH 4.37), 0.87 t ha^{-1} with 1 t lime ha^{-1} (1t lime ha^{-1} brought the soil pH to 4.85), 1.12 t ha^{-1} with 2t lime ha^{-1} (2t lime ha^{-1} brought the soil pH to 5.4), and 1.27t ha^{-1} with 3t lime ha^{-1} (3 t lime ha^{-1} brought the soil pH to 5.86).

Acid soils are often observed from many areas of Oklahoma. During 1994 to 2003, the Oklahoma State University Soil, Water, and Forage Analytical Lab received 31,335 (35% of all samples) that had a pH of <5.5 (Zhang, 2000; Zhang, 2004). These acidic conditions could be the result of heavy usage of commercial ammonia/ammonium fertilizers, organic matter decomposition, and/or crop removal of basic cations (Prasad, 1997; Sparks, 2002; Zhang, 2006). Research has shown that continuous application of ammonium fertilizers can increase soil acidity over time (Blevins, 1983; Zhang and Raun, 2006; Brandy and Weil, 2002; Sparks, 2003; Bohn, 2001). A majority of commercial N fertilizers used within the last 50 years have been an ammonia or ammonium based; these fertilizers go through the nitrification process, which results in a net loss of two hydrogen ions into the soil system (Zhang and Raun, 2006). Soil acidity can cause several problems for biological systems in soil (Brady and Weil, 2002). One of these problems is Al toxicity. Aluminum toxicity rarely happens in soils that have a pH above 5.5 (Zhang and Raun, 2006). However, when the pH falls below 5.5 the increased soil acidity can hydrolyze the Al-containing compounds and release Al ions into the soil solution (Zhang and Raun, 2006).

A major effect of soil acidity, and Al toxicity, is the reduction of root growth. In a study by Adams (1966), cotton root growth generally increased as the pH increased and the Al concentration decreased. Under the Norfolk soil type, root length ranged from 4.6 cm, at 4.8 pH and a 0.71 (meq $100g^{-1}$) of KCl-exchangeable Al, to 13.5 cm, at a pH of 6.1 and a <.01 (meq $100g^{-1}$) of KCl-exchangeable Al. Soil acidity can also have an effect on the availability of soil nutrient to plants. In lower pH conditions, <5.5, many nutrients are less available (N, K, S, Ca, Mg, and Mo) (Brady, 2002).

Very little research has been conducted to determine the critical soil pH and how soil acidity affects yield in winter canola. This is why it is important to establish a critical pH and Al concentrations winter canola in the southern Great Plains.

The objectives of this study were to: 1) determine the critical soil pH and Al concentrations for the production of winter canola; and 2) determine Al tolerance of different winter canola varieties under various soil pH conditions. These objectives will be achieved through a field experiment and laboratory analysis. We hypothesize that winter canola cultivars will vary in their tolerance to exchangeable soil Al. Findings of the study should improve the producer’s ability to choose varieties of canola best suited for production in acidic soil conditions.

CHAPTER II

REVIEW OF LITERATURE

Soil pH is thought to be one of the major contributing factors that determines what can grow in a particular soil (Weil, 2002). Soils with the pH below 7.0 are considered acidic. Soil acidification is a complex process involving the chemical, physical, and biological processes in the soil. A little more than a quarter of the world's soil is considered acidic; this includes some of the major food producing areas such as: the North-central US, the US South, Western Europe, and China (Havlin, 2005).

Formation of Acidic Soils

Soil acidity is categorized into three "pool", which are active, exchangeable, and residual (Brady and Weil, 2002). Active acidity is H^+ and Al^{3+} in the soil solution and is involved in chemical reactions. Exchangeable acidity consists of H^+ and Al^{3+} ions on exchange sites; H^+ and Al^{3+} ions can be released into the soil solution by exchanging with other cations. Residual acidity is the largest portion, typically non-exchangeable Al that is bond in the crystalline structure of clays and organic matter (Havlin, 2005).

Clay minerals are very important to the soil acidification process. Clay minerals are arranged in sheet-like structures consisting of a ratio between silica tetrahedral and aluminum octahedral sheets; these clays can be arranged in 1:1, 2:1, or 2:1:1 (Havlin 2005). Isomorphic substitutions within these octahedral and tetrahedral sheets determines the CEC (cation exchange capacity), which is a measure of the overall negative charge of the soil. This overall charge of the soil can act as a buffer against soil pH change. When the pH is increased, H^+ molecules from the exchange sites are released; therefore buffering the soil against the pH change. The rate of acidification and neutralization is highly dependent on how much the soil is buffered. In general, soils with a higher CEC have a higher buffering capacity; whereas, soils with lower CEC have a lower buffering capacity.

Soil acidity can be caused by many sources, such as: ammonia/ammonium fertilization, soil organic matter decomposition, nutrient uptake and transformation, Fe and Al hydrolysis, acid rain, dissociation of H^+, and leaching (Havlin, 2005; Brady and Weil, 2002; Sparks, 2003). Soil acidity can be increased by the addition of ammonia/ammonium fertilizers. This is due to the fact that these fertilizers go through the nitrification process, in aerobic conditions. Nitrification is an oxidation process which normally releases H^+ ions as a product as shown in the equation below (Brady and Weil, 2002; Havlin, 2005)

$$NH_4^+ + O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + H_2O + 2H^+$$

$$NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$

Net Reaction

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + H_2O + 2H^+$$

Precipitation is a way for the soil to “naturally” become acidic. Water in equilibrium with atmospheric CO_2 has the pH of 5.7 (Havlin, 2005). Precipitation can affect soil acidity in two ways. The first potential problem with precipitation is acid rain, which is more of a problem in more industrial areas due to the increased pollution (Havlin, 2005). Cation leaching is also a concern. When water is transported past the rooting zone the water can carry dissolved ions. The ions in solution can be both anions and cations, the later increases in displacement with increasing levels of acidic cations H^+ and Al^{3+} (Essington, 2004) . The displacement of these cations from the rooting zone can increase the acidity of the soil by decreasing the amount of available cations to displace these acidic cations.

Organic matter can also contribute to the overall acidification of soil. When organic matter is decomposed there is a release of CO_2 into the soil air space. This CO_2 can react with H_2O in the following reaction (Havlin, 2002):

$$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

The amount of acidity being produced is dependent on the type of organic matter as well. Organic matter that is under particular vegetation types, like that of coniferous forests, could potentially produce more acidic conditions (Havlin, 2002). Also, some soil organic matter can contain carboxylic and/or phenolic groups which can release H^+, similar to that of weak acids (Havlin, 2002). For most mineral soils, such as those in Oklahoma which could have a lower amount of organic matter, this type of acidification is minimal.

As the amount of soil acidity increase the amount of Al^{3+} does so too proportionally (Havlin, 2002). Depending on the pH, different forms Al are dominant in the soil (Sparks, 2003). The following reaction shows the hydrolysis of Al:

$$Al^{3+} + H_2O \leftrightarrow Al(OH)^{2+} + H^+$$

$$Al(OH)^{2+} + H_2O \leftrightarrow Al(OH)_2^+ + H^+$$

$$Al(OH)_2^+ + H_2O \leftrightarrow Al(OH)_3 + H^+$$

$$Al(OH)_3 + H_2O \leftrightarrow Al(OH)_4^- + H^+$$

The above reaction will move from the top to bottom as soil pH increases. As Al^{3+} goes through hydrolysis it releases an H^+ molecule which can help act as a buffer against increasing soil pH (Havlin, 2002).

Soil acidity is becoming an increasing problem for crop production in central and western Oklahoma (Raun and Zhang, 2006). In eastern Oklahoma soil acidity is more of a natural occurrence which has resulted in producer's management practices being more adaptive to high levels of soil acidity. This increasing soil acidity in the central and western part of the state is probably due to nitrogen fertilizer application in intensive management.

Classifying Soil Acidity

Soil pH is one of the soil properties that is most commonly tested. Soil pH is a logarithmic scale that can be calculated by the negative logarithm of the H^+ concentration active in the soil solution (Brady and Weil, 2002). Table 1 gives descriptive classes of soil pH.

Table 1. Descriptive terms of soil pH.

Descriptive term	soil pH range
Extremely acidic	< 4.5
Very strongly acidic	4.6-5.0
Strongly acidic	5.1-5.5
Moderately acidic	5.6-6.0
Slightly acidc to neutral	6.1-7.3
Slightly alkaline	7.4-7.8

Modified from Sparks, 2003

Soil pH can be determined by mixing soil in deionized water or a salt solution, usually $CaCl_2$, in either one part soil and either one or two parts solution. The soil pH measurement from the $CaCl_2$ is usually lower; this is due to the effect of the salt solution on the exchange sites, displacing some acidic cations.

Plant Response to Acidic Soils

About 7% of the Earth's crust is Al, making it the most abundant metal in the crust's composition (Delhaize and Ryan, 1995). Two toxicities are the major concern for soils that are in production systems, these are Al and Mn toxicities. As soil pH decreases, soluble Al^{3+} increases. Aluminum is not taken up via active transport, moving particles across a membrane through the use of energy, due to the fact that it is not a plant nutrient; however, it can enter the plant through passive water flow (Brady and Weil, 2003).

Aluminum toxicity can reduce the overall growth of the plant; however, root growth is severely reduced (Clune and Copeland, 1999; Lidon and Barreiro, 2002; Calba et al., 1999; Tabuchi and Matsumoto, 2001). The roots affected will appear short, thickened, and stubby (Brady and Weil 2003). These roots will also have minimal lateral growth and branching; also, the tips will often turn brown (Brady and Weil, 2003). There are numerous causes for this decrease in root growth, such as: the linkage of Al to carboxyl groups in pectin in root cells, the root starting cellulose accumulation instead of synthesis, inhibition of cell division (mitosis) in root apex which can block DNA synthesis, aberration of chromosomal morphology and structure, blockage of calcium uptake sites, restricts cell wall expansion, and programmed cell death by reactive oxygen species (Lidon and Barreiro, 2002; Brady and Weil 2003).

Plants can resist aluminum in one of two ways. The first mechanism is where Al is excluded from the root apex (Al exclusion) or a mechanism where the plant is able to resist Al concentrations (Al resistance) (Dong et al, 2008; Miyaskaka, 1991). Aluminum exclusion is better understood than that of Al resistance. In the mechanism of Al exclusion, the root can excrete an anionic organic acid which seems to help detoxify the Al^{3+} (Dong et al 2008). These organic acids, such as malate, citrate, and oxalate, can act as Al-chelating agents, therefore decreasing the Al solubility and helping protect the root apex. This excretion of organic acids is to help protect the actively growing root apex therefore not limiting growth.

Biological Response to Acidic Soils

Soil microbes play a significant part in most of the process that occur in the soil. These processes play an important role in the dynamic nature of soil. Processes such as organic matter decomposition, mineralization, nitrification, nitrogen fixation, etc. are keys to soil functionality. Soil pH has been recognized to control the microbial activity and species composition in a given soil.

Organic matter decomposition rate can be highly affected by soil pH. As shown by DeLaune et al (1981) the rate of decomposition of organic matter is greatest at pH of 7.0 and deceases with both increasing and decreasing pH. This is due to the increased numbers and diversity of microbial populations near neutral soil pH.

Microbial processes that control nitrogen availability are both ammonification and nitrification. Ammonification is the transformation of soil organic matter to NH_4^+ and nitrification is the transformation of NH_4^+ to NO_3^-, both processes are controlled by microbial populations. Soil acidity has limited to no effect on ammonification. Ammonification can occur even at a lower soil pH compared to nitrification, e.g., at 3.9 $CaCl_2$ soil pH (Dancer et al, 1973; Khalil, 2001). Nitrification rate generally decrease under pH of 6 and is considered very low below a pH of 4.5 (Foth and Ellis, 1988).

Another process that pH can influence is the fixation of nitrogen. Nitrogen fixation can be reduced by acidity due to injury to the plant or interfering with nodulation of the bacteria (Hohenberg and Munns, 1984). In a study by Hohenberg and Munns (1984) nodulation of cowpea (*Vigna unduiculata* L.) can be delayed multiple days due to aluminum concentrations and to a lesser extent soil acidity. They found that at a pH of 5.5 nodules would be present around 11 days, if the pH was decreased to 4.5 they found a delay of 1 to 2 day. At similar pH with low to intermediate aluminum concentration the nodules would be delayed 2-4 days.

Liming Chemistry

Acidity is commonly neutralized by the addition of calcium or magnesium carbonates, oxides, or hydroxides commonly called liming agents (Brady and Weil, 1999). The general reaction occurs when a liming agent, such as $CaCO_3$, is added to an acidic soil (Sparks, 2003):

$$CaCO_3 + H_2O \longrightarrow Ca^{2+} + HCO^- + OH^-$$

The hydroxide formed will react with the various sources of H^+ ions in soil. Liming materials react directly with the acidic ions on the soil surface, replacing them with either calcium or magnesium (Brady and Weil, 1999). The overall reaction of acidic soils with lime is the following:

$$2Al\text{-}soil + 3CaCO_3 + 3H_2O \longrightarrow 3Ca\text{-}soil + 2Al(OH)_3 + 3CO_2$$

The replacement of the acidic cations with the basic cations raises the percent base saturation. Liming alters many chemical processes in the soil; McLean (1971) stated that liming the soil causes the follow to occur:

- Neutralization of acidity
- Increasing base saturation
- Solubility of nutrients changes, due to an increase in pH
- Acidic ion toxicities are neutralized
- Acid weather of primary and secondary minerals decreases
- pH dependant CEC is increased
- pH dependant AEC is decreased
- Fixation and mineralization of nitrogen increases because of both increase in pH and base saturation

Not all of these effects are beneficial to a growing plant, some actually may be detrimental. For example, if mineralization is increased then losses via leaching and denitrification may also increase, depending on environmental circumstances.

Lime Applied

The amount of lime required to increase soil pH to the desired level is dependent on properties of both the soil and the liming agent, these include: 1) the change required, 2) the buffer capacity of the soil, 3) the composition of the liming agent, such as calcium carbonate equivalent, and 4) the fineness of the liming agent (Brady and Weil, 1999).

Calcium carbonate equivalent (CCE) is a measure of a liming agents neutralizing ability compared to calcium carbonate (Havlin 2005). Some of the more commonly used liming agents and their CCE are giving below:

Table 2. CCE of common liming materials.

Liming Material	CCE
	- % -
CaO	179
$Ca(OH)_2$	135
$CaMg(CO_3)_2$	109
$CaCO_3$	100
$CaSiO_3$	86

Modified from Havlin, 2005

The fineness, sometimes call the fineness factor (FF), of the liming agent will affect the reactivity of the liming agent. The smaller the lime the quicker it reacts in the soil because of the increased surface area. The FF is determined by passing the liming agent through a designated number sieve. The effective calcium carbonate equivalent (ECCE) is determined using the CCE and the FF. Using the ECCE you can determine the amount of a specific liming agent you need to apply to raise the pH to reach certain level.

Canola Response to Liming

The issue of the response of liming in crops has been fully addressed for several crops but limited research has been done for winter canola, which is evident in the limited literature. There has been studies performed in Australia on spring canola, however, they are limited and sometimes only addresses spring canola's response to lime.

In a study by Mullen (2006), canola showed a positive response to liming (95-96% Effective Calcium Carbonate Equivalent) in acidic soils (pH <5). Yield was increased as lime increased by the following: 800 (kg ha^{-1}) with no lime, 870 (kg ha^{-1}) with 1 (ton lime ha^{-1}), 1120 (kg ac^{-1}) with 2 (tons lime ac^{-1}), and 1270 (kg ac^{-1}) with 3 (tons lime ac^{-1}). Similarly, in a study by Slattery and Conventry (1993), canola showed an increase in yield with decreasing acidity. Slattery and Conventry (1993) also measured the effects of liming on the concentrations of both aluminum and manganese. They found that on the sites in which liming decreased the concentrations of aluminum and manganese there was a significant increase in yield. However, for one site that the lime did not decrease the aluminum and manganese concentrations there was not an increase in yield. No substantial literature was found for the response of winter canola to soil pH or aluminum concentrations.

Summary

Over the last couple of years there has been a large push for potential biofuel crops. Canola has the potential to be one of those crops; however, we still have limited understanding for producing winter canola. In the southern Great Plains the surface application of ammonia/ammonium based fertilizers has lead to the increase of soil acidity in the surface horizons, therefore putting greater stress on non-acid tolerance crop species. Research has been very limited in regards to the effects of acidic soils on winter canola production. Currently recommendations for the critical limit for winter canola production are based on spring canola and greenhouse experimentation.

CHAPTER III

METHODOLOGY

Field Experiment

The field experiment were established in 2007 and 2008 at the Cimarron Research Station, near Perkins, Oklahoma (35˚59’45.88” N, 97˚02’33.68” W). Temperatures and precipitation for both growing seasons and 30-year averages are given in Figure 1. The dominant soil series at the location is the Konawa series, which is a fine-loamy, mixed, thermic ultic haplustalfs.

Five blocks were set up at the Cimarron Research Station in the Fall of 2006. Each blocks had the dimensions of 8-m wide and 20-m in length, as shown in Figure 2. The blocks were laid out to follow a preexisting soil acidity gradient in an incomplete block design. Prior to planting in 2006, one composite soil sample was taken from 0-15 cm to determine plant available N, P, and K concentrations. Soil tests indicated 48 lb NO_3-N ac^{-1}, soil test P index of 71, and soil test K index of 403 were present at the location. No additional P or K were added during the study since soil test indicated 100% sufficiency of both nutrients.

Eight cultivars were then selected. In each block only six cultivars, due to space limitations, were planted at the seeding rate of 5.6 kg ha^{-1}. Each cultivar was planted in 4 row wide plots at a spacing of 20 cm. Cultural practices are outlined in Table 3. Onehundred and sixty eight kg N ha^{-1} was applied with one-third applied at planting and two-thirds applied top-dress. Throughout the season the plots were maintained weed free.

Table 3. Culturial practices for the 2007 and 2008 growing season

	Planting date	Top-dress date	Harvesting date
2006-2007	9/13/2006	2/13/2007	6/7/2007
2007-2008	9/3/2007	2/11/2008	6/10/2008

The canola was hand harvested in early June 2007 and 2008. At harvest the blocks were divided into individual plots measuring 1 m by 1.3 m (width of four rows), as shown in Figure 2. These plots were harvested by hand clipping all 4 rows. Each plot was thrashed on-site using an Almaco Thrasher (Almaco; Ames, Iowa), and the seed was placed in plastic bags. The seeds were then allowed to air dry at room temperature for 4 days. Then the grain was weighed and moisture readings taken and analyzed. Grain yield was corrected to 100 g kg^{-1} moisture.

Soil samples were taken in both 2007 and 2008 immediately after harvest. A composite soil sample consisting of four soil cores were taken from all the individual plots, 1m by 1.3 m, to a depth of 15 cm and were placed in a mesh soil sample bag. The samples were then placed in drying ovens, 67˚ C, for 72 hours and ground to pass a 2-mm sieve.

Soil pH was analyzed by preparing a 1:1 soil/water ratio (10g of soil and 10mL of water) and pH was measured using a pH electrode (Fisher Scientific; Hampton, New Hampshire) (Thomas, 1996). In addition, extractable-Al measurements were determined by using the Bertsch and Bloom method (1996). In this method 5 g of soil was mixed with 25 mL of 1*M* KCl, extracts were obtained using Q2 quantitative filter paper, and analyzed using a coupled plasma-atomic emission spectroscopy (Spectro; Germany).

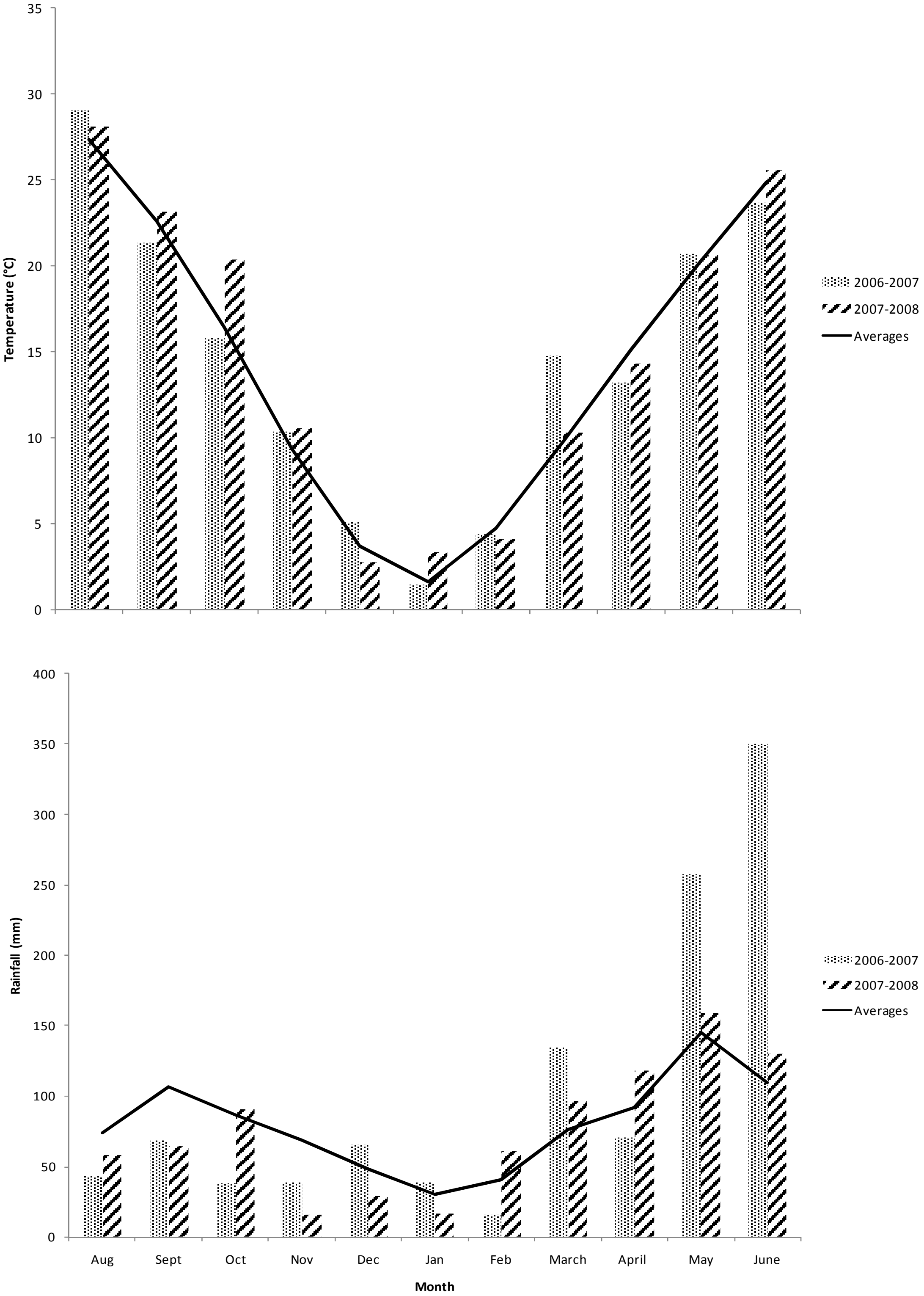

Figure 1. Temperature and precipitation observed in 2006-2008 at Perkins, Oklahoma (2008, MESONET).

