THE EFFECT OF SOIL pH, ALUMINUM, AND MANGANESE ON WHEAT CULTIVARS

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CHAPTER I

INTRODUCTION

Soils with low pH require liming to reach their production potential. However, liming may not always be economically feasible to farmers. New wheat cultivars that have already been tested under low pH should be tested further and perhaps considered as another approach when dealing with acid soils.

Wheat cultivars can be tested in the laboratory using a method which stains the roots of the seedlings to show their tolerance to aluminum (Al). This method can identify which cultivars should be tested further for Al tolerance in the field.

The main objectives of this study were: (i) to determine the effects of Al and manganese (Mn) on wheat grain yield in both limed and unlimed soils, (ii) to determine Al tolerance levels of wheat seedlings grown under laboratory conditions, and (iii) to determine the relationship between the effects of Al under field conditions and results obtained with the hematoxylin dye technique used in the laboratory.

CHAPTER II

LITERATURE REVIEW

Low soil pH is usually not the factor that limits plant growth, but toxicity in the soil and/or a deficiency of mineral elements is. The initial site of Al injury is in the root (17) because Al directly inhibits cell division in the root apical meristem (1). Plant tops affected by Al toxicity show symptoms similar to those of P deficiency (4). Reduced nutrient uptake has been attributed to Al toxicity (4, 11) and P deficiency has often appeared on plants grown on acid soil (6, 18). In more than 70 percent of the acid soils of tropical America, Al toxicity and Ca and Mg deficiency exists, and nearly 100 percent of the soils are P-deficient or have a high P-fixing capacity (24). Aluminum binds P on root surfaces and cell walls in plant roots and inhibits P uptake (2). Phosphorus absorption has been improved by increasing soil pH, liming, and precipitating Al (6). Manganese, unlike aluminum, does not injure the root directly but affects the shoot, regardless of the manganese tolerance of a species or cultivar (25). Occurrences of Mn deficiency and toxicity have been reported for several crops in the southeastern United States (20).

When limestone initially reacts with soil acidity, it neutralizes readily exchangeable Al (13) and does not cause a change in the effective CEC if the rate of limestone is based on exchangeable Al removed by KCl. Liming acid soils precipitate soil aluminum and renders it inactive. But alleviation of Al toxicity by amending the soil is not feasible in many instances (4). This is one reason why the study of new cultivars of wheat that are tolerant to Al will be helpful to farmers.

When seedling roots of wheat were tested with solutions containing Al^{3+} and then stained in an aqueous solution of hematoxylin, they developed a pattern of staining that correlated remarkably well with their Al tolerance level as estimated by root elongation methods and field trials (21). Greenhouse studies to determine the critical Al toxicity level for a specific wheat (Triticulm aestivium L.) cultivar showed that Al toxicity reduced top dry weight, root dry weight, plant height, tiller numbers, and top/root dry weight ratios (19). Nutrient solution results and greenhouse tests have indicated that tolerance to high levels of Al was associated with the region of development of wheat (7). Studies to investigate possible interactions between plant Mn concentration and the growth and forage quality of wheat showed that critical Mn deficiency and toxicity levels affecting normal growth of wheat shoot were 35 and 475 ug/g dry weight, respectively (3).

Readily exchangeable Al in soils can be measured by extracting with KCl (13). Certain acid soils are toxic to plants because they contain excessive amounts of soluble or exchangeable Al (5, 9, 10, 15, 22). Plant species have long been known to differ in Al tolerance (6, 9, 10, 12, 16, 23) and more recently such differences have also been reported among varieties of the same plant species. It has been concluded that more highly tolerant varieties must be bred by accumulation of various tolerant genes from different genetic backgrounds (27).