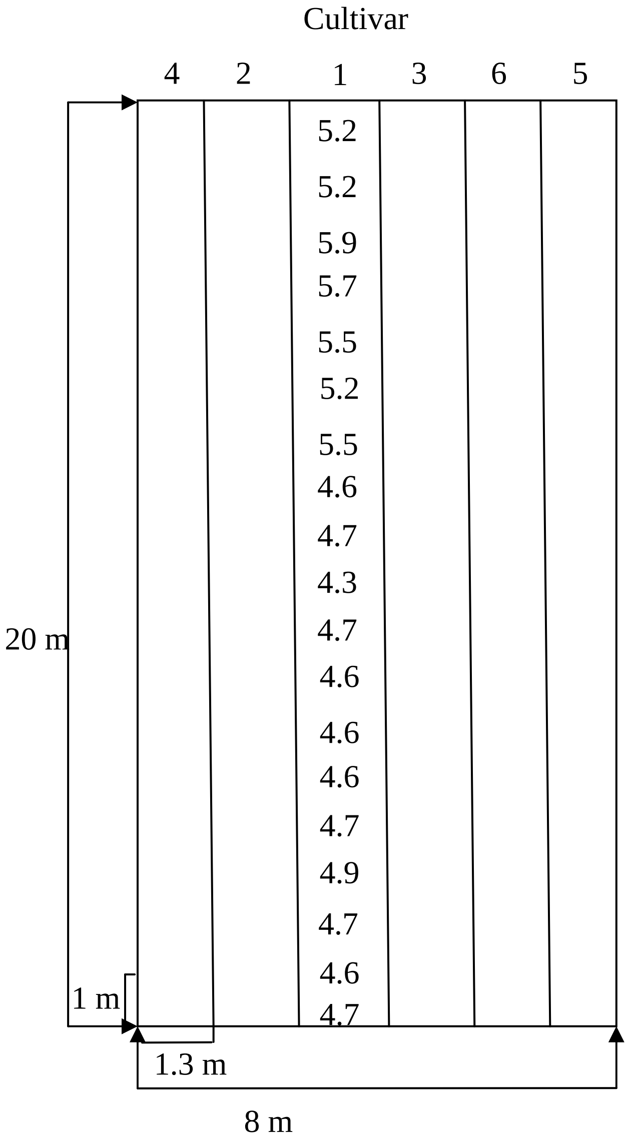

Figure 2. Example diagram of 1 block at the site. Individual cultivars were planted the length of the block. Each block is 8-m wide and 20-m in length. Individual plots are 1.3-m wide and 1-m in length. Four soil cores were taken per plot post harvest.

Laboratory Experiment

A laboratory experiment was conducted to determine the influence of Al concentrations on root growth. Nine winter canola cultivars, which were used in the field experiment, were included in this study. Canola seedlings were germinated on cotton balls that were placed on top of 15 mL conical centrifuge tubes that contained DI water. The experiment was laid out in a split plot design with Al concentrations as the main plot and cultivar as the sub-plot. After germination, seedlings were allowed to grow for 72-hours in DI water. After the 72-hour period the seedlings were transplanted into different Al concentration solutions. The aluminum solutions were made using aluminum chloride ($AlCl_3$) which was then diluted to give the final Al concentrations of 20, 40, 60, 80 mg L^{-1}. The seedlings were allowed to grow in the aluminum solutions for 96-hours. Root lengths were measured and analyzed.

Statistical Analysis

Soil and yield data was analyzed using SAS software version 9.2 (SAS, 2001). Main effects for the field study were year, soil pH, and cultivar. Since the variances between years were different, years were analyzed separately. The 2008 growing season data was not normally distributed; therefore the data were adjusted using a square root transformation (Steel and Torrie, 1997), taking square root of the winter canola grain yield plus 0.5 ($\sqrt{}$yield + 0.5). Regression analysis was performed using PROC REG to determine the relationship between soil pH and winter canola grain yields. The slopes from the regression analysis were compared to determine the differences in response to the soil pH by the winter canola cultivars. A linear plateau model was fit, using PROC NLIN, to determine the critical soil pH for the 2007 growing season. For the laboratory experiment, the main effects were aluminum concentration and variety. A paired comparison was used to determine the response of winter canola’s root lengths to aluminum concentration both between different aluminum concentrations and between cultivars.

CHAPTER IV

RESULTS AND CONCLUSIONS

1.1 Field Experiment

1.1.1 Soil pH and KCl-extractable aluminum

Soil pH (water:soil) varied along the pH gradient from 4.1 to 6.5 and 3.9 to 6.5 in 2007 and 2008, respectively. Differences between years were observed for soil pH. Soil pH was lower on average in 2008 compared to 2007. This difference can probably be attributed to temporal variability in soil pH. For example, soil samples collected in 2007 from plot 101-6 indicated a soil pH 4.9; however in 2008 the soil pH was lower at 4.6. This was the case for most plots (data not shown).

Potassium chloride extractable Al ranged from 1 to 201 mg kg^{-1} and 1 to 162 mg kg^{-1} in 2007 and 2008, respectively. Similar to soil pH, Al concentrations were different between 2007 and 2008. Potassium chloride-extractable Al was lower in 2008 compared to 2007 concentrations. This difference is surprising since soil pH was actually lower in 2008 and one would expect higher Al concentrations. For example, plot 101-8 in 2007 the KCl-extractable aluminum concentration was at 153 mg kg^{-1}(with the soil pH of 4.8) and in 2008 the KCl-extractable aluminum concentration was at 115 mg kg^{-1} (with the soil pH of 4.6). This difference between years was probably due to temporal variation between the two sampling years. Samples for the 2007-2008 season were collected in drier conditions; whereas, in 2006-2007 samples were collected in moist conditions. The drier conditions could increase the ionic strength, therefore lowering the soil pH (Dyer et al., 2008).

Potassium chloride-extractable Al decreased exponentially with increasing soil pH (Figure 3). Even though the relationship between KCl-extractable Al and soil pH was different between the 2 years, KCl-extractable Al approached 0mg kg^{-1} at a soil pH near 5.9.

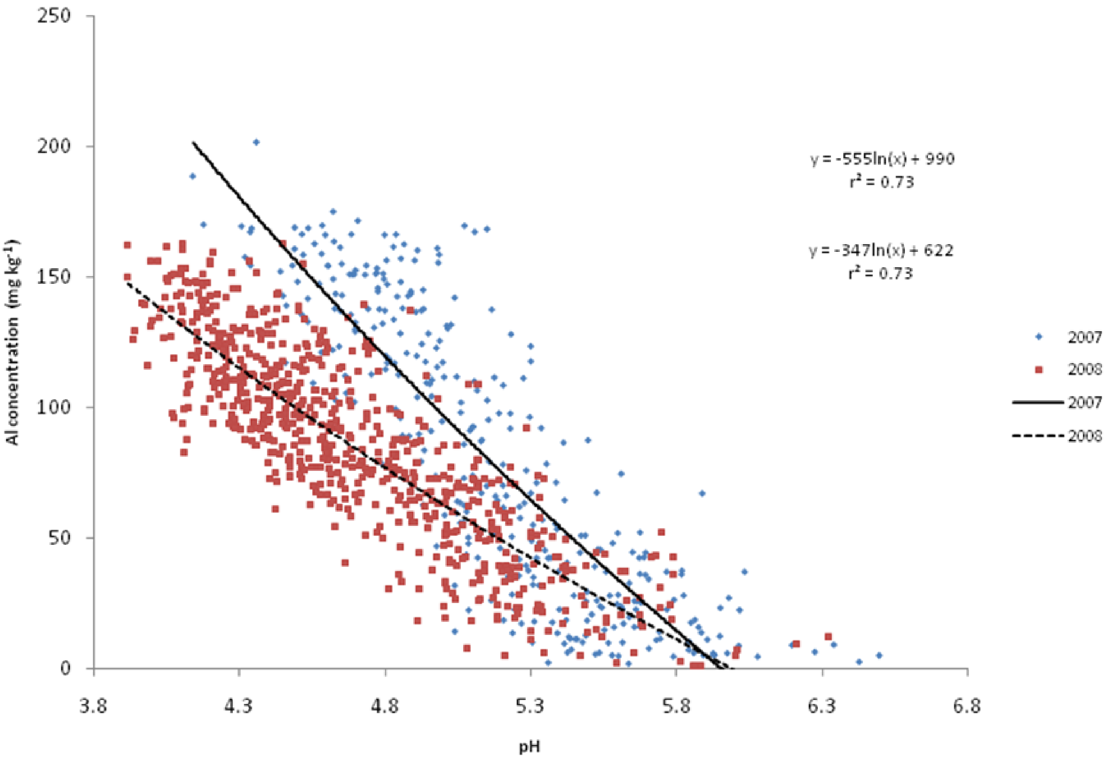

Figure 3. Potassium chloride extractable-Al as a function of 1:1 (soil:water) soil pH.

1.1.2 Grain yields

Differences were observed betweens years, so yield data were analyzed separately for each year. The relationship between canola grain yield and soil pH is given in Figures 4 and 5. For the 2007 growing season, the canola grain yields ranged from 0 to 2826 kg ha^{-1} with an average of 1046 kg ha^{-1}. In 2007, there was a strong linear relationship between canola grain yield and soil pH (r^2=0.70 p-value <0.01), for every 0.1 increase in soil pH canola grain yield increased 157 kg ha^{-1}. Figure 4 also illustrates a linear plateau model that was fit to the data (p-value <0.01). Canola grain yield reached a critical soil pH at soil pH of 5.8, whereas soil pH increased canola grain yield did not continue to increase. In reality we would have like more data points above a pH of 5.8 but this model seems appropriate based on other data and we would assume a plateau at or near a soil pH of 5.8.

For the 2008 growing season, canola grain yields were lower compared to yield observed in 2007. Grain yield ranged from 0 to 1800 kg ha^{-1} with an average yield of 133.8 kg ha^{-1}. Due to the increased amount of low yielding plots in 2007-2008 growing season data were not normally distributed. Therefore, canola grain yields were transformed using a square root transformation (√yield+0.5). Similar to the 2007 growing season there is a linear relationship between canola grain yields and soil pH (r^2=.55 p-value <0.01), where for every 0.1 increase in soil pH canola grain yields increased 38 kg ha^{-1}.

Lower yields for the 2007-2008 season can probably be attributed to the climatic differences between the two years, as seen in Figure 1. In the 2006-2007 season temperature in the month of March was above average. Also, below average rainfall in the late fall of the 2008 growing season (Figure 1) possibly decreased the over winter survivability of the canola rosettes due to lack of moisture. This is due to additional stress that would not allow for adequate crown and root system development (Boyles, 2006). This lack of root development was compounded due to most of the plants were already stressed because of stunted root systems due to Al toxicity.

The relationship, for both years, between canola grain yields and soil pH is similar to that found by others (Slattery and Conventry, 1993; Mullen, 2006) in spring canola. Slattery and Conventry (1993) found a decrease in spring canola grain yields, as soil pH decreased. In a study by Mullen (2006), spring canola grain yield was increased as soil pH increased from 1120 kg ha^{-1} at soil pH of 5.4 to 1270 kg ha^{-1} at the soil pH of 5.9 (a 13% increase in yield). In the 2006-2007 growing season we found a similar increase, when soil pH was at 5.4 canola grain yield averaged 1500 kg ha^{-1} and averaged 2000 kg ha^{-1} at soil pH 5.8 (a 33% increase in yield). For the 2007-2008 growing season there was also a similar trend however not as pronounced as 2006-2007, when soil pH was 5.4 canola grain yield averaged 450 kg ha^{-1} and averaged 550 kg ha^{-1} at soil pH 5.8 (a 22% increase in yield).

Figure 4 shows that in the 2007 growing season canola grain yields reached an critical soil pH at 5.8. In 2008, a lack of observations above a soil pH of 5.8 prevented identifying a plateau in grain yield. Previous research has found that spring canola can tolerate soil pH levels as low as 5.5 (Canola Council of Canada, 2003; OMAFRA, 2002). Slattery and Conventry (1993) stated that compared to wheat and triticale canola is considered sensitive to soil acidity. This is due to canola having a higher critical pH.

This study would confirm this when compared to the results found by Kariuki (2007), which found that winter wheat has a critical soil pH of 5.5.

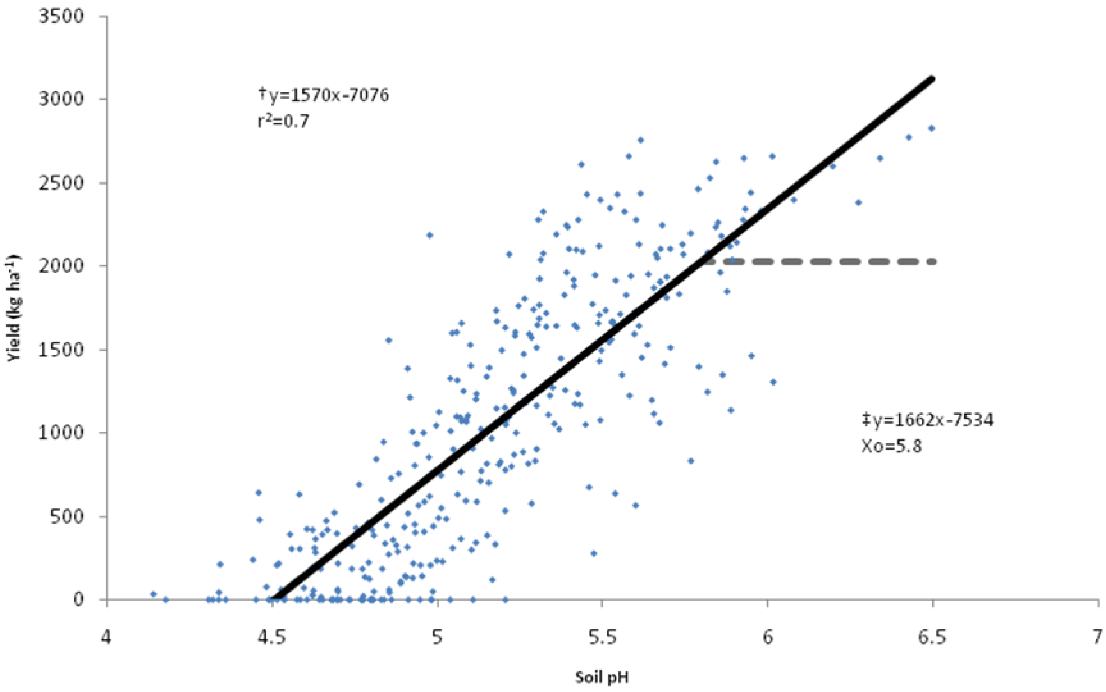

Figure 4. 2006-2007 winter canola grain yield as a function of 1:1 (soil :water) soil pH. The dark line represents the linear relationship between soil pH and yield, while the dashed line represents the linear-plateau model. Both models were significant ($p < 0.01$).

†Line equation for linear model

‡Line equation for linear-plateau model

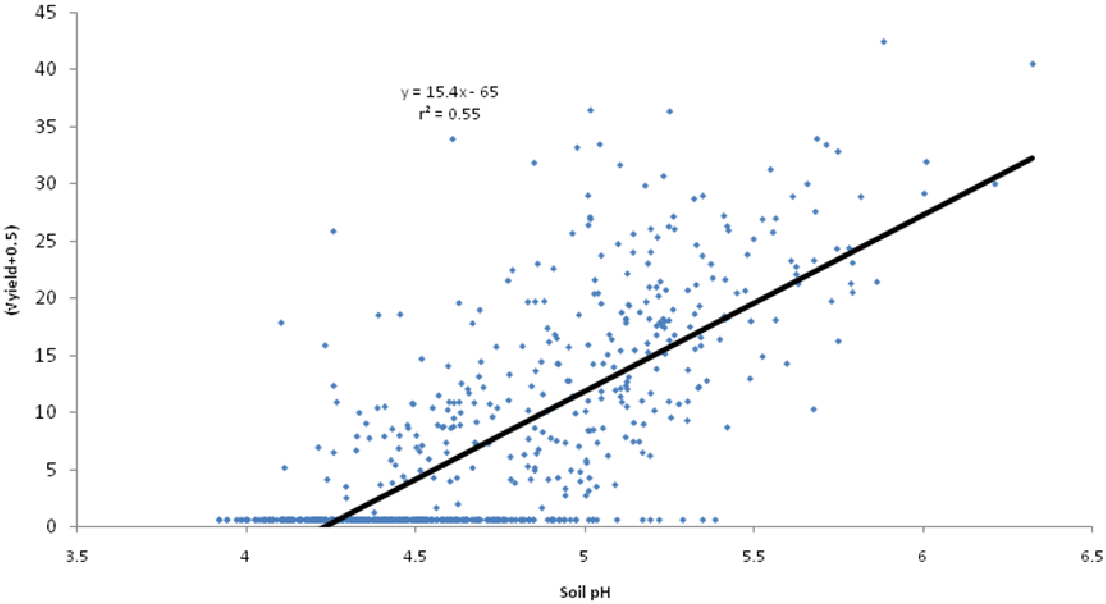

Figure 5. 2007-2008 transformed winter canola grain yields as a function of 1:1 (soil:water) soil pH. Yield data was transformed using a square root transformation, taking the square root of grain yields plus 0.5 (√yield−0.5).

1.1.3 Cultivar response to soil pH

Table 4 shows a correlation between individual cultivar and soil pH. Individual cultivars showed different response to soil pH. In the 2006-2007 growing season, grain yields of KS 9135, Wichita, and Baldur were correlated to soil pH having an r^2 value of 0.88, 0.85, and 0.81, respectively (p-value <0.0001).

Grain yield for KS 9135 increased 189.7 kg ha^{-1} for every 0.1 increase in soil pH. Canola grain yields of Wichita and Baldur increased 181.3 kg ha^{-1} and 161.3 kg ha^{-1}, respectively, for every 0.1 increase in soil pH.

For the 2008 growing season Kronos grain yields were correlated with soil pH (r^2= 0.74). KS 3269 and Sumner grain yields were also correlated with soil pH (r^2= 0.64 and 0.63 respectively). Grain yields for Kronos, KS 3269, and Sumner increased 53.1, 30.6, and 32 kg ha^{-1}, respectively, for every 0.1 increase in soil pH. Unlike the 2006-

2007 growing season both KS 9135 and Wichita grain yields were correlated with soil pH in the 2007-2008 growing season. DKW 13-69 also was correlated to soil pH. The differences between years may be attributed to variation of climate between the two years, as shown in Figure 1.

Table 4. Winter canola grain yields as a function of 1:1 (soil:water) soil pH. Soil pH ranged from 4.1 to 6.5 in 2006-2007 and from 3.9 to 6.5 in 2007-2008.

	2006-2007		2007-2008†	
	Equation	r^2	Equation	r^2
KS 9135	1897x-8710	0.88	14.5x-59.6	0.46
Wichita	1813x-8486	0.85	15.5x-64.4	0.48
Sumner	2075x-9541	0.54	14.6x-62.9	0.63
Baldur	1613x-7308	0.81	12.8x-54.5	0.55
KS 3269	na‡	na	15.3x-64.8	0.64
KS 3074	1035x-4277	0.44	18.8x-80.7	0.56
DKW 13-69	1456x-6455	0.68	9.5x-38.9	0.42
Virginia	1164x-5186	0.61	na	na
Kronos	na	na	18.2x-77.5	0.74

† 2007-2008 data was transformed using square root transformation (√yield+0.5)

‡ Data is unavailable since cultivar was not used that given year

Table 5. P-values for slope comparison between 2007 winter canola cultivars response to 1:1 (soil:water) soil pH

	KS 9135	Wichita	Virginia	Sumner	Baldur	EXP 3269	KS 3074	DKW 13-69
KS 9135		0.61	<0.01	0.55	0.13	0.10	<0.01	0.04
Wichita	0.61		<0.01	0.33	0.21	0.17	<0.01	0.07
Virginia	<0.01	<0.01		<0.01	0.02	0.02	0.57	0.20
Sumner	0.55	0.33	<0.01		0.13	0.10	<0.01	0.08
Baldur	0.13	0.21	0.02	0.13		0.93	0.01	0.50
EXP 3269	0.10	0.17	0.02	0.10	0.93		0.01	0.52
KS 3074	<0.01	<0.01	0.57	<0.01	0.01	0.01		0.13
DKW 13-86	0.04	0.07	0.20	0.08	0.50	0.52	0.13	

Table 6. P-values for slope comparison between 2008 winter canola cultivars reponse to 1:1 (soil:water) soil pH.

	KS 9135	Wichita	Kronos	Sumner	Baldur	KS 3269	KS 3074	DKW 13-69
KS 9135		0.68	0.07	0.97	0.41	0.73	0.07	0.02
Wichita	0.68		0.20	0.69	0.19	0.92	0.18	0.01
Kronos	0.07	0.20		0.05	<0.01	0.12	0.79	<0.01
Sumner	0.97	0.69	0.05		0.35	0.71	0.07	0.01
Baldur	0.41	0.19	0.00	0.35		0.20	0.01	0.08
KS 3269	0.73	0.92	0.12	0.71	0.20		0.13	<0.01
KS 3074	0.07	0.18	0.79	0.07	0.01	0.13		<0.01
DKW 13-69	0.02	0.01	<0.01	0.01	0.08	0.00	<0.01	

To determine if the canola cultivars responded differently to varying soil pH the slopes of the linear regression lines were compared for 2006-2007 and 2007-2008 growing season (Figure 5 and 6). For 2006-2007, Virginia responded differently compared to every cultivar with the exception of KS 3074 and DKW 13-86. The slopes for Virginia and KS 3074 possibly indicated they are less sensitive to soil acidity. KS9135 responded differently to only Virginia and KS 3074. The larger slope of KS9135 could indicate it being more sensitive to soil acidity. In 2007-2008, DKW 13-69 responded differently to every cultivar with the exception of Baldur. The smaller slope of DKW 13-69 may indicate that it is less sensitive to soil acidity. KS 3074 responded similarly to every cultivar with the exception of DKW 13-69. The slope for KS 3074 possibly indicated that it is more sensitive to soil acidity.

These results were not consistent between years. In 2006-2007, when there was less environmental stress, cultivars such as DKW 13-86 seemed to be less sensitive to soil acidity, but in 2007-2008 growing season, when there were more environmental stresses, DKW 13-86 appeared to be more sensitive to soil acidity. Due to inconsistencies between years a greenhouse study was established to try to eliminate the inconsistencies due to the temporal variability. We predict that if the temporal variability was minimized our results would be similar to the results found by Kariuki et. al. (2007) in winter wheat. Kariuki found that the differing winter wheat cultivars response varied when grown in acidic soils.

2.1 Laboratory Experiment

A laboratory experiment was carried out to determine if canola root growth is affected by increasing aluminum concentrations. The overall mean length for each cultivar at each aluminum concentration is given in Figure 6. A Tukey's test was used to determine differences in the response to the various Al concentrations within each cultivar, as well as determining differences within Al concentrations for each cultivar. Differences in root lengths were found by subtracting root lengths from increasing Al concentrations. For example, the root length at 20 mg Al kg^{-1} will be subtracted from the root length at 0 mg Al kg^{-1}.

Table 7. Difference of root length at increasing aluminum concentrations (0-20, 20-40, 40-60, 60-80 mg Al L^{-1}) for winter canola cultivars.

	0-20	20-40	40-60	60-80
		- - - mm - - -		
KS 3074	1.9a†	3.3a	1.9a	11.0a
Virginia	3.1b	4.0ab	3.8b	9.1bc
Sumner	5.5d	4.9bc	1.9a	8.2bc
Kronos	4.3bc	6.1de	3.6b	8.3c
DKW 13-69	1.7a	7.4de	5.0b	6.8d
KS 9135	4.0bc	4.5bc	1.7a	9.3bc
Wichita	4.7cd	5.8d	1.0a	11.7a
Baldur	4.1bcd	5.2cd	3.8b	9.1bc

†Different letters within column indicate differences

This was used to determine the decrease in root length of each cultivar with increasing aluminum concentrations. The decrease in root length from 0 to 20 mg Al L^{-1} was the smallest for KS 3074 and DKW 13-69, indicating less sensitivity to Al.

However, the difference in root growth between 20 mg Al L^{-1} and 40 mg Al L^{-1} indicated DKW 13-69 had a greater decrease in root length compared to KS3074, Virginia, Sumner, and KS 9135.

Looking at difference within each cultivar (Figure 6) the average root length for each aluminum level were compared using the Tukey comparison method.

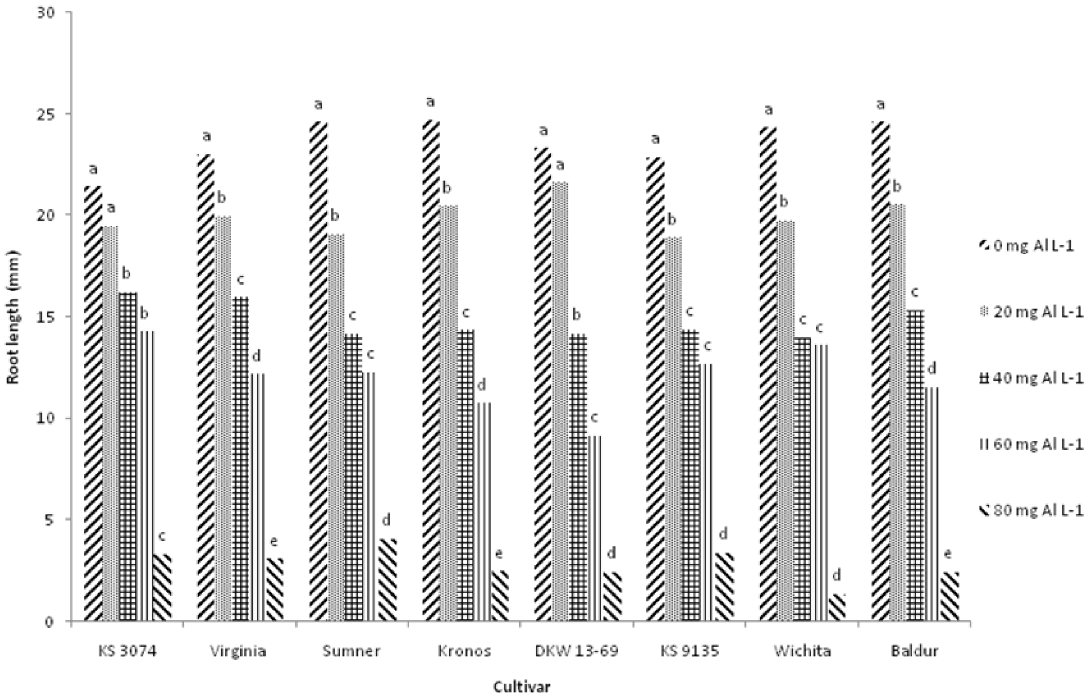

Figure 6. Winter canola root length as a function of aluminum concentration. Different letters indicate differences within cultivar ($P<0.05$).

When comparing the mean root length for 0 mg Al L^{-1} to 20 mg Al L^{-1} there was a difference for every cultivar with the exception of KS 3074 and DKW 13-69. This could possibly show that these two cultivars are less sensitive to low concentrations of Al. However, the difference between 0 mg Al L^{-1} and 40 mg Al L^{-1} was significant for all cultivars. Both KS 3074 and DKW 13-69 had differences in mean root length between the 20 mg Al L^{-1} and 40 mg Al L^{-1}. When comparing the mean root length between 40 mg Al L^{-1} to 60 mg Al L^{-1} there was no difference for KS 3074, but there was a difference for DKW 13-69; however, there is a difference for both cultivars between 40 mg Al L^{-1} and 80 mg Al L^{-1}. Both cultivars had a significant difference between 60 mg Al L^{-1} and 80 mg Al L^{-1}. This possibly showed that these two cultivars seemed to be less sensitive of low Al concentrations due to showing no difference between 0 mg Al L^{-1} to 20 mg Al L^{-1}. In both the laboratory and the field (2006-2007) experiment KS 3074 and DKW 13-69 appeared to be less sensitive to the effects of soil acidity.

This study found similar results as Clune and Copeland (1999), where canola seedlings root length was decreased by 45% at aluminum concentrations of 80µmol. Clune and Copeland found that the greatest spring canola root growth occurred between 20 and 40 µM; this study also found that at low aluminum concentrations (20 mg L^{-1}) canola roots were decreased. Adams (1966) found when determining the effects of chemical activity in different soil types in all soil types, as aluminum concentration increased cotton roots decreased. The varying response of the cultivars is similar to the findings of Kariuki et. al. (2007), were wheat cultivars responded different to varying levels of aluminum saturation. This study agrees with previous research in that as aluminum concentrations increased root length and root growth decreased.

Relating Field and Laboratory:

According to the field experiment our critical pH 5.8 correlated to 14.7 mg Al kg^{-1} and 11.3 mg Al kg^{-1} in 2007 and 2008 respectively (Figure 7). This is similar to the results found in the laboratory experiment where 7 of the 9 cultivars decreased in root length at 20 mg Al L^{-1}, which is greater than our critical Al level, where Al concentrations are high enough to reduce yield.

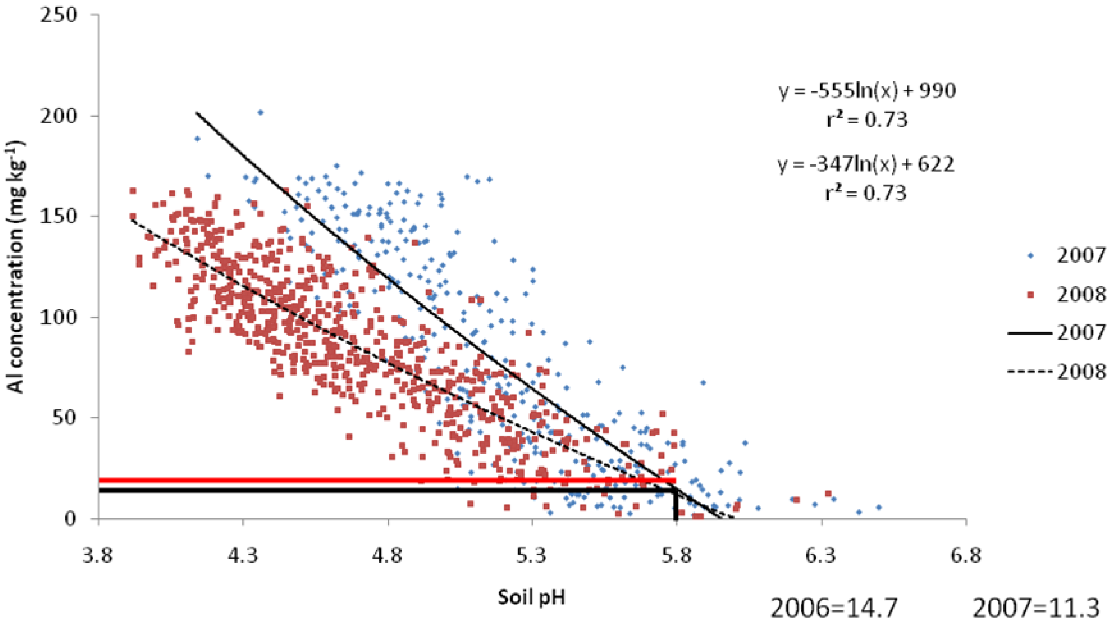

Figure 7. Aluminum concentrations correlated to critical soil pH of 5.8.

2006=14.7 mg Al kg^{-1}

2007=11.3 mg Al kg^{-1}

CHAPTER V

CONCLUSION

Potassium chloride extractable-Al concentrations and 1:1 (soil:water) soil pH influenced winter canola grain yields. Current critical soil pH recommendations, given by Oklahoma State University Department of Plant and Soil Sciences, of 5.8 were found to be adequate for winter canola growth. Field and laboratory studies indicated that winter canola is very sensitive to KCl extractable-Al.

Field testing to determine the effect of soil pH on individual cultivars was not consistent between years due to environmental differences. However, laboratory studies indicated that differences do exist in Al tolerance of winter canola cultivars.

Winter canola producers in the southern plains need to closely monitor their soil pH in order to limit yield loss due to soil acidity. Variety selection appears to be a management tool for slightly acidic soils (5.5 to 5.8). Future research will need to further investigate these differences between cultivars.

CHAPTER VI

FUTURE RESEARCH

Future research will need to further examine the differences in cultivar response to soil acidity. Differences in cultivars have shown promise in a controlled laboratory environment and could provide producers a valuable management tool when they try to grow winter canola in acidic soils. Also, future research needs to be conducted in finding the critical soil pH for winter canola production in other soils type and other environmental conditions. Both 2006-2007 and 2007-2008 where not “normal” year in Oklahoma; therefore, extending the study a couple more years might help to decrease the inconsistencies that were found in the field study.

Also, trying to determine what species of aluminum are causing the decrease in winter canola production. Trying to determine if any other toxicities are present at these low soil pH’s that might be decreasing winter canola production; such as manganese. Additional laboratory work will always need to be continued to determine the aluminum sensitivity of new winter canola cultivars.

Although many steps were taken in this study to determine the affects of low soil pH’s on winter canola production, there is more research that needs to be done in order to fully understand the interaction between winter canola and soil pH.

REFERENCES

Adams F., Z. F. Lund. 1966. Effect of Chemical Activity of Soil Solution Aluminum on Cotton Root Penetration of Acid Subsoil. Soil Science. 101:193-198.

Bertsch, P. M., P. R. Bloom. 1996. Aluminum. P 517-550. *IN* D. L. Sparks (ed.) Methods of soil analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.

Blevins, R. L., G. W. Thomas, M. S. Smith, W. W. Frye, P. L. Cornelius. 1983. Changes in Soil Properties after 10 Years of Continuous Non-Tilled and Conventionally Tilled Corn. Soil and Tillage Research. 3:135-146.

Bohn H. L., B. L. McNeal, G. A. O'Connor. 2001. Soil Chemistry. John Wiley and Sons, New York.

Boyles, M., T. Peeper, C. Medlin. 2007. Producing Winter Hardy Canola in Oklahoma. Oklahoma Coop. Ext. F-2130. Oklahoma State Univ., Stillwater, OK

Boyles, M., T. Peeper, M. Stamm. 2006. Great Plains Canola Production Handbook. Agric. Exp. Stn. and Cooperative Ex. Service. MF-2734. Kansas State Univ. Manhattan, KS.

Brady, N. C., R. R. Weil. 1999. The Nature and Properties of Soils. 12th ed. Prentice Hall, New Jersey.

Brady, N. C., R. R. Weil. 2002. The Nature and Properties of Soils. 13th ed. Prentice Hall, New Jersey.

Calba, H., P. Cazevieille, B. Jaillard. 1999. Modelling the dynamics of Al and protons in the rhizosphere of maize cultivated in acidic substrate. Plant and Soil. 209:57-69.

Canola Council of Canada. 2001. Canola Standards and Regulations. Available at http://www.canola-council.org/oil_tech.html (verified 12 January 2009).

Canola Council of Canada 2003. Canola Growers Manual. Available at http://www.canola-council.org/canola_growers_manual.aspx (verified 22 February 2009).

Clune, T. S., L. Copeland. 1999. Effects of aluminum on canola roots. Plant and Soil. 216:27-33.

Dancer, W. S., L. A. Peterson, G. Chesters. 1973. Ammonification and nitrification of Nitrogen as influenced by soil pH and previous nitrogen treatments. Soil Science Society of America Proceedings. 37:67-69.

Delhaize E., P. R. Ryan. 1995. Aluminum toxicity and tolerance in plant. Plant Physiology. 107:315-321.

DeLaune R. D., C. N. Reddy, W. H. Patrick Jr., 1981. Organic matter decomposition in soil as influenced by pH and redox conditions. Soil Biology and Biochemistry. 13:533-534.

Dong, X. Y., R. F. Shen, R. F. Chen, Z. L. Zhu, J. F. Ma. 2008. Secretion of malate and citrate from roots is related to high Al-resistance in *Lespedeza bicolor*. Plant and Soil. 306:139-147.

Dyer, C. L., P. M. Kopittke, A. R. Sheldon, N. W. Menzies. 2008. Influence of soil moisture content on soil solution composition. SSSJA. 72:355-361.

Essington, M. E., 2004. Soil and Water Chemistry. CRC Press, Boca Raton, FL.

Foth, H. D., B. G. Ellis. 1988. Soil Fertility. Wiley, New York.

Hansen, C., E. Oelke. 1998. Canola Production. University of Minnesota Extention. 641. Minneapolis, Minnesota. Available at http://www.extension.umn.edu/info-u/farming/BC641.html (verified 12 January 2009).

Havlin, J. L., J. D. Beaton, S. L. Tisdale, W. L. Nelson. 2005. Soil fertility and fertilizers: an introduction to nutrient management. 7th ed. Prentice Hall, New Jersey.

Hohenberg, J. S., D. N. Munns. 1984. Effect of soil acidity factors on nodulation and growth of *Vigna unguiculata* in solution culture. Agronomy Journal. 76:477-481.

Kariuki, S. H. Zhang,* J. L. Schroder, J. Edwards, M. Payton, B. F. Carver, W. R. Raun, and E. G. Krenzer. 2007. Hard Red Winter Wheat Cultivar Response to a pH and Aluminum concentration gradient. Agronomy Journal, 99:88-98.

Khalil, M. I., O. V. Cleemput, P. Boeckx, A. B. Rosenani. 2001. Nitrogen transformations and emissions of greenhouse gases from three acidic soils of humid sub-tropics amended with N sources and moisture regimes. I. Nitrogen transformations. Communications in Soil Science and Plant Analysis. 32:2893-2907.

Lindon, F. C., M. G. Barreiro. 2002. An Overview of Aluminum Toxicity in Maize. Bulgarian Journal of Plant Physiology. 28:96-112.

McLean E. O., 1971. Potential beneficial effects of liming: Chemical and physical. Soil and Crop Science Society of Florida Proceedings. 31:189-196.

Miyasaka, S. C., J. G. Buta, R. K. Howell, C. D. Foy. 1991. Mechanism of Aluminum Tolerance in Snapbeans. Plant Physiology. 96:737-743.

Mudrock, L., D. Call. 2006. Managing Seasonal Fluctuations of Soil Tests. Univer. of Kentucky Cooperative Ext., AGR-189. University of Kentucky, Lexington, KY.

Mullen, C. L., B. J. Scott, C. M. Evans, M. K. Coyers. 2006. Effects of soil acidity and liming on lucerne and following crops in central-western New South Whales. Australian Journal of Experimental Agriculture 46:1291-1300.

OMAFRA. 2002. Spring and Winter Canola. *IN* Agronomy Guide to Field Crops. Publication 811. Ridgetown, Ontario, Canada. Available at http://www.omafra.gov.on.ca/english/crops/pub811/p811toc.html (verified 1/26/2009).

Prasad, R., and J.F. Power. 1997. Soil fertility management for sustainable agriculture. CRC Lewis Publ., Boca Raton, FL.

SAS Institute. 2001. SAS/STAT: Procedures. SAS Proprietary Software Release 9.1 (TS2M0). SAS Inst., Cary, NC.

Slattery, W. J., D. R. Coverty. 1993. Response of wheat, triticale, barley, and canola to lime on four soil types in north-eastern Victoria. Australian Journal of Experimental Agriculture 33: 609-618.

Sparks, D. L. 2002. Environmental Soil Chemistry. 2nd ed. Academic Press, San Diego, CA.

Steel R. G. D., J. H. Torrie, D. A. Dickey. 1997. Principles and Procedures of Statistics a Biometrical Approach. 3rd ed. WCB McGraw-Hill, Boston, MA.

Tabunchi, A., H. Matsumoto. 2001. Changes in cell wall properties of wheat (*Triticum aestivum*) roots during aluminum-induced growth inhibition. Physiologia Plantarum. 112:353-358.

Thomsa, G. W. 1996. Soil pH and soil acidity. P. 475-490. *IN* D. L. Sparks (ed.) Methods of soil analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.

Zhang, H. 2000. Oklahoma Agriculture Soil Test Summary 1994-1999. Oklahoma Coop Ext. CR-2247. Oklahoma State Univ. Stillwater, OK.

Zhang, H., B. McCray. 2004. Oklahoma Agriculture Soil Test Summary 2002-2003. Oklahoma Coop Ext. CR-2253. Oklahoma State Univ. Stillwater, OK.

Zhang, H., B. Raun. 2006. Oklahoma Soil Fertility Handbook. 6th ed. Department of Plant and Soil Sciences. Oklahoma State Univ. Stillwater, OK.

APPENDIX A

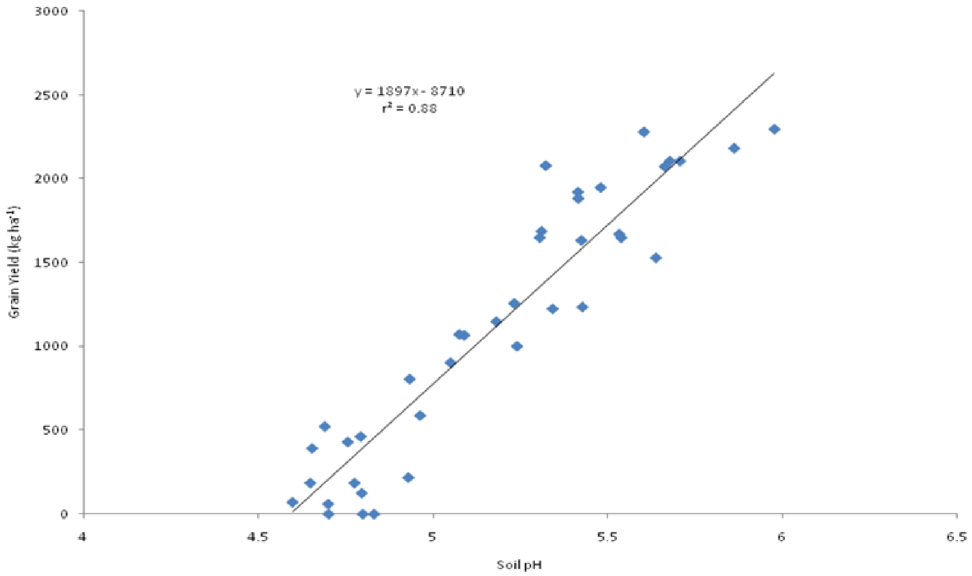

Figure A1. 2006-2007 KS 9135 grain yield as a function of 1:1 (soil:water) soil pH.