CHAPTER III

MATERIALS AND METHODS

Field Study

Field studies were initiated in 1985 on the North Central Research Station at Lahoma, Oklahoma and the Sandy Land Research Station at Mangum, Oklahoma. The planting date at Lahoma was October 25, 1985 with a seeding rate of 76 kg/ha. In Mangum, the first planting date was September 27, 1985. However, due to poor stand establishment, the crop was replanted October 31 using a seeding rate of 67 kg/ha. The soil type at Lahoma was a Pond Creek silt loam (Pachic Argiustolls) and a Meno and Altus loamy fine sand complex (Aguic Arenic Haplustalfs and Pachic Argiustolls) at Mangum. Plots were arranged in a split plot arrangement with two main plots, limed and unlimed. Lime was applied at a rate of 4450 and 1780 kg/ha of ECCE using 50% Ag lime at Lahoma on August 22, 1985 and Mangum on August 30, 1985, respectively. Four replications of sub-plots with sixteen and seventeen cultivars were randomized at Lahoma and Mangum, respectively (Table 1). After field studies were initiated, it was determined that part of the unlimed main plots had been limed previously at Lahoma; thus only 2 replications were analyzed for this study. Ammonium nitrate (34-0-0) was applied at Lahoma on August 27, 1985 and at Mangum on August 30, 1985. Glean herbicide was applied on February 26, 1986 at a rate of 12 g/ha.

Table 1. Wheat cultivars used in field experiments at Lahoma, Mangum, and in laboratory studies.

1.	Chisholm	12.	Stallion
2.	Mustang	13.	Pioneer 2157
3.	Wrangler	14.	Pioneer 2165
4.	Siouxland	15.	Pony
5.	Tam W-101	16.	Garst HR48
6.	Tam 107	17.	Tam 108
7.	Triumph 64	*18.	McNair 1003
8.	Bounty Hybrid 122	*19.	Fronteira (CI 12019)
9.	Quantum XH-551	*20.	Atlas 66
10.	Hybrex 1010	*21.	Arthur 71
11.	Victory		

*Wheat cultivars used as checks in the laboratory.
Cultivars 1-16 used at Lahoma.
Cultivars 1-17 used at Mangum.
Cultivars 1-16 and 18-21 used in the laboratory.

Five stand counts of ½ m row length were taken at random from each plot on January 8, 1986 at Lahoma and January 10, 1986 at Mangum at the beginning of tillering (Feekes Stage 2).

Twenty soil cores, 0 to 15 cm deep, were taken at random and combined from each plot on January 15, 1986 at Lahoma and January 10, 1986 at Mangum. These samples were run in duplicate and analyzed for pH, Al and Mn. Soil pH was measured each on 1:1 soil:H_2O and a 1:1 soil:KCl soil-solution ratio suspension. For the pH measurement using 1:1 soil:KCl, 10 g of soil was weighed in duplicate and placed into disposable translucent plastic cups, P5A-148 ml. Then 10 ml of 1 M KCl was added to each cup and the samples placed on a shaker for 5 minutes, removed and allowed to stand for 30 minutes. After 30 minutes, the pH was determined and 40 ml of 1 M KCl was added to each sample. The contents were swirled and transferred to a funnel fitted with a Whatman 42 filter paper (9.0 cm). The soil was leached with an additional 50 ml of 1 M KCl. The leachate was collected in a 250 ml Erlenmeyer flask and transferred to labeled test tubes containing a drop of toulene for storage. The test tubes were stoppered and placed in a refrigerator at 9° C for later analyses of Al and Mn by atomic absorption spectrometry. Soil samples for analyses were taken again, as previously described, on July 10, 1986 at Lahoma and June 10, 1986 at Mangum.

Grain yields were obtained on June 13, 1986 at Lahoma by harvesting a 2 m strip out of a 2 x 12 m plot. At Mangum, grain yields were obtained on June 9, 1986 by harvesting a 3 m strip out of a 3 x 15 m plot using a Gleanor Model A combine.

Hematoxylin Staining

Wheat (Triticulm aestivum L.) cultivars (Table 1) were tested for Al tolerance in the laboratory using hematoxylin as a stain (21). The cultivars used in this study had been reported as having the highest yields the previous year in the western region of the state.