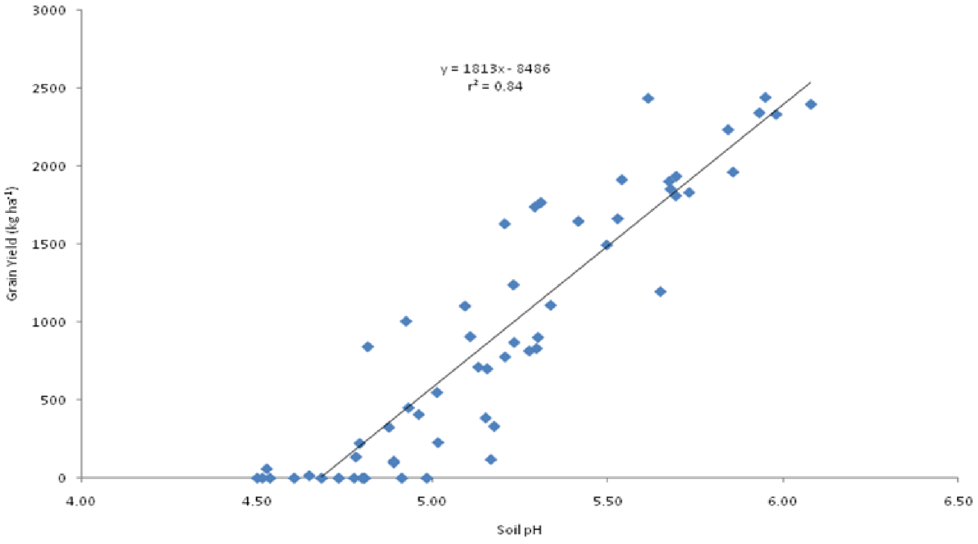

Figure 2A. 2006-2007 Wichita grain yield as a function of 1:1 (soil:water) soil pH.

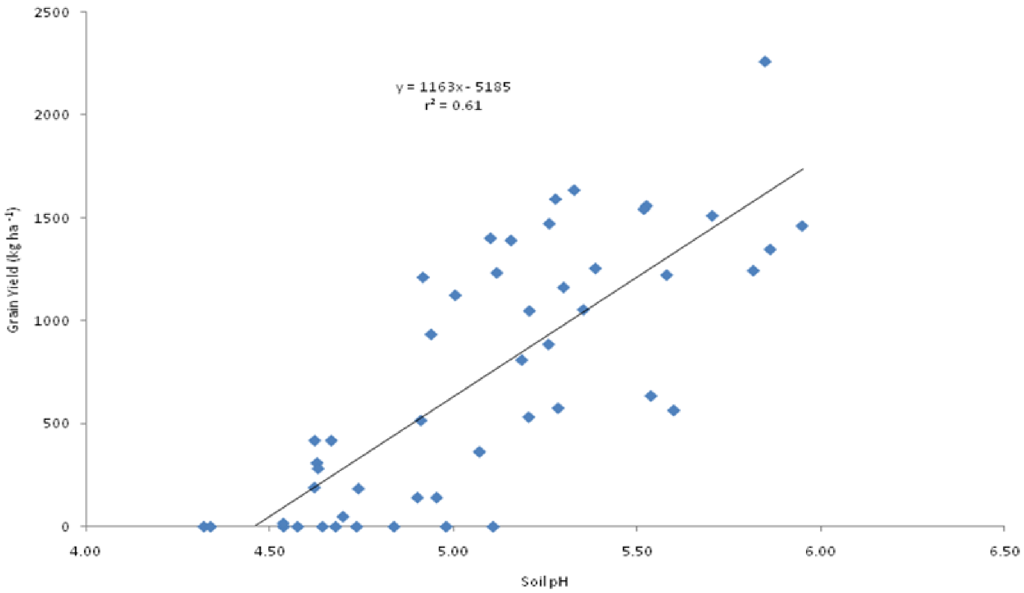

Figure 3A. 2006-2007 Virginia grain yield as a function of 1:1 (soil:water) soil pH.

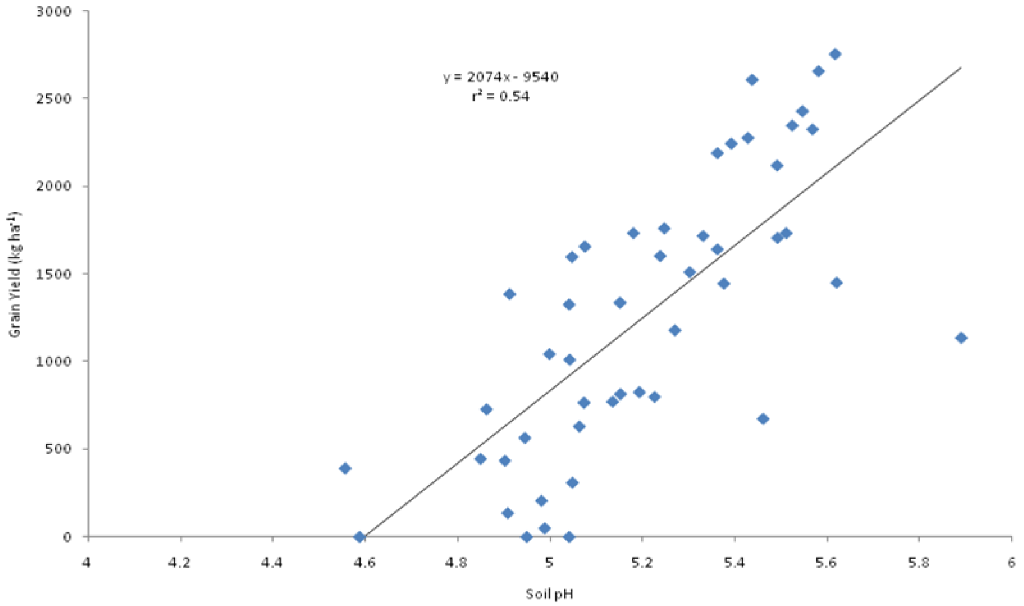

Figure 4A. 2006-2007 Sumner grain yield as a function of 1:1 (soil:water) soil pH.

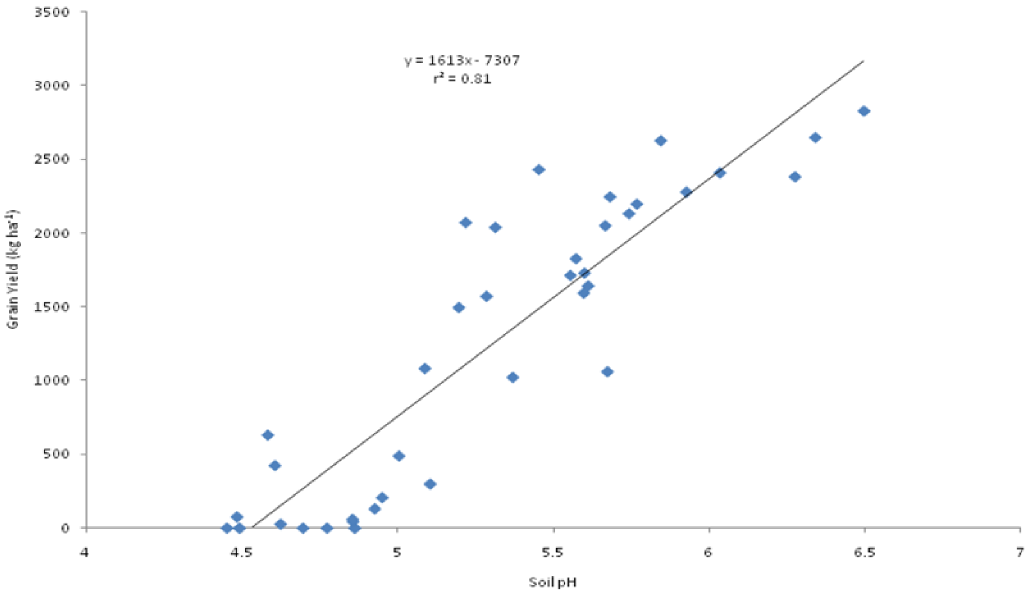

Figure 5A. 2006-2007 Baldur grain yield as a function of 1:1 (soil:water) soil pH.

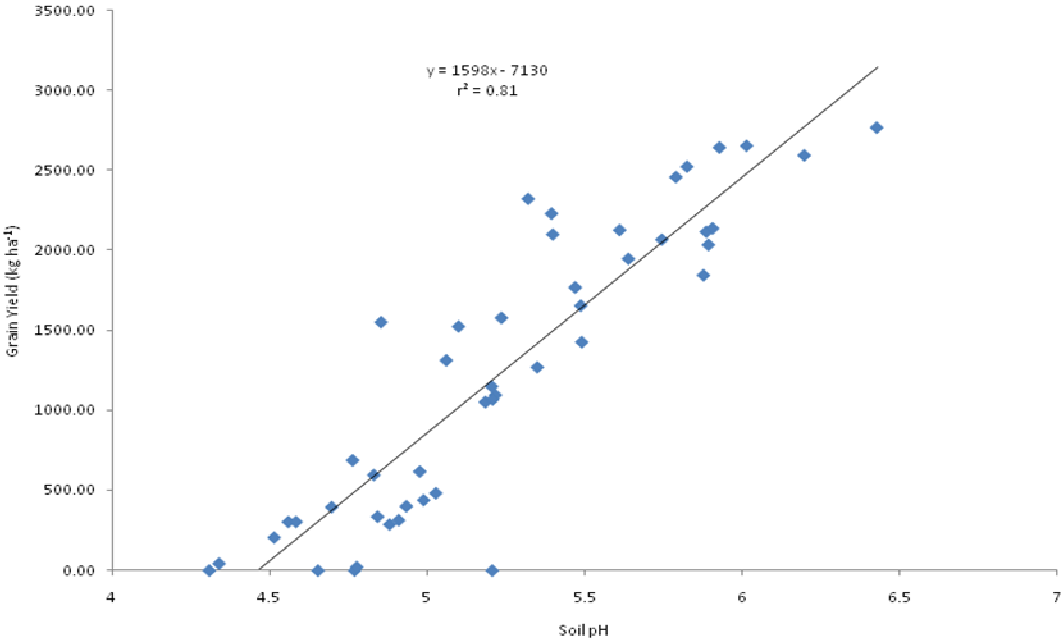

Figure 6A. 2006-2007 EXP 3269 grain yield as a function of 1:1 (soil:water) soil pH.

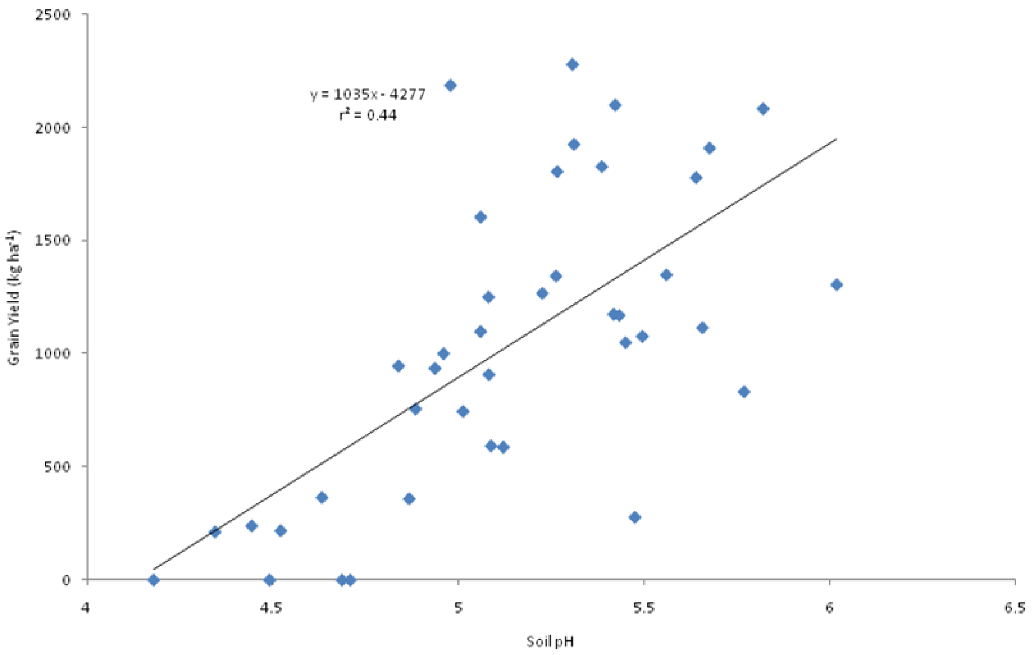

Figure 7A. 2006-2007 KS 3074 grain yield as a function of 1:1 (soil:water) soil pH.

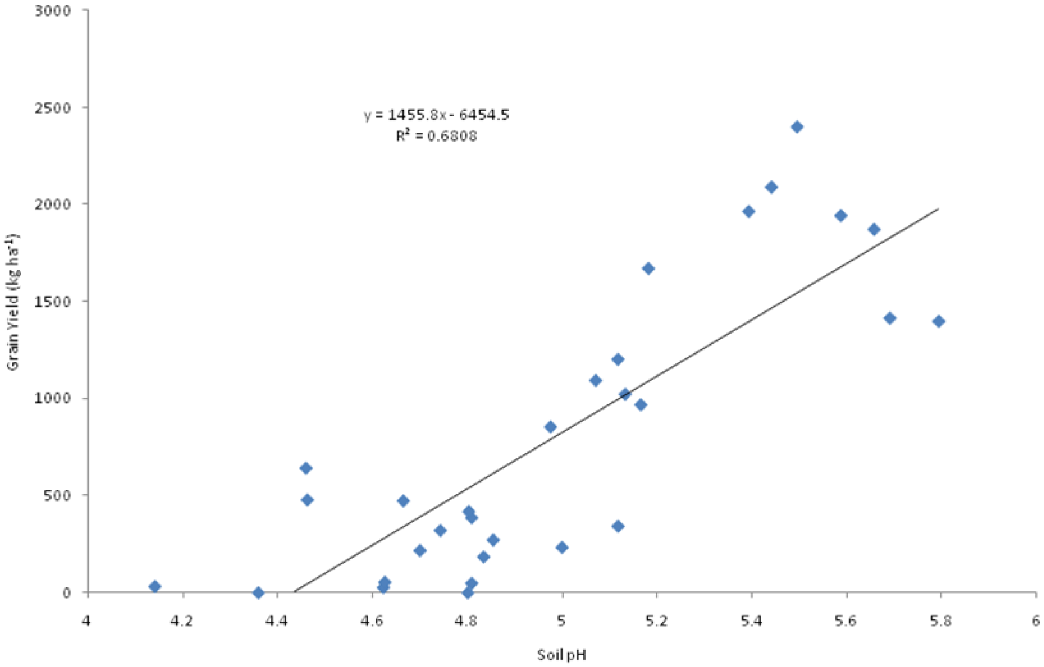

Figure 8A. 2006-2007 DKW 13-86 grain yield as a function of 1:1 (soil:water) soil pH.

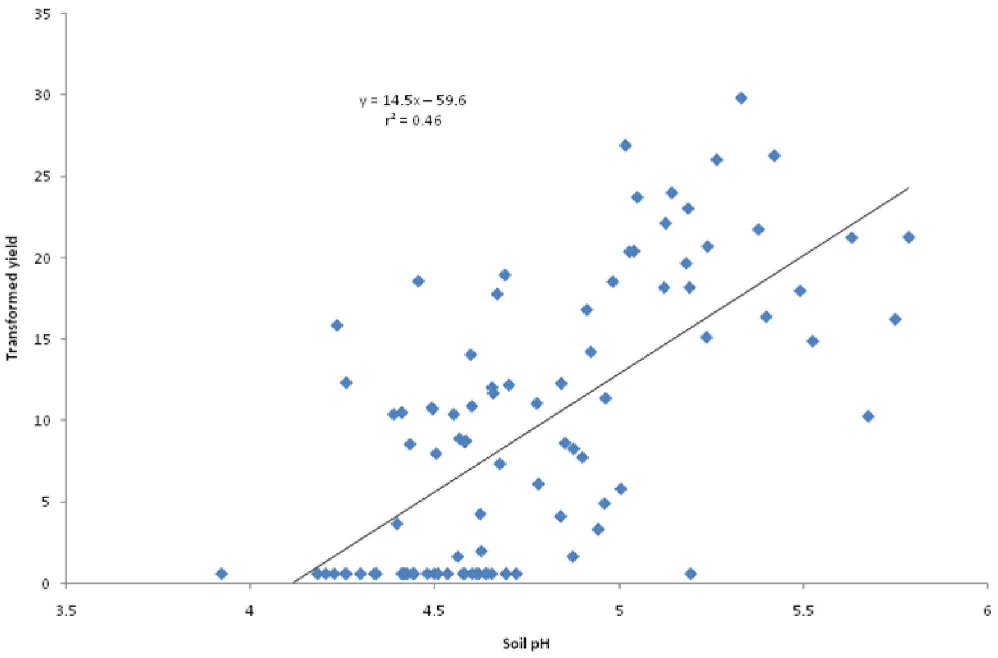

Figure 9A. 2007-2008 KS 9135 transformed grain yield as a function of 1:1 (soil:water) soil pH.

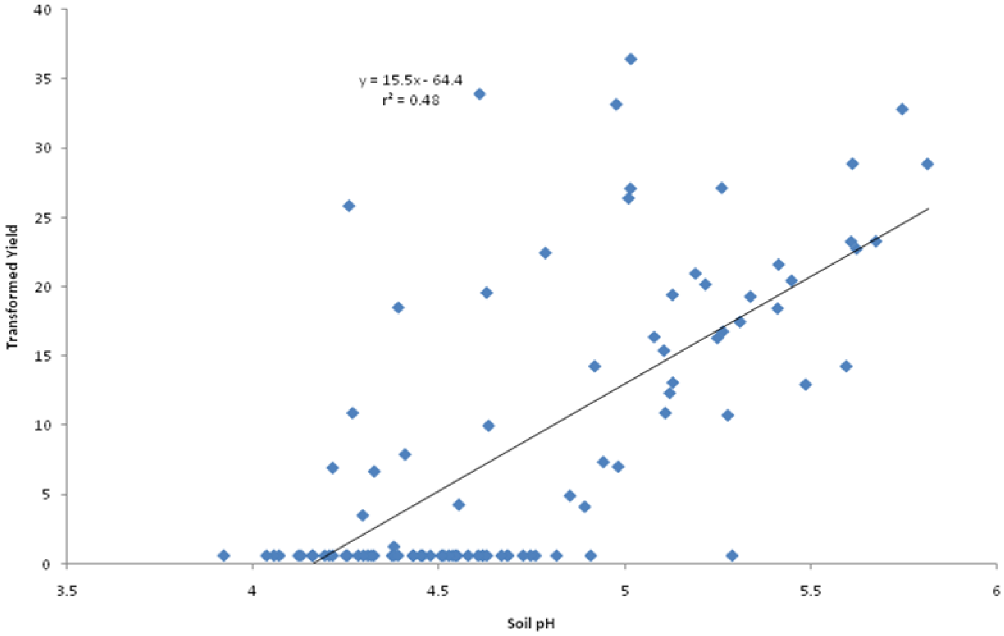

Figure 10A. 2007-2008 Wichita transformed grain yield as a function of 1:1 (soil:water) soil pH.

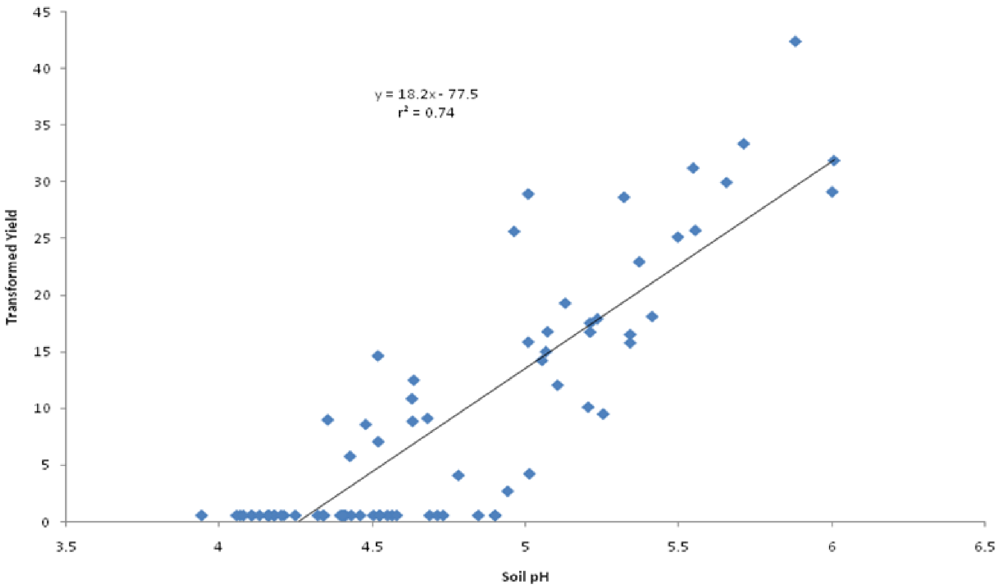

Figure 11A. 2007-2008 Kronos transformed grain yield as a function of 1:1 (soil:water) soil pH.

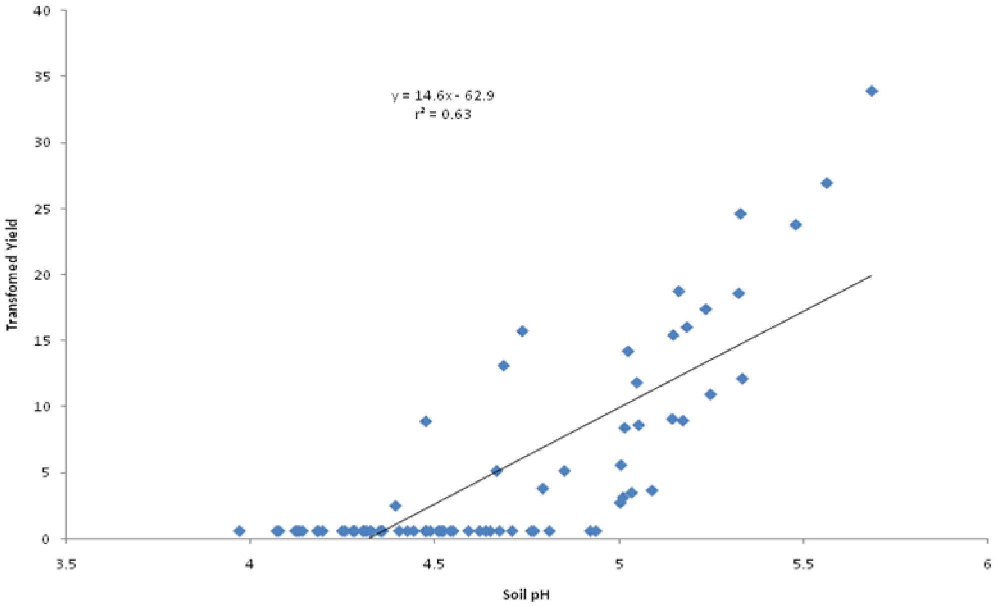

Figure 12A. 2007-2008 Sumner transformed grain yield as a function of 1:1 (soil:water) soil pH.

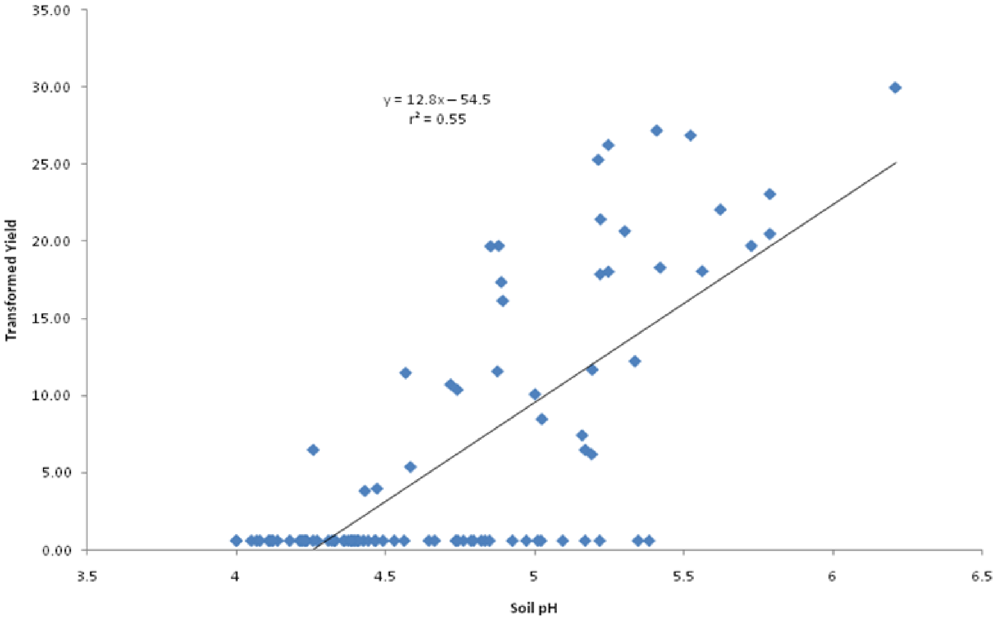

Figure 13A. 2007-2008 Baldur transformed grain yield as a function of 1:1 (soil:water) soil pH.

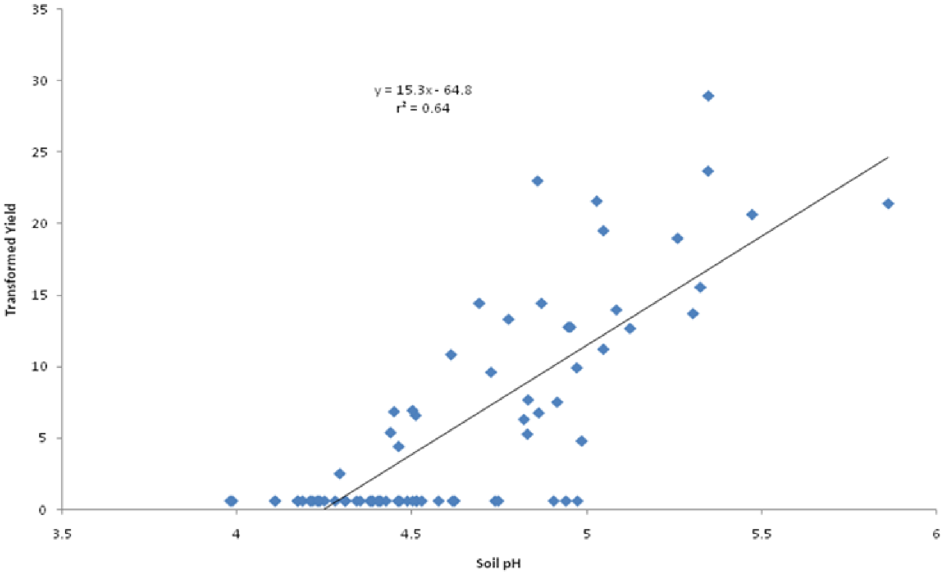

Figure 14A. 2007-2008 KS 3269 transformed grain yield as a function of 1:1 (soil:water) soil pH.

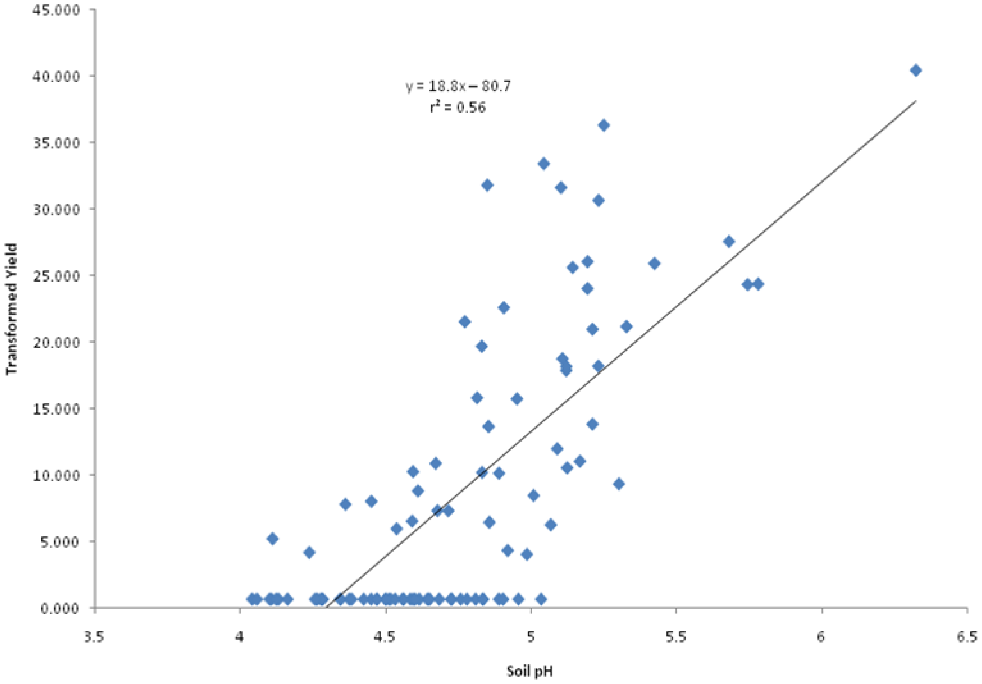

Figure 15A. 2007-2008 KS 3074 transformed grain yield as a function of 1:1 (soil:water) soil pH.

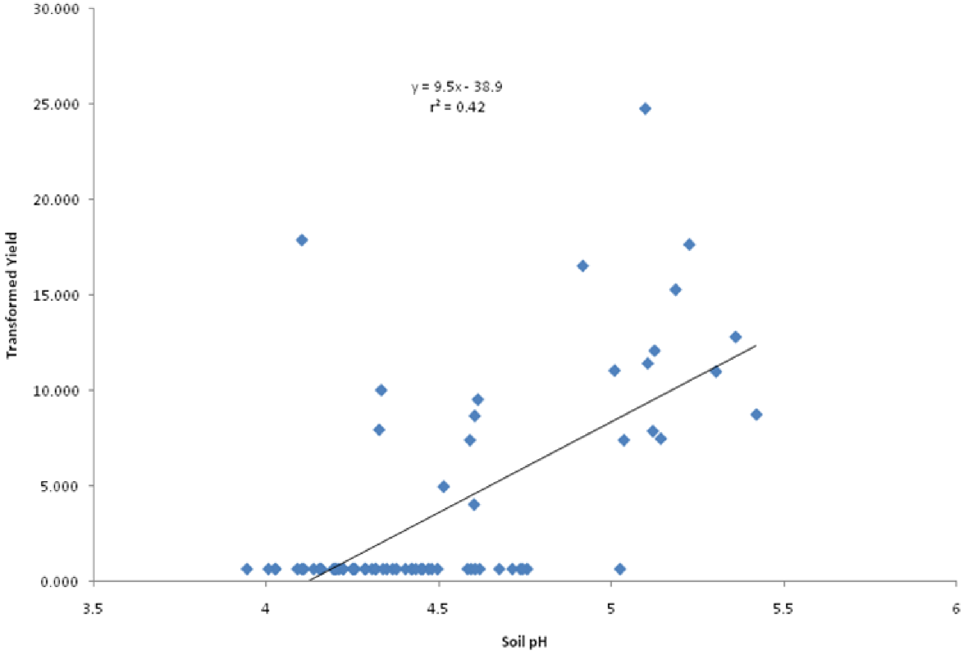

Figure 16A. 2007-2008 DKW 13-69 transformed grain yield as a function of 1:1 (soil:water) soil pH.

2006-2007 growing season data:

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
101-1	1708.616	0.353	1918.263	5.413	4.632	86.70
101-2	1118.103	0.231	1255.294	5.231	4.157	92.10
101-3	1021.297	0.211	1146.61	5.18	4.05	66.20
101-4	1089.061	0.225	1222.689	5.341	4.563	57.15
101-5	803.485	0.166	902.0726	5.049	4.002	64.20
101-6	716.3601	0.148	804.2575	4.932	4.333	62.80
101-7	382.3814	0.079	429.2996	4.755	3.841	112.80
101-8	164.5692	0.034	184.7619	4.774	3.968	153.35
101-9	0	0	0	4.83	3.974	161.55
101-10	53.24298	0.011	59.7759	4.699	3.95	130.05
101-11	193.6108	0.04	217.3669	4.928	4.125	124.40
101-12	411.423	0.085	461.9046	4.792	3.87	78.40
101-13	1848.984	0.382	2075.854	5.321	4.623	71.30
101-14	1466.602	0.303	1646.554	5.304	4.452	49.10
101-15	1452.081	0.3	1630.252	5.423	4.28	18.84
101-16	890.6099	0.184	999.8877	5.239	4.683	13.84
101-17	1732.817	0.358	1945.434	5.478	4.141	10.29
101-18	948.6931	0.196	1065.098	5.088	4.527	22.59
101-19	2028.074	0.419	2276.918	5.602	4.262	5.09
102-1	0	0	0	4.805	3.901	119.85
102-2	895.4501	0.185	1005.322	4.925	4.398	79.50
102-3	1103.582	0.228	1238.991	5.231	4.523	97.80
102-4	808.3253	0.167	907.5068	5.108	4.347	110.15
102-5	363.0203	0.075	407.5629	4.961	4.185	104.45
102-6	87.12488	0.018	97.8151	4.89	4.013	144.55
102-7	0	0	0	4.501	3.667	148.20
102-8	0	0	0	4.807	3.996	156.40
102-9	0	0	0	4.913	3.94	160.25
102-10	0	0	0	4.984	3.956	155.45
102-11	203.2914	0.042	228.2352	5.016	4.019	130.30
102-12	634.0755	0.131	711.8766	5.131	4.2	87.25
102-13	1331.075	0.275	1494.397	5.497	4.659	87.60
102-14	2168.441	0.448	2434.509	5.615	4.798	22.99
102-15	1611.81	0.333	1809.579	5.694	4.694	36.10
102-16	1631.171	0.337	1831.316	5.732	4.801	11.15
102-17	1650.532	0.341	1853.053	5.679	4.833	25.52
102-18	1481.123	0.306	1662.857	5.528	4.201	26.30
102-19	2076.476	0.429	2331.26	5.98	4.712	27.30
103-1	0	0	0	4.644	3.589	123.45
103-2	169.4095	0.035	190.196	4.622	3.821	122.15
103-3	372.7009	0.077	418.4313	4.668	3.98	105.65
103-4	459.8258	0.095	516.2464	4.912	3.956	104.05
103-5	164.5692	0.034	184.7619	4.742	4.167	123.75
103-6	372.7009	0.077	418.4313	4.623	4.126	111.80
103-7	0	0	0	4.576	3.569	147.45
103-8	275.8955	0.057	309.7478	4.629	3.988	137.90

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
103-9	0	0	0	4.68	4.019	151.05
103-10	0	0	0	4.321	3.625	157.60
103-11	0	0	0	4.737	3.884	154.45
103-12	251.6941	0.052	282.577	4.632	4.106	102.90
103-13	1389.158	0.287	1559.607	5.527	4.689	67.55
103-14	934.1723	0.193	1048.795	5.208	4.556	18.76
103-15	1374.637	0.284	1543.305	5.52	4.701	39.31
103-16	1345.595	0.278	1510.7	5.706	4.9	7.95
103-17	2013.553	0.416	2260.616	5.85	5.015	17.81
103-18	788.9642	0.163	885.7701	5.26	4.532	35.78
103-19	1311.713	0.271	1472.661	5.262	4.361	42.06
104-1	275.8955	0.057	309.7478	5.047	4.013	111.90
104-2	503.3882	0.104	565.1539	4.944	4.092	109.55
104-3	1423.04	0.294	1597.647	5.046	4.079	59.65
104-4	687.3185	0.142	771.6525	5.134	4.287	87.75
104-5	682.4782	0.141	766.2183	5.072	4.189	73.15
104-6	648.5963	0.134	728.1791	4.861	4.078	89.45
104-7	561.4714	0.116	630.364	5.062	4.132	102.05
104-8	121.0068	0.025	135.8543	4.907	3.998	136.65
104-9	43.56244	0.009	48.90755	4.987	3.891	158.60
104-10	0	0	0	5.04	3.995	142.15
104-11	929.332	0.192	1043.361	4.997	4.085	94.80
104-12	1999.032	0.413	2244.313	5.391	4.563	53.60
104-13	2163.601	0.447	2429.075	5.545	4.682	23.61
104-14	900.2904	0.186	1010.756	5.041	4.722	14.45
104-15	2454.017	0.507	2755.125	5.616	4.783	10.24
104-16	2323.33	0.48	2608.403	5.436	4.747	11.67
104-17	1519.845	0.314	1706.33	5.491	4.854	13.25
104-18	1011.617	0.209	1135.742	5.889	4.876	67.25
105-1	0	0	0	4.452	3.979	142.85
105-2	561.4714	0.116	630.364	4.583	4.081	121.25
105-3	0	0	0	4.862	3.719	138.05
105-4	266.2149	0.055	298.8795	5.104	4.093	92.80
105-5	183.9303	0.038	206.4985	4.95	3.92	128.40
105-6	116.1665	0.024	130.4201	4.926	3.946	137.25
105-7	377.5411	0.078	423.8654	4.606	3.895	154.45
105-8	38.72217	0.008	43.47338	4.856	3.941	157.10
105-9	67.76379	0.014	76.07841	4.484	3.832	154.45
105-10	24.20136	0.005	27.17086	4.624	3.859	149.25
105-11	53.24298	0.011	59.7759	4.855	3.96	148.15
105-12	435.6244	0.09	489.0755	5.004	4.099	111.75
105-13	1461.762	0.302	1641.12	5.611	4.671	74.75
105-14	1955.47	0.404	2195.406	5.767	4.753	37.27
105-15	1824.782	0.377	2048.683	5.666	4.692	26.01
105-16	1524.685	0.315	1711.764	5.554	4.989	15.04
105-17	2337.851	0.483	2624.705	5.844	4.804	10.54
105-18	909.971	0.188	1021.624	5.369	4.46	42.61
106-1	0	0	0	4.77	3.984	151.25
106-2	551.7909	0.114	619.4956	4.977	4.101	122.90

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
106-4	256.5344	0.053	288.0111	4.881	4.113	142.80
106-5	614.7144	0.127	690.1399	4.764	3.944	130.70
106-6	532.4298	0.11	597.759	4.831	3.934	133.75
106-7	271.0552	0.056	304.3136	4.56	3.899	162.70
106-8	280.7357	0.058	315.182	4.91	3.934	119.85
106-9	358.1801	0.074	402.1288	4.934	3.933	137.80
106-10	300.0968	0.062	336.9187	4.843	4.083	142.55
106-11	271.0552	0.056	304.3136	4.584	3.665	158.90
106-12	392.062	0.081	440.168	4.989	4.076	125.60
106-13	1171.346	0.242	1315.07	5.061	4.151	98.20
106-14	0		0	5.207	3.8	60.25
106-15	1476.283	0.305	1657.423	5.488	4.509	51.20
106-16	977.7348	0.202	1097.703	5.217	4.215	66.35
106-17	1132.623	0.234	1271.596	5.35	4.421	45.45
106-18	939.0126	0.194	1054.229	5.185	4.239	62.85
201-1	0	0	0	4.7	3.899	152.60
201-2	0	0	0	4.798	3.883	149.25
201-3	348.4995	0.072	391.2604	4.653	3.895	155.05
201-4	464.666	0.096	521.6805	4.689	4.022	151.05
201-5	953.5334	0.197	1070.532	5.074	4.2	62.55
201-6	1500.484	0.31	1684.593	5.309	4.495	55.20
201-7	1940.949	0.401	2179.103	5.86	4.951	6.25
201-8	1844.143	0.381	2070.42	5.662	4.701	22.85
201-9	1098.742	0.227	1233.557	5.426	4.577	40.77
201-10	1466.602	0.303	1646.554	5.537	4.783	6.36
202-1	0	0	0	4.777	3.819	144.55
202-2	14.52081	0.003	16.30252	4.649	3.712	137.05
202-3	0	0	0	4.684	3.85	135.60
202-4	290.4163	0.06	326.0503	4.876	4.007	120.90
202-5	1452.081	0.3	1630.252	5.206	4.651	70.30
202-6	2086.157	0.431	2342.128	5.932	4.488	5.45
202-7	1694.095	0.35	1901.96	5.675	5.002	36.47
202-8	1723.136	0.356	1934.565	5.695	4.697	44.61
202-9	1703.775	0.352	1912.829	5.54	5.061	45.75
202-10	1064.86	0.22	1195.518	5.65	4.909	44.80
205-1	0	0	0	4.696	3.69	151.05
205-2	0	0	0	4.773	3.78	151.65
205-3	0	0	0	4.492	3.741	168.95
205-4	1331.075	0.275	1494.397	5.196	4.18	46.28
205-5	1398.838	0.289	1570.476	5.285	4.21	39.65
205-6	1815.102	0.375	2037.815	5.313	4.382	18.25
205-7	1999.032	0.413	2244.313	5.681	4.816	17.40
205-8	2028.074	0.419	2276.918	5.926	4.744	6.13
205-9	1418.199	0.293	1592.212	5.597	5.031	24.91
205-10	943.8529	0.195	1059.664	5.673	4.836	42.62
206-1	0	0	0	4.654	3.745	143.05
206-2	0	0	0	4.309	3.465	169.45
206-3	38.72217	0.008	43.47338	4.34	3.907	154.45
206-4	1384.318	0.286	1554.173	4.854	4.09	96.15

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
206-6	1887.706	0.39	2119.327	5.886	4.878	14.05
206-7	1577.928	0.326	1771.54	5.47	4.587	44.61
206-8	2357.212	0.487	2646.442	5.928	4.821	5.39
206-9	1844.143	0.381	2070.42	5.745	4.879	11.64
206-10	1853.824	0.383	2081.288	5.69	4.427	30.60
207-1	0	0	0	4.491	3.569	160.75
207-2	0	0	0	4.179	3.707	170.05
207-3	324.2982	0.067	364.0895	4.632	3.612	143.55
207-4	663.1171	0.137	744.4816	5.012	4.058	51.15
207-5	1127.783	0.233	1266.162	5.225	4.38	35.64
207-6	1713.456	0.354	1923.697	5.31	4.299	35.12
207-7	1868.345	0.386	2097.591	5.421	4.317	50.35
207-8	1945.789	0.402	2184.537	4.978	4.212	47.05
207-9	2028.074	0.419	2276.918	5.306	4.563	10.19
207-10	1113.262	0.23	1249.86	5.08	4.168	43.85
208-1	29.04163	0.006	32.60503	4.142	3.52	188.60
208-2	24.20136	0.005	27.17086	4.623	3.657	175.05
208-3	285.576	0.059	320.6162	4.743	3.889	137.80
208-4	571.152	0.118	641.2323	4.46	3.661	117.20
208-5	759.9226	0.157	853.1651	4.975	4.149	73.95
208-6	1747.338	0.361	1961.736	5.392	4.456	13.80
208-7	1485.963	0.307	1668.291	5.181	4.16	52.90
208-8	2134.56	0.441	2396.47	5.494	4.301	18.64
208-9	909.971	0.188	1021.624	5.132	4.129	67.40
208-10	1069.7	0.221	1200.952	5.117	4.087	69.30
302-1	0	0	0	4.606	3.852	154.20
302-2	0	0	0	4.8	3.892	166.15
302-3	198.4511	0.041	222.8011	4.793	3.986	132.20
302-4	488.8674	0.101	548.8514	5.013	4.103	131.40
302-5	740.5615	0.153	831.4284	5.297	4.14	96.45
302-6	750.242	0.155	842.2967	4.816	4.127	118.55
302-7	982.575	0.203	1103.137	5.093	4.137	91.35
302-8	624.395	0.129	701.0082	5.156	4.121	95.40
302-9	726.0407	0.15	815.1258	5.276	4.239	111.30
302-10	987.4153	0.204	1108.571	5.337	4.008	92.25
303-1	0	0	0	4.339	3.396	167.25
303-2	43.56244	0.009	48.90755	4.7	3.862	132.60
303-3	832.5266	0.172	934.6776	4.94	4.014	117.60
303-4	1079.38	0.223	1211.82	4.918	4.17	89.95
303-5	721.2004	0.149	809.6917	5.187	4.012	64.45
303-6	1001.936	0.207	1124.874	5.006	4.127	58.95
303-7	1456.922	0.301	1635.686	5.33	4.413	48.35
303-8	1248.79	0.258	1402.016	5.102	4.184	74.10
303-9	1239.109	0.256	1391.148	5.158	4.351	79.45
303-10	1418.199	0.293	1592.212	5.279	4.458	63.55
304-1	396.9022	0.082	445.6021	4.848	3.979	112.65
304-2	1234.269	0.255	1385.714	4.911	4.07	79.05
304-3	1544.046	0.319	1733.501	5.179	4.288	51.80
304-4	1529.526	0.316	1717.198	5.33	4.314	32.10

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
304-6	2028.074	0.419	2276.918	5.427	4.579	6.42
304-7	2071.636	0.428	2325.826	5.567	4.621	10.05
304-8	2366.893	0.489	2657.31	5.58	4.623	5.35
304-9	1887.706	0.39	2119.327	5.49	4.487	12.87
304-10	711.5198	0.147	798.8233	5.225	4.322	35.45
305-1	963.2139	0.199	1081.4	5.087	4.253	50.40
305-2	1844.143	0.381	2070.42	5.218	4.356	44.73
305-3	1626.331	0.336	1825.882	5.572	4.691	28.16
305-4	2163.601	0.447	2429.075	5.453	4.578	11.51
305-5	2120.039	0.438	2380.167	6.275	5.316	6.63
305-6	1897.386	0.392	2130.196	5.742	5.012	14.28
305-7	2516.941	0.52	2825.77	6.496	5.487	5.27
305-8	2357.212	0.487	2646.442	6.34	5.21	9.36
305-9	2144.24	0.443	2407.338	6.034	5.141	37.26
305-10	1539.206	0.318	1728.067	5.599	4.701	52.10
306-1	953.5334	0.197	1070.532	5.208	4.651	61.80
306-2	1989.351	0.465	2233.445	5.395	4.478	37.35
306-3	2250.726	0.51	2526.89	5.825	4.798	28.21
306-4	2366.893	0.411	2657.31	6.014	5.025	8.91
306-5	2468.538	0.489	2771.428	6.427	5.633	2.82
306-6	2071.636	0.428	2325.826	5.321	4.479	42.59
306-7	2313.65	0.478	2597.534	6.197	5.02	9.23
306-8	1645.692	0.34	1847.619	5.877	4.969	16.10
306-9	1907.067	0.394	2141.064	5.906	4.872	11.35
306-10	1815.102	0.375	2037.815	5.893	4.874	5.34
307-1	832.5266	0.172	934.6776	4.936	4.045	83.70
307-2	1626.331	0.336	1825.882	5.385	4.323	55.65
307-3	1427.88	0.295	1603.081	5.059	4.023	63.70
307-4	1606.97	0.332	1804.145	5.265	4.563	57.80
307-5	1853.824	0.383	2081.288	5.819	4.348	37.70
307-6	1582.769	0.327	1776.974	5.639	4.792	32.92
307-7	1200.387	0.248	1347.675	5.559	4.692	37.26
307-8	1161.665	0.24	1304.201	6.017	5.093	22.60
307-9	1698.935	0.351	1907.394	5.675	4.872	16.28
307-10	246.8538	0.051	277.1428	5.474	4.647	51.15
401-1	62.92352	0.013	70.64424	4.597	3.943	166.15
401-2	164.5692	0.034	184.7619	4.648	3.985	161.35
401-3	111.3262	0.023	124.986	4.795	3.814	151.30
401-4	522.7493	0.108	586.8906	4.962	4.119	110.65
401-5	1873.185	0.387	2103.025	5.676	4.782	52.30
401-6	1360.116	0.281	1527.002	5.636	4.414	2.12
401-7	1485.963	0.307	1668.291	5.531	4.421	45.82
401-8	1873.185	0.387	2103.025	5.705	5.001	34.45
401-9	1674.734	0.346	1880.224	5.414	4.598	38.30
401-10	2042.594	0.422	2293.221	5.975	5.098	6.15
402-1	0	0	0	4.537	3.881	141.75
402-2	121.0068	0.025	135.8543	4.782	3.954	137.70
402-3	53.24298	0.011	59.7759	4.528	3.583	134.35
402-4	1548.887	0.32	1738.935	5.292	4.21	37.75

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
402-6	1747.338	0.361	1961.736	5.857	4.871	1.30
402-7	2173.282	0.449	2439.943	5.949	5.011	12.65
402-8	2134.56	0.441	2396.47	6.079	4.639	4.81
402-9	1466.602	0.303	1646.554	5.416	5.01	9.80
402-10	1989.351	0.411	2233.445	5.843	4.985	7.40
403-1	0	0	0	4.839	3.894	166.30
403-2	0	0	0	5.109	3.879	167.30
403-3	125.847	0.026	141.2885	4.955	3.979	109.05
403-4	1302.033	0.269	1461.792	5.951	4.96	23.47
403-5	1108.422	0.229	1244.425	5.818	4.778	36.30
403-6	1098.742	0.227	1233.557	5.119	5.143	42.64
403-7	1089.061	0.225	1222.689	5.582	5.05	48.19
403-8	503.3882	0.104	565.1539	5.601	4.772	28.46
403-9	566.3117	0.117	635.7982	5.539	4.702	24.09
403-10	1200.387	0.248	1347.675	5.864	4.881	18.90
404-1	0	0	0	4.586	3.552	169.75
404-2	183.9303	0.038	206.4985	4.98	4.016	115.60
404-3	735.7212	0.152	825.9942	5.192	3.984	97.90
404-4	1190.707	0.246	1336.806	5.15	4.245	70.10
404-5	1568.248	0.324	1760.672	5.246	4.355	22.81
404-6	1427.88	0.295	1603.081	5.237	4.36	28.61
404-7	1292.352	0.267	1450.924	5.619	4.751	17.43
404-8	2090.997	0.432	2347.562	5.523	4.426	5.76
404-9	600.1936	0.124	673.8374	5.46	4.433	11.51
404-10	1050.339	0.217	1179.215	5.269	4.782	17.47
407-1	0	0	0	4.686	3.751	166.35
407-2	0	0	0	4.708	3.71	171.55
407-3	319.4579	0.066	358.6554	4.867	4.002	162.55
407-4	890.6099	0.184	999.8877	4.959	4.079	91.10
407-5	672.7977	0.139	755.35	4.884	4.247	89.20
407-6	522.7493	0.108	586.8906	5.12	4.157	51.20
407-7	808.3253	0.167	907.5068	5.081	4.191	60.25
407-8	1195.547	0.247	1342.241	5.262	4.365	62.15
407-9	977.7348	0.202	1097.703	5.059	4.202	55.95
407-10	527.5895	0.109	592.3248	5.087	4.181	48.05
408-1	0	0	0	4.36	3.411	201.60
408-2	0	0	0	4.801	3.882	137.20
408-3	242.0136	0.05	271.7086	4.854	3.904	128.45
408-4	421.1036	0.087	472.773	4.665	3.892	112.20
408-5	343.6592	0.071	385.8262	4.809	3.96	117.15
408-6	372.7009	0.077	418.4313	4.803	4.028	114.75
408-7	208.1317	0.043	233.6694	4.999	3.976	117.40
408-8	304.9371	0.063	342.3529	5.117	4.235	106.60
408-9	164.5692	0.034	184.7619	4.834	3.979	117.10
408-10	193.6108	0.04	217.3669	4.7	4.023	129.20
502-1	0	0	0	4.733	3.692	150.90
502-2	0	0	0	4.516	3.547	166.40
502-3	401.7425	0.083	451.0363	4.932	4.046	145.05
502-4	96.80542	0.02	108.6834	4.89	3.925	143.60

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
502-6	774.4434	0.16	869.4676	5.233	4.151	128.15
502-7	803.485	0.166	902.0726	5.301	4.451	117.75
502-8	692.1588	0.143	777.0866	5.207	4.478	108.60
502-9	295.2565	0.061	331.4845	5.176	4.173	111.60
502-10	343.6592	0.071	385.8262	5.152	4.113	102.85
503-1	0	0	0	4.538	3.777	168.75
503-2	14.52081	0.003	16.30252	4.537	3.895	132.90
503-3	0	0	0	4.981	3.879	161.05
503-4	125.847	0.026	141.2885	4.903	4.08	156.40
503-5	939.0126	0.194	1054.229	5.355	4.211	78.55
503-6	1118.103	0.231	1255.294	5.388	4.304	71.40
503-7	1035.818	0.214	1162.913	5.301	4.242	67.35
503-8	324.2982	0.067	364.0895	5.072	4.127	86.05
503-9	513.0687	0.106	576.0223	5.286	4.365	76.00
503-10	474.3466	0.098	532.5489	5.206	4.252	78.30
504-1	0	0	0	4.948	3.827	112.55
504-2	348.4995	0.072	391.2604	4.555	3.844	109.45
504-3	387.2217	0.08	434.7338	4.901	4.178	73.10
504-4	726.0407	0.15	815.1258	5.151	4.115	168.35
504-5	1476.283	0.305	1657.423	5.074	4.56	169.60
504-6	1345.595	0.278	1510.7	5.301	4.594	123.56
504-7	1181.026	0.244	1325.938	5.04	4.433	32.00
504-8	1287.512	0.266	1445.49	5.375	4.219	17.92
504-9	1544.046	0.319	1733.501	5.51	4.491	20.96
504-10	1461.762	0.302	1641.12	5.361	4.414	42.55
506-1	19.36108	0.004	21.73669	4.777	3.978	145.80
506-2	183.9303	0.038	206.4985	4.515	3.907	135.70
506-3	353.3398	0.073	396.6946	4.697	4.052	102.25
506-4	1360.116	0.281	1527.002	5.1	4.546	92.45
506-5	1026.137	0.212	1152.045	5.205	4.497	61.60
506-6	1737.657	0.359	1950.868	5.639	4.656	19.90
506-7	1897.386	0.392	2130.196	5.611	4.742	24.11
506-8	2192.643	0.453	2461.68	5.79	4.599	4.86
506-9	1408.519	0.291	1581.344	5.236	4.501	50.70
506-10	1272.991	0.263	1429.187	5.491	4.639	25.97
507-1	193.6108	0.04	217.3669	4.521	3.643	158.50
507-2	188.7706	0.039	211.9327	4.344	3.588	168.65
507-3	212.9719	0.044	239.1036	4.443	3.56	152.15
507-4	842.2072	0.174	945.546	4.838	4.08	99.45
507-5	1045.499	0.216	1173.781	5.417	4.649	64.65
507-6	958.3737	0.198	1075.966	5.494	4.718	29.60
507-7	1040.658	0.215	1168.347	5.432	4.602	12.37
507-8	992.2556	0.205	1114.005	5.656	4.478	16.18
507-9	740.5615	0.153	831.4284	5.768	4.995	22.87
507-10	934.1723	0.193	1048.795	5.449	4.592	28.16
508-1	43.56244	0.009	48.90755	4.809	3.971	147.25
508-2	48.40271	0.01	54.34172	4.626	3.931	163.60
508-3	425.9439	0.088	478.2072	4.463	3.622	139.10
508-4	972.8945	0.201	1092.269	5.07	4.239	56.15

Plot #	lb/ac	lb/plot	kg/ha	H_2O pH	$CaCl_2$	Adjusted Al
508-6	1727.977	0.357	1940	5.586	4.445	16.11
508-7	1858.664	0.384	2086.722	5.44	4.609	7.55
508-8	1665.053	0.344	1869.355	5.656	4.724	26.10
508-9	1243.95	0.257	1396.582	5.792	4.797	26.55
508-10	861.5682	0.178	967.2827	5.165	4.34	26.35

2007-2008 growing season data:

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
101-1	0.0	0.000	0	0	4.339	3.28	156.2
101-2	0.0	0.000	0	0	4.496	3.323	97.05
101-3	0.2	0.000	2.132278	2.3939085	4.56	3.452	102.9
101-4	27.6	0.061	294.25436	330.35937	5.12	3.674	71.25
101-5	0.9	0.002	9.595251	10.772588	4.941	3.521	58.15
101-6	16.5	0.036	175.91293	197.49745	4.595	3.38	84.45
101-7	10.2	0.022	108.74618	122.08933	4.774	3.294	92.55
101-8	12.1	0.027	129.00282	144.83146	4.653	3.251	115.6
101-9	9.9	0.022	105.54776	118.49847	4.598	3.175	121.2
101-10	0.3	0.001	3.198417	3.5908628	4.624	3.272	111.3
101-11	0.0	0.000	0	0	4.418	3.156	128.05
101-12	6.6	0.015	70.365174	78.998981	4.564	3.321	77.25
101-13	12.4	0.027	132.20124	148.42233	4.699	3.482	66.45
101-14	44.3	0.098	472.29958	530.25073	5.185	3.984	18.75
101-15	56.6	0.125	603.43467	677.47611	5.263	3.978	38.8
101-16	34.8	0.077	371.01637	416.54008	5.038	3.813	52
101-17	10.8	0.024	115.14301	129.27106	4.961	3.712	64.5
101-18	6.3	0.014	67.166757	75.408118	4.578	3.325	70.6
101-19	1.5	0.003	15.992085	17.954314	4.621	3.385	97.8
102-1	0.0	0.000	0	0	4.684	3.613	83.9
102-2	0.0	0.000	0	0	4.815	3.541	79.3
102-3	0.0	0.000	0	0	4.506	3.329	100.75
102-4	0.0	0.000	0	0	4.475	3.577	77.35
102-5	0.0	0.000	0	0	4.616	3.551	74.7
102-6	0.0	0.000	0	0	4.616	3.583	70.9
102-7	0.0	0.000	0	0	4.627	3.312	64.35
102-8	0.0	0.000	0	0	4.547	3.366	62.75
102-9	0.0	0.000	0	0	4.372	3.241	129.25
102-10	0.0	0.000	0	0	4.535	3.344	123.45
102-11	0.0	0.000	0	0	4.455	3.471	109.3
102-12	0.0	0.000	0	0	4.577	3.264	124.45
102-13	28.6	0.063	304.91575	342.32892	4.389	3.331	116.65
102-14	96.1	0.212	1024.5596	1150.273	4.608	3.582	83.05
102-15	110.9	0.244	1182.3481	1327.4223	5.015	4.021	51.6
102-16	91.9	0.202	979.78174	1100.001	4.976	3.873	42.7
102-17	34.0	0.075	362.48726	406.96445	5.216	3.854	39.25
102-18	17.0	0.037	181.24363	203.48222	5.595	4.085	2.26
102-19	2.0	0.004	21.32278	23.939085	4.851	3.761	76.15
103-1	0.0	0.000	0	0	4.9	3.36	75.05
103-2	0.0	0.000	0	0	4.845	3.25	97.8
103-3	0.0	0.000	0	0	4.899	3.311	70.3
103-4	0.0	0.000	0	0	4.563	3.156	106.9

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
103-6	12.2	0.027	130.06896	146.02842	5.104	3.41	64.25
103-7	0.0	0.000	0	0	4.412	3.325	113.35
103-8	0.6	0.001	6.396834	7.1817255	4.941	3.372	112.4
103-9	0.0	0.000	0	0	4.548	3.171	99.8
103-10	0.0	0.000	0	0	4.394	3.079	102.85
103-11	0.0	0.000	0	0	4.521	3.379	87.25
103-12	1.4	0.003	14.925946	16.75736	4.78	3.495	82.75
103-13	22.9	0.050	244.14583	274.10252	5.341	3.449	21.8
103-14	55.4	0.122	590.64101	663.11266	5.554	3.847	43.7
103-15	75.1	0.165	800.67039	898.91264	5.656	4.108	6.265
103-16	52.9	0.117	563.98753	633.1888	5.497	4.089	14.13
103-17	81.6	0.180	869.96942	976.71467	5.547	4.012	12.25
103-18	8.6	0.019	91.687954	102.93807	5.204	3.784	37.4
103-19	20.9	0.046	222.82305	250.16344	5.341	3.679	31.65
104-1	0.0	0.000	0	0	4.549	3.312	118.85
104-2	0.0	0.000	0	0	4.351	3.174	94.55
104-3	0.0	0.000	0	0	4.921	3.471	95.1
104-4	0.0	0.000	0	0	4.474	3.334	73.1
104-5	0.0	0.000	0	0	4.513	3.329	74.7
104-6	0.0	0.000	0	0	4.476	3.394	78.9
104-7	0.0	0.000	0	0	4.81	3.471	72.55
104-8	0.0	0.000	0	0	4.278	3.298	125.15
104-9	0.0	0.000	0	0	4.65	3.354	92.05
104-10	0.0	0.000	0	0	4.356	3.258	135.3
104-11	0.0	0.000	0	0	4.591	3.477	129.2
104-12	0.0	0.000	0	0	4.621	3.27	85.6
104-13	10.0	0.022	106.6139	119.69543	5.247	3.483	35.6
104-14	60.7	0.134	647.14637	726.55123	5.562	3.472	19.45
104-15	96.2	0.212	1025.6257	1151.47	5.684	3.631	16.35
104-16	47.3	0.104	504.28375	566.15936	5.478	3.596	28.05
104-17	50.7	0.112	540.53247	606.85581	5.328	3.539	24.65
104-18	2.6	0.006	27.719614	31.120811	5.004	3.555	23.7
104-19	6.7	0.015	71.431313	80.195935	5.172	3.601	27.1
105-1	0.0	0.000	0	0	4.403	3.332	78.65
105-2	0.0	0.000	0	0	4.821	3.37	99.25
105-3	0.0	0.000	0	0	4.645	3.318	61.8
105-4	0.0	0.000	0	0	4.388	3.454	95.65
105-5	32.5	0.072	346.49517	389.01013	4.879	3.338	83.25
105-6	0.0	0.000	0	0	4.408	3.249	72.9
105-7	0.0	0.000	0	0	4.36	3.247	119.4
105-8	0.0	0.000	0	0	4.562	3.377	130.05
105-9	0.0	0.000	0	0	4.107	3.145	136.55

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
105-11	0.0	0.000	0	0	4.211	3.299	129.35
105-12	0.0	0.000	0	0	4.27	3.336	126.95
105-13	0.0	0.000	0	0	4.441	3.28	97.1
105-14	2.4	0.005	25.587336	28.726902	4.583	3.342	93.05
105-15	0.0	0.000	0	0	4.735	3.447	123.55
105-16	21.8	0.048	232.4183	260.93603	4.893	3.512	56.25
105-17	53.5	0.118	570.38436	640.37053	5.213	3.76	33.15
105-18	35.7	0.079	380.61162	427.31267	5.302	3.703	14.6
105-19	61.8	0.136	658.8739	739.71773	5.409	3.805	17.2
106-1	0.0	0.000	0	0	4.973	3.628	72.6
106-2	1.9	0.004	20.256641	22.742131	4.985	3.601	83.2
106-3	2.3	0.005	24.521197	27.529948	4.83	3.504	81.95
106-4	13.6	0.030	144.9949	162.78578	4.947	3.856	53.9
106-5	4.9	0.011	52.240811	58.650758	4.832	3.705	68.6
106-6	3.6	0.008	38.381004	43.090353	4.511	3.522	95.9
106-7	0.0	0.000	0	0	4.466	3.331	92.45
106-8	0.5	0.001	5.330695	5.9847713	4.294	3.317	92.8
106-9	14.8	0.033	157.78857	177.14923	4.776	3.698	98.95
106-10	0.0	0.000	0	0	4.23	3.365	128.25
106-11	0.0	0.000	0	0	4.175	3.394	141.1
106-12	0.0	0.000	0	0	4.576	3.486	118.45
106-13	0.0	0.000	0	0	4.173	3.271	147.7
106-14	0.0	0.000	0	0	4.738	3.501	125.45
106-15	0.0	0.000	0	0	4.514	3.582	100.85
106-16	31.8	0.070	339.0322	380.63145	5.047	3.904	69.3
106-17	70.0	0.154	746.2973	837.86798	5.347	3.854	53
106-18	38.9	0.086	414.72807	465.6152	5.028	3.799	77.25
106-19	4.7	0.010	50.108533	56.25685	4.915	3.705	78.8
201-1	0.0	0.000	0	0	4.414	3.356	113.1
201-2	5.0	0.011	53.30695	59.847713	4.898	3.541	86.3
201-3	5.7	0.013	60.769923	68.226392	4.874	3.472	72.9
201-4	6.2	0.014	66.100618	74.211164	4.851	3.493	56.1
201-5	4.5	0.010	47.976255	53.862941	4.674	3.358	61.1
201-6	23.6	0.052	251.6088	282.4812	4.91	3.335	86.75
201-7	47.0	0.104	501.08533	562.5685	5.047	3.658	85.6
201-8	74.3	0.164	792.14128	889.33701	5.177	3.519	57.9
201-9	28.7	0.063	305.98189	343.52587	4.981	3.574	103.05
201-10	5.3	0.012	56.505367	63.438575	4.501	3.332	107.7
201-11	1.1	0.002	11.727529	13.166497	4.395	3.208	128.45
201-12	6.1	0.013	65.034479	73.01421	4.43	3.196	115.95
201-13	0.0	0.000	0	0	4.609	3.39	90.95
201-14	0.0	0.000	0	0	4.532	3.255	114.5

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
201-16	12.6	0.028	134.33351	150.81624	4.841	3.37	82.45
201-17	34.7	0.076	369.95023	415.34313	5.026	3.748	67.35
201-18	28.8	0.063	307.04803	344.72283	4.453	3.207	97.05
201-19	0.0	0.000	0	0	3.919	3.046	162.4
202-1	25.5	0.056	271.86544	305.22333	5.309	3.742	39.75
202-2	8.3	0.018	88.489537	99.347203	4.632	3.586	106.15
202-3	9.9	0.022	105.54776	118.49847	5.108	3.708	72.3
202-4	0.0	0.000	0	0	4.758	3.565	122.75
202-5	69.6	0.153	742.03274	833.08016	5.814	4.012	2.8
202-6	9.6	0.021	102.34934	114.90761	5.276	3.676	30.65
202-7	42.1	0.093	448.84452	503.91774	4.785	3.582	54.4
202-8	32.0	0.070	341.16448	383.02536	4.627	3.485	111.4
202-9	0.0	0.000	0	0	4.512	3.4	115.7
202-10	0.0	0.000	0	0	4.542	3.397	120
202-11	0.0	0.000	0	0	4.323	3.408	130.75
202-12	0.0	0.000	0	0	4.683	3.487	100.6
202-13	0.1	0.000	1.066139	1.1969543	4.377	3.458	128.9
202-14	0.0	0.000	0	0	4.068	3.449	137.55
202-15	1.0	0.002	10.66139	11.969543	4.293	3.384	129.4
202-16	0.0	0.000	0	0	4.451	3.339	117.8
202-17	0.0	0.000	0	0	4.378	3.405	126.15
202-18	1.5	0.003	15.992085	17.954314	4.552	3.481	94.45
202-19	1.4	0.003	14.925946	16.75736	4.891	3.701	137.05
203-1	0.0	0.000	0	0	4.106	3.55	132.25
203-2	17.0	0.037	181.24363	203.48222	5.053	3.656	71.15
203-3	6.8	0.015	72.497452	81.392889	4.353	3.603	112.25
203-4	44.1	0.097	470.1673	527.85683	5.371	3.742	34.1
203-5	31.2	0.069	332.63537	373.44973	5.129	3.807	26.55
203-6	18.9	0.042	201.50027	226.22435	5.066	3.841	42.25
203-7	7.6	0.017	81.026564	90.968523	5.253	3.65	23.1
203-8	27.5	0.061	293.18822	329.16242	5.413	3.748	17.5
203-9	6.6	0.015	70.365174	78.998981	4.63	3.475	99.65
203-10	0.0	0.000	0	0	4.523	3.377	154.85
203-11	0.0	0.000	0	0	4.247	3.28	128.05
203-12	0.0	0.000	0	0	4.177	3.363	146.55
203-13	0.0	0.000	0	0	4.104	3.399	143.9
203-14	0.0	0.000	0	0	4.43	3.456	143.35
203-15	0.0	0.000	0	0	4.162	3.332	143.85
203-16	0.0	0.000	0	0	4.067	3.32	150.6
203-17	0.0	0.000	0	0	4.055	3.289	149.25
203-18	0.0	0.000	0	0	4.502	3.501	107.75
203-19	0.0	0.000	0	0	4.159	3.322	118.7

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
204-2	19.9	0.044	212.16166	238.1939	5.146	3.801	48.85
204-3	11.7	0.026	124.73826	140.04365	5.047	3.589	39.2
204-4	1.0	0.002	10.66139	11.969543	5.033	3.615	40.5
204-5	0.8	0.002	8.529112	9.575634	5.01	3.751	32.6
204-6	0.6	0.001	6.396834	7.1817255	5.002	3.691	47.15
204-7	1.1	0.002	11.727529	13.166497	5.088	3.689	108.8
204-8	0.5	0.001	5.330695	5.9847713	4.393	3.51	95.1
204-9	0.0	0.000	0	0	4.308	3.471	91.6
204-10	0.0	0.000	0	0	4.183	3.384	98.2
204-11	0.0	0.000	0	0	4.195	3.348	115.05
204-12	0.0	0.000	0	0	4.278	3.35	95.85
204-13	0.0	0.000	0	0	4.133	3.295	108.7
204-14	0.0	0.000	0	0	3.97	3.39	139.95
204-15	0.0	0.000	0	0	4.936	3.714	92.8
204-16	0.0	0.000	0	0	4.128	3.263	99.9
204-17	0.0	0.000	0	0	4.181	3.254	99.15
204-18	0.0	0.000	0	0	4.326	3.405	122.55
204-19	0.0	0.000	0	0	4.077	3.326	151.1
205-1	0.0	0.000	0	0	5.094	3.845	68.35
205-2	0.0	0.000	0	0	5.021	3.789	72.55
205-3	4.6	0.010	49.042394	55.059896	5.159	4.023	59.3
205-4	3.5	0.008	37.314865	41.893399	5.169	3.917	53.6
205-5	0.0	0.000	0	0	5.384	3.845	42.6
205-6	0.0	0.000	0	0	5.169	3.88	71.25
205-7	9.0	0.020	95.95251	107.72588	4.74	3.629	97.8
205-8	0.0	0.000	0	0	4.217	3.289	112.95
205-9	0.0	0.000	0	0	4.327	3.365	105.45
205-10	0.0	0.000	0	0	4.395	3.452	137.55
205-11	0.0	0.000	0	0	4.234	3.401	126
205-12	0.0	0.000	0	0	4.137	3.378	120.1
205-13	0.0	0.000	0	0	4.362	3.201	151.6
205-14	0.0	0.000	0	0	4.178	3.351	136.85
205-15	0.0	0.000	0	0	3.999	2.904	156
205-16	0.0	0.000	0	0	4.049	3.085	142.35
205-17	0.0	0.000	0	0	4.374	3.243	107.65
205-18	0.0	0.000	0	0	4.067	3.07	127.35
205-19	0.0	0.000	0	0	3.999	3.31	130.85
207-1	0.0	0.000	0	0	5.034	3.498	60.05
207-2	0.0	0.000	0	0	4.889	3.43	67.8
207-3	1.3	0.003	13.859807	15.560405	4.985	3.474	63.1
207-4	5.9	0.013	62.902201	70.620301	5.008	3.392	51.25
207-5	0.0	0.000	0	0	4.562	3.332	97.25

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
207-7	0.0	0.000	0	0	4.725	3.319	73.5
207-8	7.2	0.016	76.762008	86.180706	5.301	3.687	50.7
207-9	0.0	0.000	0	0	4.758	3.403	76.15
207-10	0.0	0.000	0	0	4.835	3.483	74.35
207-11	0.0	0.000	0	0	4.903	3.407	56.1
207-12	3.2	0.007	34.116448	38.302536	5.067	3.562	55.15
207-13	0.0	0.000	0	0	4.956	3.421	72.5
207-14	9.2	0.020	98.084788	110.11979	5.123	3.574	64.1
207-15	11.9	0.026	126.87054	142.43756	5.089	3.541	62.25
207-16	10.1	0.022	107.68004	120.89238	5.167	3.574	56
207-17	15.9	0.035	169.5161	190.31573	5.21	3.518	58.15
207-18	0.0	0.000	0	0	4.809	3.37	77.4
207-19	0.0	0.000	0	0	4.684	3.344	88.2
301-1	0.0	0.000	0	0	4.257	3.259	142.25
301-2	0.0	0.000	0	0	4.296	3.303	145.55
301-3	0.0	0.000	0	0	4.441	3.34	108.6
301-4	0.2	0.000	2.132278	2.3939085	4.872	3.426	87.9
301-5	39.5	0.087	421.1249	472.79693	5.376	3.621	50.6
301-6	57.7	0.127	615.1622	690.6426	5.419	3.453	49.2
301-7	22.0	0.048	234.55058	263.32994	5.747	3.701	52.25
301-8	8.8	0.019	93.820232	105.33197	5.674	3.645	27.39
301-9	0.0	0.000	0	0	4.652	3.417	91.15
301-10	40.9	0.090	436.05085	489.55429	5.124	3.543	36.7
301-11	19.1	0.042	203.63255	228.61826	5.235	3.509	60.55
301-12	2.8	0.006	29.851892	33.514719	5.003	3.517	85.75
301-13	21.0	0.046	223.88919	251.36039	4.232	3.326	113.85
301-14	0.0	0.000	0	0	4.179	3.284	139.2
301-15	0.0	0.000	0	0	4.255	3.257	122.65
301-16	0.0	0.000	0	0	5.192	3.457	50.35
301-17	0.0	0.000	0	0	4.44	3.461	115.75
301-18	0.0	0.000	0	0	4.408	3.352	112.1
301-19	0.0	0.000	0	0	4.334	3.335	112.95
302-1	0.0	0.000	0	0	4.252	3.365	122.9
302-2	0.0	0.000	0	0	4.428	3.405	105.7
302-3	0.0	0.000	0	0	4.907	3.398	79.05
302-4	14.0	0.031	149.25946	167.5736	5.486	3.458	24.25
302-5	31.1	0.069	331.56923	372.25277	5.337	3.569	24
302-6	90.0	0.198	959.5251	1077.2588	5.746	3.547	23.4
302-7	23.5	0.052	250.54266	281.28425	5.263	3.562	28.15
302-8	22.2	0.049	236.68286	265.72384	5.248	3.563	34.9
302-9	17.0	0.037	181.24363	203.48222	4.918	3.495	44.6
302-10	28.4	0.063	302.78348	339.93501	5.41	3.568	38.75

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
302-12	0.0	0.000	0	0	5.288	3.522	92.25
302-13	0.0	0.000	0	0	4.745	3.378	120.75
302-14	0.0	0.000	0	0	4.449	3.389	162.7
302-15	0.0	0.000	0	0	4.157	3.419	135.9
302-16	0.0	0.000	0	0	4.525	3.517	133.65
302-17	0.0	0.000	0	0	4.43	3.444	108.55
302-18	0.0	0.000	0	0	4.388	3.385	136.45
302-19	0.0	0.000	0	0	4.506	3.307	138.8
304-1	0.0	0.000	0	0	4.141	3.265	132.95
304-2	0.0	0.000	0	0	4.283	3.302	110.35
304-3	0.0	0.000	0	0	4.638	3.412	92.25
304-4	0.0	0.000	0	0	4.357	3.365	85.6
304-5	0.0	0.000	0	0	4.542	3.56	80.75
304-6	0.0	0.000	0	0	4.709	3.368	64.15
304-7	20.7	0.046	220.69077	247.76953	4.737	3.541	51.15
304-8	21.5	0.047	229.21988	257.34516	5.183	3.782	29.9
304-9	14.4	0.032	153.52402	172.36141	4.686	3.681	58.2
304-10	25.3	0.056	269.73317	302.82943	5.234	3.843	36.55
304-11	6.6	0.015	70.365174	78.998981	4.475	3.547	73.7
304-12	0.0	0.000	0	0	4.487	3.483	93.7
304-13	0.0	0.000	0	0	4.315	3.579	100.7
304-14	0.0	0.000	0	0	4.307	3.522	105.55
304-15	0.0	0.000	0	0	4.326	3.59	112.8
304-16	0.0	0.000	0	0	4.249	3.344	123.8
304-17	0.0	0.000	0	0	4.519	3.401	114.05
304-18	0.0	0.000	0	0	4.761	3.601	103.7
304-19	0.0	0.000	0	0	4.675	3.485	110.7
306-1	0.0	0.000	0	0	4.237	3.24	127.85
306-2	0.0	0.000	0	0	4.188	3.189	140.8
306-3	0.0	0.000	0	0	4.31	3.161	105.25
306-4	0.0	0.000	0	0	4.622	3.384	104.25
306-5	0.0	0.000	0	0	4.512	2.976	91.2
306-6	0.0	0.000	0	0	4.25	3.206	107.6
306-7	3.8	0.008	40.513282	45.484262	4.862	3.501	87.25
306-8	7.7	0.017	82.092703	92.165478	4.726	3.425	83.7
306-9	20.2	0.044	215.36008	241.78476	5.324	3.721	46.3
306-10	17.4	0.038	185.50819	208.27004	4.87	3.601	74.95
306-11	13.6	0.030	144.9949	162.78578	4.953	3.589	72.9
306-12	0.0	0.000	0	0	4.487	3.401	104.2
306-13	0.0	0.000	0	0	4.94	3.581	62.25
306-14	0.0	0.000	0	0	4.309	3.256	129.6
306-15	0.0	0.000	0	0	4.21	3.265	138.85

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
306-17	0.0	0.000	0	0	4.407	3.25	102.9
306-18	0.0	0.000	0	0	4.38	3.214	128.1
306-19	3.9	0.009	41.579421	46.681216	4.449	3.356	109.85
307-1	0.0	0.000	0	0	4.585	3.487	115.8
307-2	0.0	0.000	0	0	4.5	3.373	106.3
307-3	15.5	0.034	165.25154	185.52791	4.853	3.484	97.35
307-4	4.4	0.010	46.910116	52.665987	4.678	3.439	102.65
307-5	78.6	0.173	837.98525	940.80604	5.231	3.504	71.3
307-6	36.7	0.081	391.27301	439.28221	5.21	3.58	57.55
307-7	32.3	0.071	344.3629	386.61622	4.83	3.471	74.95
307-8	56.1	0.124	598.10398	671.49134	5.423	3.562	39.35
307-9	37.4	0.082	398.73599	447.66089	5.327	3.601	74
307-10	26.6	0.059	283.59297	318.38983	5.12	3.541	80.05
307-11	29.3	0.065	312.37873	350.7076	5.107	3.491	77.15
307-12	8.6	0.019	91.687954	102.93807	4.831	3.478	85.7
307-13	20.6	0.045	219.62463	246.57258	4.951	3.4118	57.3
307-14	1.4	0.003	14.925946	16.75736	4.238	3.337	127.3
307-15	4.4	0.010	46.910116	52.665987	4.715	3.391	77.95
307-16	6.4	0.014	68.232896	76.605072	4.611	3.357	92.8
307-17	3.5	0.008	37.314865	41.893399	4.591	3.434	100.9
307-18	0.0	0.000	0	0	4.779	3.471	114.1
307-19	0.0	0.000	0	0	4.643	3.456	114.9
308-1	0.0	0.000	0	0	4.582	3.468	87.95
308-2	0.0	0.000	0	0	4.452	3.385	85.15
308-3	5.2	0.011	55.439228	62.241621	4.326	3.401	98.65
308-4	7.5	0.017	79.960425	89.771569	4.612	3.521	80.65
308-5	4.6	0.010	49.042394	55.059896	5.142	3.714	37.1
308-6	10.8	0.024	115.14301	129.27106	5.104	3.749	32.55
308-7	13.6	0.030	144.9949	162.78578	5.359	3.698	14.45
308-8	10.1	0.022	107.68004	120.89238	5.008	3.578	33.45
308-9	4.5	0.010	47.976255	53.862941	5.035	3.625	28.65
308-10	0.0	0.000	0	0	4.735	3.334	76.45
308-11	2.0	0.004	21.32278	23.939085	4.513	3.246	82.7
308-12	6.2	0.014	66.100618	74.211164	4.603	3.434	80.2
308-13	10.0	0.022	106.6139	119.69543	5.302	3.701	52.25
308-14	0.0	0.000	0	0	4.025	3.225	156.25
308-15	0.0	0.000	0	0	4.365	3.274	103.25
308-16	8.3	0.018	88.489537	99.347203	4.332	3.39	100.15
308-17	0.0	0.000	0	0	4.305	3.294	107.55
308-18	0.0	0.000	0	0	4.469	3.405	80.2
308-19	0.0	0.000	0	0	4.42	3.351	82.9
401-1	3.1	0.007	33.050309	37.105582	4.779	3.158	79.65

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
401-3	37.8	0.083	403.00054	452.44871	5.784	3.687	19.06
401-4	18.5	0.041	197.23571	221.43654	5.523	3.685	44.65
401-5	48.1	0.106	512.81286	575.735	5.141	3.401	37.05
401-6	60.5	0.133	645.01409	724.15732	5.015	3.426	30.5
401-7	37.7	0.083	401.9344	451.25175	5.629	3.709	26
401-8	22.4	0.049	238.81514	268.11775	5.397	3.685	42.6
401-9	16.9	0.037	180.17749	202.28527	4.921	3.389	30.65
401-10	35.8	0.079	381.67776	428.50962	5.238	3.695	39.1
401-11	27.6	0.061	294.25436	330.35937	5.189	3.58	53.2
401-12	27.0	0.059	287.85753	323.17765	5.489	3.601	39.205
401-13	0.0	0.000	0	0	4.616	3.335	63.2
401-14	2.0	0.004	21.32278	23.939085	4.958	3.305	67.6
401-15	11.4	0.025	121.53985	136.45278	4.656	3.3	72.3
401-16	12.7	0.028	135.39965	152.01319	4.257	3.175	115.75
401-17	9.0	0.020	95.95251	107.72588	4.386	3.077	112.25
401-18	9.0	0.020	95.95251	107.72588	4.549	3.208	77.35
401-19	1.4	0.003	14.925946	16.75736	4.839	3.319	81.25
402-1	0.0	0.000	0	0	4.667	3.458	64.85
402-2	14.3	0.031	152.45788	171.16446	5.128	3.574	33.7
402-3	39.0	0.086	415.79421	466.81216	5.413	3.885	34.45
402-4	45.3	0.100	482.96097	542.22028	5.675	3.964	20.6
402-5	61.5	0.135	655.67548	736.12687	5.26	3.998	23.15
402-6	36.7	0.081	391.27301	439.28221	5.189	3.978	19.75
402-7	34.9	0.077	372.08251	417.73703	5.448	3.874	37.75
402-8	22.4	0.049	238.81514	268.11775	5.078	3.776	42.7
402-9	45.2	0.100	481.89483	541.02332	5.608	3.805	20.6
402-10	31.5	0.069	335.83378	377.04059	5.127	3.449	52.3
402-11	19.8	0.044	211.09552	236.99694	5.104	3.422	72.55
402-12	43.2	0.095	460.57205	517.08424	5.623	3.816	37.15
402-13	3.7	0.008	39.447143	44.287307	4.324	3.278	112.05
402-14	9.9	0.022	105.54776	118.49847	4.266	3.126	93.7
402-15	0.0	0.000	0	0	4.307	3.096	118.25
402-16	0.0	0.000	0	0	4.316	3.055	114.25
402-17	5.2	0.011	55.439228	62.241621	4.407	3.137	95.6
402-18	0.0	0.000	0	0	4.281	3.189	130.7
402-19	4.0	0.009	42.64556	47.87817	4.212	3.301	93.7
405-1	8.5	0.019	90.621815	101.74111	5.001	3.596	74.05
405-2	0.0	0.000	0	0	4.308	3.344	109.25
405-3	0.0	0.000	0	0	4.761	3.583	87.65
405-4	28.0	0.062	298.51892	335.14719	5.421	3.965	22.5
405-5	11.4	0.025	121.53985	136.45278	5.193	3.587	39.2
405-6	0.0	0.000	0	0	5.01	3.626	67.6

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
405-8	44.5	0.098	474.43185	532.64464	5.789	4.102	36.15
405-9	0.0	0.000	0	0	5.218	3.824	44.35
405-10	0.0	0.000	0	0	4.664	3.644	40.55
405-11	11.2	0.025	119.40757	134.05888	4.875	3.467	62.6
405-12	1.3	0.003	13.859807	15.560405	4.471	3.485	109.6
405-13	9.6	0.021	102.34934	114.90761	4.718	3.501	67.25
405-14	0.0	0.000	0	0	4.786	3.415	90.2
405-15	0.0	0.000	0	0	4.36	3.457	85.65
405-16	1.2	0.003	12.793668	14.363451	4.43	3.562	71.75
405-17	3.5	0.008	37.314865	41.893399	4.257	3.396	121.2
405-18	0.0	0.000	0	0	4.463	3.407	99.2
405-19	0.0	0.000	0	0	4.078	3.341	96.3
406-1	0.0	0.000	0	0	4.11	3.286	93.6
406-2	0.0	0.000	0	0	4.388	3.365	88.45
406-3	0.0	0.000	0	0	4.342	3.287	91.8
406-4	9.8	0.022	104.48162	117.30152	4.612	3.475	76.8
406-5	0.0	0.000	0	0	4.411	3.367	82.7
406-6	0.0	0.000	0	0	4.426	3.345	60.95
406-7	3.3	0.007	35.182587	39.49949	4.82	3.504	60.65
406-8	0.0	0.000	0	0	4.905	3.479	73.15
406-9	13.4	0.030	142.86263	160.39187	5.123	3.549	50.1
406-10	10.5	0.023	111.94459	125.6802	5.047	3.602	52.6
406-11	4.0	0.009	42.64556	47.87817	4.502	3.473	97.15
406-12	0.0	0.000	0	0	4.528	3.394	75.9
406-13	2.4	0.005	25.587336	28.726902	4.439	3.29	82.4
406-14	0.0	0.000	0	0	4.281	3.387	93
406-15	0.0	0.000	0	0	4.461	3.434	97.7
406-16	0.0	0.000	0	0	4.387	3.416	97.4
406-17	1.6	0.004	17.058224	19.151268	4.462	3.375	95.25
406-18	0.0	0.000	0	0	4.21	3.294	110.05
406-19	0.0	0.000	0	0	4.233	3.256	124.4
407-1	0.0	0.000	0	0	4.45	3.248	93.6
407-2	0.0	0.000	0	0	4.375	3.184	109.1
407-3	0.0	0.000	0	0	4.726	3.388	92.8
407-4	2.9	0.006	30.918031	34.711673	4.538	3.332	87.25
407-5	3.4	0.007	36.248726	40.696445	4.856	3.406	66.3
407-6	0.0	0.000	0	0	4.615	3.241	85.75
407-7	0.0	0.000	0	0	4.51	3.352	79.2
407-8	0.0	0.000	0	0	4.517	3.321	72.9
407-9	0.0	0.000	0	0	4.558	3.318	69.8
407-10	8.5	0.019	90.621815	101.74111	4.889	3.557	64.25
407-11	0.0	0.000	0	0	4.533	3.336	97.25

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
407-13	0.0	0.000	0	0	4.601	3.316	80.75
407-14	0.0	0.000	0	0	4.651	3.443	70.7
407-15	0.0	0.000	0	0	4.284	3.198	100.6
407-16	0.0	0.000	0	0	4.383	3.247	118.2
407-17	0.0	0.000	0	0	4.132	3.142	142.7
407-18	0.0	0.000	0	0	4.108	3.127	162.7
407-19	0.0	0.000	0	0	4.833	3.457	77.05
408-1	0.0	0.000	0	0	4.447	3.312	104.75
408-2	0.0	0.000	0	0	4.402	3.343	89.25
408-3	0.0	0.000	0	0	4.617	3.487	93.8
408-4	1.3	0.003	13.859807	15.560405	4.601	3.477	82.6
408-5	4.5	0.010	47.976255	53.862941	4.589	3.479	88.6
408-6	0.0	0.000	0	0	4.592	3.525	80.45
408-7	0.0	0.000	0	0	4.495	3.472	90.05
408-8	0.0	0.000	0	0	4.201	3.291	103.15
408-9	0.0	0.000	0	0	4.251	3.397	109.7
408-10	0.0	0.000	0	0	4.348	3.376	112.85
408-11	0.0	0.000	0	0	4.478	3.502	103.4
408-12	0.0	0.000	0	0	4.421	3.454	87.25
408-13	0.0	0.000	0	0	4.285	3.295	95.6
408-14	0.0	0.000	0	0	4.604	3.526	66.4
408-15	0.0	0.000	0	0	4.712	3.547	71.3
408-16	0.0	0.000	0	0	4.256	3.276	109.8
408-17	0.0	0.000	0	0	4.136	3.231	114.65
408-18	0.0	0.000	0	0	4.102	3.205	132.8
408-19	0.0	0.000	0	0	4.193	3.269	135.95
503-1	0.0	0.000	0	0	4.21	3.196	109.8
503-2	0.0	0.000	0	0	4.179	3.205	151.25
503-3	0.0	0.000	0	0	4.201	3.186	156.25
503-4	0.0	0.000	0	0	4.578	3.288	127.35
503-5	0.0	0.000	0	0	4.522	3.285	102.7
503-6	9.9	0.022	105.54776	118.49847	4.628	3.387	54.25
503-7	26.9	0.059	286.79139	321.98069	5.234	3.499	34.7
503-8	21.1	0.046	224.95533	252.55735	5.008	3.526	19.215
503-9	23.5	0.052	250.54266	281.28425	5.21	3.503	5.25
503-10	23.6	0.052	251.6088	282.4812	5.071	3.428	69.3
503-11	25.8	0.057	275.06386	308.8142	5.21	3.489	59.3
503-12	71.0	0.156	756.95869	849.83752	6.001	4.078	4.92
503-13	13.1	0.029	139.66421	156.80101	4.634	3.302	80.2
503-14	2.8	0.006	29.851892	33.514719	4.426	3.257	75.2
503-15	0.0	0.000	0	0	4.321	3.265	87.7
503-16	0.0	0.000	0	0	4.686	3.373	105.95

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
503-18	0.0	0.000	0	0	4.403	3.266	98.7
503-19	0.0	0.000	0	0	4.408	2.954	100.65
504-1	0.0	0.000	0	0	4.256	2.974	107.6
504-2	0.0	0.000	0	0	4.305	3.358	111.9
504-3	0.0	0.000	0	0	4.122	3.145	105.4
504-4	0.0	0.000	0	0	4.425	3.401	112.9
504-5	0.0	0.000	0	0	4.768	3.339	62.7
504-6	0.0	0.000	0	0	4.442	3.365	104.25
504-7	6.9	0.015	73.563591	82.589844	5.143	3.627	72.6
504-8	12.3	0.027	131.1351	147.22537	5.333	3.903	65.6
504-9	2.2	0.005	23.455058	26.332994	4.851	3.567	64.25
504-10	5.9	0.013	62.902201	70.620301	5.014	3.727	53.9
504-11	6.2	0.014	66.100618	74.211164	5.052	3.841	45.35
504-12	29.4	0.065	313.44487	351.90455	5.161	3.758	49.4
504-13	16.9	0.037	180.17749	202.28527	5.023	3.647	41.7
504-14	28.9	0.064	308.11417	345.91978	5.323	3.788	51.25
504-15	2.2	0.005	23.455058	26.332994	4.667	3.422	68.7
504-16	0.0	0.000	0	0	4.071	3.095	97.8
504-17	0.0	0.000	0	0	4.523	3.268	118.05
504-18	0.0	0.000	0	0	4.403	3.202	108.4
504-19	0.0	0.000	0	0	4.509	3.479	109.25
505-1	0.0	0.000	0	0	4.113	3.331	99.45
505-2	0.0	0.000	0	0	4.466	3.298	105.15
505-3	0.0	0.000	0	0	4.256	3.113	124.35
505-4	0.0	0.000	0	0	4.742	3.455	95.7
505-5	0.0	0.000	0	0	4.925	3.357	87.15
505-6	0.0	0.000	0	0	5.347	3.842	72.9
505-7	75.1	0.165	800.67039	898.91264	6.21	4.231	9.45
505-8	35.1	0.077	374.21479	420.13094	5.789	4.156	42.8
505-9	40.7	0.090	433.91857	487.16038	5.623	4.005	37.05
505-10	12.5	0.028	133.26737	149.61928	5.336	3.988	47.8
505-11	32.5	0.072	346.49517	389.01013	5.727	3.947	43.15
505-12	38.4	0.085	409.39738	459.63043	5.221	3.967	23.9
505-13	26.7	0.059	284.65911	319.58679	5.22	3.723	37.8
505-14	27.2	0.060	289.98981	325.57156	5.247	3.608	70.7
505-15	0.0	0.000	0	0	4.833	3.495	88
505-16	0.0	0.000	0	0	4.395	3.368	111.75
505-17	0.0	0.000	0	0	4.221	3.277	132.45
505-18	0.0	0.000	0	0	4.12	3.174	153.2
505-19	0.0	0.000	0	0	4.529	3.501	124.25
506-1	0.0	0.000	0	0	4.386	3.369	93.35
506-2	0.0	0.000	0	0	3.987	3.247	115.85

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
506-4	0.0	0.000	0	0	4.403	3.376	94.65
506-5	8.2	0.018	87.423398	98.150249	4.971	3.624	59.5
506-6	16.3	0.036	173.78066	195.10354	5.084	3.785	7.6
506-7	46.9	0.103	500.01919	561.37155	5.346	3.894	6.15
506-8	38.3	0.084	408.33124	458.43348	5.861	4.003	1.15
506-9	15.7	0.035	167.38382	187.92182	5.303	3.729	11.2
506-10	35.6	0.078	379.54548	426.11571	5.472	3.945	5.25
506-11	30.1	0.066	320.90784	360.28323	5.259	3.67	21.05
506-12	44.2	0.097	471.23344	529.05378	4.859	3.514	33.15
506-13	17.4	0.038	185.50819	208.27004	4.692	3.514	77.1
506-14	0.0	0.000	0	0	4.616	3.421	92
506-15	0.0	0.000	0	0	4.747	3.509	125.55
506-16	0.0	0.000	0	0	4.502	3.356	122.9
506-17	0.0	0.000	0	0	4.352	3.365	135.95
506-18	0.0	0.000	0	0	4.46	3.453	134
506-19	0.0	0.000	0	0	4.109	3.265	160.7
507-1	0.0	0.000	0	0	4.344	3.374	137.7
507-2	0.0	0.000	0	0	4.102	3.39	153.35
507-3	0.0	0.000	0	0	4.47	3.586	112.65
507-4	27.5	0.061	293.18822	329.16242	5.12	3.574	108.85
507-5	27.6	0.061	294.25436	330.35937	5.23	3.587	77.1
507-6	136.9	0.302	1459.5443	1638.6304	6.321	4.12	12.35
507-7	49.4	0.109	526.67267	591.2954	5.743	3.745	31.4
507-8	20.8	0.046	221.75691	248.96648	4.814	3.544	30.75
507-9	63.5	0.140	676.99826	760.06595	5.679	3.851	17.25
507-10	49.6	0.109	528.80494	593.68931	5.779	3.924	24.25
507-11	38.7	0.085	412.59579	463.2213	4.772	3.541	52.25
507-12	9.8	0.022	104.48162	117.30152	4.672	3.415	82.15
507-13	5.3	0.012	56.505367	63.438575	4.451	3.318	124.2
507-14	0.0	0.000	0	0	4.647	3.468	101.55
507-15	2.2	0.005	23.455058	26.332994	4.112	3.326	82.7
507-16	0.0	0.000	0	0	4.5	3.238	98.1
507-17	0.0	0.000	0	0	4.47	3.301	101.55
507-18	0.0	0.000	0	0	4.425	3.327	112.7
507-19	0.0	0.000	0	0	4.278	3.562	151.8
508-1	0.0	0.000	0	0	4.315	3.243	115.35
508-2	0.0	0.000	0	0	4.21	3.275	123.6
508-3	0.0	0.000	0	0	4.108	3.184	137.1
508-4	0.0	0.000	0	0	4.285	3.309	122.55
508-5	0.0	0.000	0	0	4.197	3.227	119.75
508-6	0.0	0.000	0	0	4.249	3.267	100.75
508-7	0.0	0.000	0	0	4.376	3.326	91.8

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
508-9	0.0	0.000	0	0	4.755	3.541	74.25
508-10	0.0	0.000	0	0	4.742	3.524	74.75
508-11	0.0	0.000	0	0	4.159	3.185	125.7
508-12	0.0	0.000	0	0	4.089	2.865	142.8
508-13	0.0	0.000	0	0	4.255	3.245	120.3
508-14	26.6	0.059	283.59297	318.38983	4.102	3.185	139
508-15	0.0	0.000	0	0	4.026	3.178	134.25
508-16	0.0	0.000	0	0	4.203	3.256	142.55
508-17	0.0	0.000	0	0	4.222	3.279	138.95
508-18	0.0	0.000	0	0	4.286	3.295	110.7
508-19	0.0	0.000	0	0	4.005	3.147	133.35
601-1	0.0	0.000	0	0	4.412	3.154	123.75
601-2	0.0	0.000	0	0	4.506	2.941	136.9
601-3	0.0	0.000	0	0	4.477	3.256	105.25
601-4	0.0	0.000	0	0	4.423	3.188	112.85
601-5	30.0	0.066	319.8417	359.08628	4.688	3.255	121.8
601-6	0.0	0.000	0	0	4.574	3.274	102.95
601-7	9.7	0.021	103.41548	116.10456	4.489	3.247	85.75
601-8	0.0	0.000	0	0	4.225	3.099	143.15
601-9	0.0	0.000	0	0	4.639	3.258	75.2
601-10	6.4	0.014	68.232896	76.605072	4.582	3.284	77.25
601-11	9.2	0.020	98.084788	110.11979	4.408	3.189	88
601-12	0.0	0.000	0	0	4.719	3.302	79.5
601-13	32.3	0.071	344.3629	386.61622	5.18	3.501	62.9
601-14	0.0	0.000	0	0	4.691	3.289	80.5
601-15	0.0	0.000	0	0	4.579	3.307	66.5
601-16	0.0	0.000	0	0	4.635	3.301	94.9
601-17	0.0	0.000	0	0	4.438	3.142	143.7
601-18	0.0	0.000	0	0	4.599	3.209	125.2
601-19	0.0	0.000	0	0	4.202	3.143	155.1
602-1	0.0	0.000	0	0	4.12	3.167	148.15
602-2	0.0	0.000	0	0	4.203	3.173	137.25
602-3	0.0	0.000	0	0	4.191	3.065	147.7
602-4	0.0	0.000	0	0	4.054	3.295	161.65
602-5	58.2	0.128	620.4929	696.62738	5.009	3.462	52.5
602-6	61.3	0.135	653.54321	733.73296	5.014	3.334	55.1
602-7	69.7	0.154	743.09888	834.27712	5.612	3.701	37.25
602-8	12.7	0.028	135.39965	152.01319	5.12	3.504	69.4
602-9	4.1	0.009	43.711699	49.075124	4.981	3.478	72.85
602-10	0.0	0.000	0	0	4.159	3.226	128.7
602-11	0.0	0.000	0	0	4.295	3.184	102.6
602-12	0.0	0.000	0	0	4.725	3.367	79.5

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
602-14	0.0	0.000	0	0	4.248	3.201	114.25
602-15	0.0	0.000	0	0	4.034	3.105	137.8
602-16	0.0	0.000	0	0	4.127	3.162	147.7
602-17	0.0	0.000	0	0	4.212	3.213	159.35
602-18	0.0	0.000	0	0	4.604	3.212	122.9
602-19	0.0	0.000	0	0	3.919	3.197	150.1
603-1	0.0	0.000	0	0	4.341	3.282	128.2
603-2	0.0	0.000	0	0	4.156	3.233	134.35
603-3	0.0	0.000	0	0	3.941	3.356	125.95
603-4	0.0	0.000	0	0	4.4	3.305	131.55
603-5	0.0	0.000	0	0	4.337	3.472	120.6
603-6	0.0	0.000	0	0	4.73	3.384	139.55
603-7	150.4	0.331	1603.4731	1800.2192	5.881	4.025	1.2
603-8	85.1	0.187	907.28429	1018.6081	6.007	3.974	7.05
603-9	93.2	0.205	993.64155	1115.5614	5.712	3.941	42.55
603-10	55.0	0.121	586.37645	658.32484	4.962	3.468	37.8
603-11	68.7	0.151	732.43749	822.30757	5.321	3.614	22.25
603-12	70.1	0.154	747.36344	839.06493	5.008	3.472	63.55
603-13	7.0	0.015	74.62973	83.786798	4.679	3.472	89.65
603-14	18.0	0.040	191.90502	215.45177	4.517	3.331	77.35
603-15	6.2	0.014	66.100618	74.211164	4.477	3.406	81.25
603-16	4.2	0.009	44.777838	50.272079	4.518	3.448	87.25
603-17	0.0	0.000	0	0	4.459	3.352	92.7
603-18	0.0	0.000	0	0	4.13	3.264	108.25
603-19	0.0	0.000	0	0	4.077	3.369	118.8
605-1	0.0	0.000	0	0	4.234	3.214	104.75
605-2	0.0	0.000	0	0	4.228	3.178	109.25
605-3	0.0	0.000	0	0	4.121	3.185	112.8
605-4	0.0	0.000	0	0	4.331	3.368	102.25
605-5	0.0	0.000	0	0	4.319	3.204	109.45
605-6	60.4	0.133	643.94796	722.96037	5.523	3.962	14.9
605-7	57.6	0.127	614.09606	689.44565	5.247	3.845	19.25
605-8	6.0	0.013	63.96834	71.817255	5.024	3.425	47.7
605-9	0.0	0.000	0	0	4.972	3.568	58.35
605-10	0.0	0.000	0	0	4.795	3.204	50.05
605-11	32.4	0.071	345.42904	387.81318	4.852	3.226	46.4
605-12	25.2	0.056	268.66703	301.63247	4.888	3.338	58.7
605-13	11.0	0.024	117.27529	131.66497	4.567	3.407	67.7
605-14	3.2	0.007	34.116448	38.302536	5.191	3.485	71.95
605-15	0.0	0.000	0	0	4.385	3.096	102.9
605-16	0.0	0.000	0	0	4.409	3.154	114.55
605-17	0.0	0.000	0	0	4.491	3.006	115.8

Plot	g/plot	lb/plot	lb/ac	kg/ha	H2O pH	CaCl pH	Adjusted Al
605-19	0.0	0.000	0	0	4.848	3.437	87.9
607-1	0.0	0.000	0	0	4.282	2.951	145.35
607-2	0.0	0.000	0	0	4.042	3.105	126.5
607-3	0.0	0.000	0	0	4.265	3.227	117.75
607-4	0.0	0.000	0	0	4.124	3.096	88
607-5	48.2	0.106	513.879	576.93195	5.193	3.552	49.7
607-6	110.3	0.243	1175.9513	1320.2405	5.249	3.527	42.05
607-7	83.6	0.184	891.2922	1000.6538	5.102	3.612	56.25
607-8	54.8	0.121	584.24417	655.93093	5.142	3.84	40.05
607-9	93.4	0.206	995.77383	1117.9553	5.043	3.792	26.8
607-10	84.6	0.186	901.95359	1012.6233	4.849	3.765	36.4
607-11	56.7	0.125	604.50081	678.67306	5.193	3.685	60.5
607-12	42.6	0.094	454.17521	509.90251	4.906	3.526	64.45
607-13	8.7	0.019	92.754093	104.13502	4.594	3.319	86.35
607-14	5.0	0.011	53.30695	59.847713	4.362	3.283	92.2
607-15	0.0	0.000	0	0	4.278	3.219	97.4
607-16	0.0	0.000	0	0	4.346	3.205	87.45
607-17	0.0	0.000	0	0	4.258	3.354	111.75
607-18	0.0	0.000	0	0	4.163	3.096	121.8
607-19	0.0	0.000	0	0	4.058	2.893	148.05
608-1	0.0	0.000	0	0	4.432	3.224	137.5
608-2	0.0	0.000	0	0	4.337	3.214	135.75
608-3	0.0	0.000	0	0	4.152	2.954	148.15
608-4	0.0	0.000	0	0	4.249	3.105	122.3
608-5	22.7	0.050	242.01355	271.70862	4.916	3.456	18.55
608-6	6.3	0.014	67.166757	75.408118	5.419	3.788	37.3
608-7	5.1	0.011	54.373089	61.044667	5.119	3.739	53.25
608-8	0.0	0.000	0	0	5.024	3.544	40.7
608-9	12.1	0.027	129.00282	144.83146	5.124	3.985	26.4
608-10	19.4	0.043	206.83097	232.20913	5.185	3.906	24.7
608-11	25.9	0.057	276.13	310.01115	5.225	3.746	56.15
608-12	51.1	0.113	544.79703	611.64362	5.097	3.515	18.25
608-13	0.0	0.000	0	0	4.285	3.133	92.25
608-14	0.0	0.000	0	0	4.674	3.398	134.2
608-15	0.0	0.000	0	0	4.221	3.224	123.5
608-16	0.0	0.000	0	0	4.197	2.948	130.6
608-17	0.0	0.000	0	0	3.943	3.343	129.4
608-18	0.0	0.000	0	0	4.157	3.258	147.65
608-19	0.0	0.000	0	0	4.102	3.307	151.2

VITA

Joshua Jon Lofton

Candidate for the Degree of

Master of Science

Thesis: DETERMINING AL TOLERANCE AND CRITICAL SOIL PH FOR WINTER CANOLA IN THE SOUTHERN GREAT PLAINS

Major Field: Plant and Soil Sciences

Biographical:

Personal Data: Born in Tulsa, Oklahoma May 24, 1985

Education: Received a Bachelor's degree from Oklahoma State University, Stillwater, Oklahoma in May 2007. Completed the requirements for a Master's of Science degree in May 2009.

Experience: Employed as an Undergraduate Research Assistant from May2004-May 2007 and a Research Assistant from May 2004-current.

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Name: Joshua Jon Lofton Date of Degree: May 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: DETERMINING AL TOLERANCE AND CRITICAL SOIL PH FOR WINTER CANOLA IN THE SOUTHERN GREAT PLAINS

Pages in Study: 72 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Science

Scope and Method of Study: An in-field study was conducted to determine the effect of soil acidity on winter canola grain yields. A pre-established soil pH gradient was used in Perkins, Ok. A randomized incomplete block design with 6 cultivars per block was established. A laboratory experiment was established to determine the effect of aluminum concentrations on root growth and determine if the different cultivars responded differently to the changing aluminum concentrations. Eight cultivars were chosen. The treatments consisted of 0, 20, 40, 60, and 80 mg Al kg^{-1}. The seeds were allowed to germinate and grow for 72-hours in DI water. The seedlings were then transplanted into the varying concentrations of aluminum and allowed to grow for 96-hours. Root lengths were then taken and compared between the aluminum concentrations and between cultivars.

Findings and Conclusions: Soil acidity greater affected winter canola grain yields for both 2006-2007 and 2007-2008 growing seasons. In the 2006-2007 growing season the current critical level for growing winter canola, pH 5.8, was found to be adequate; however, in 2007-2008 not enough data points were found above 5.8 to see the same results. In the laboratory study it was found that for most cultivars Al concentrations as low as 20 mg Al kg^{-1} were found to reduce canola root growth. Overall, the effects of soil acidity highly effects winter canola production in the Southern Great Plains. For non-weather stressed years a critical pH of at least 5.8 will be appropriate for winter canola production.

ADVISER'S APPROVAL: Dr. Chad Godsey