Three trays were made into a 7 by 8 grid and fastened by screws at each corner. A nylon screen was glued to the bottom of each tray with silicon glue. There were 56 cells formed by PVC pipe cylinders 2.5 cm tall in each tray. Four eyelet hooks, two on each side, were fastened to the sides of the trays. Fishing line was tied through the eyelet hooks so that the trays could be suspended in tubs of nutrient solution. Two bubble wands were glued to the top and bottom of each tub with silicon glue. A piece of tubing was connected to each bubble wand and then to the water filter which was connected to the air outlet in the laboratory bench.

The nutrient solution consisted of 5 mM $CaCl_2$, 6.5 mM KNO_3, 2.5 mM $MgCl_2$, 0.1 mM $(NH_4)_2SO^4$ and 0.4 mM NH_4NO_3. A ratio of 1 liter of nutrient solution to 4 liters of H_2O was used per tub.

The staining solution consisted of 2 g hematoxylin and 0.2g of $NaIO_3$ dissolved in one liter distilled water (8).

Aluminum was added to the nutrient solutions from a stock of $AlK(SO_4)_2 \cdot 12H_2O$. Three Al^{3+} concentrations were used: 0.18, 0.36, and 0.72 mM.

About 20 seeds from each cultivar were placed in petri dishes lined with filter paper which contained 2 to 3 drops of fungicide added with a dropper. Terracoat, 0.1 g/100L, was placed in the petri dishes to prevent fungal growth. Each lid was labeled to keep track of the cultivar and then the petri dishes were placed in a refrigerator for 12 hours.

Tubs were filled with 5 liters of distilled water and 5 seeds from each cultivar were then placed in each cell at random in two replications. The trays were then placed in the tubs suspended by fishing line. Each tub was placed under fluorescent growth lights at 12 hr intervals. The trays were covered with clear plastic to insure a humid environment. The next day the water in the Erlenmeyer flask, which served as a water filter, was checked and filled when necessary with distilled water. About 40 hrs after the seeds were placed in distilled water, the water was changed from distilled water to one liter of nutrient solution plus 4 liters of distilled water adjusted to pH 4. The tubs were placed under the lights again and covered with clear plastic. After 24 hrs, the nutrient solution containing Al treatments were added. Tubs were placed under the lights without the clear plastic. Twenty-four hrs later, the nutrient solution was replaced with 5 liters of distilled water. The trays were left in the tubs for 1 hr while the hematoxylin dye was prepared and put into a separate tub for dying the roots. One tray at a time was placed in the tub containing the dye and left for 15 mins. After dying, the cases were rinsed under running distilled water in the sink for 1 min. The trays containing the cases were placed back in the tubs containing aerated distilled water for 1 hr. After 1 hr, the seedlings were removed from the trays and placed on trays that were covered with a paper towel-type cloth with a plastic backing (plastic side facing downward). The cloth was saturated with water to provide adequate moisture to keep the seedling roots from shriveling. The trays were labeled as to the replication number and Al concentration. When the trays were full with seedling roots, they were sprayed with water and covered with a clear plastic film. The seedlings were then ready to be rated according to stain development on a scale of five, ten, or fifteen. Five stood for no staining, ten stood for partial staining, and fifteen stood for complete staining of the root tip.

Mean Variance

Mean variance was calculated using the data from the Lahoma field study and from the lab study using hematoxylin stain. Mean variance was calculated in order to understand precision in the area of sampling for future experiments (14). In order to calculate mean variance, several formulas were used (14):

1. The numerical value of the variance component for experimental error was determined by the following formula:

$$\sigma_p^2 = \frac{s_p^2 - s_s^2}{n_s}$$

σ_p^2 = true error variance between plots

s_p^2 = estimated error variance between plots

s_s^2 = represents the estimated error variance between sampling units per plot

True error variance (σ_p^2) can be calculated because s_p^2 and s_s^2 are both obtainable from the analysis of variance.

2. By use of variance components, the variance of a mean is calculated as follows:

$$s_{\bar{x}}^2 = \frac{\sigma_s^2 + n_s \sigma_p^2}{n_p n_s} = \frac{1}{n_p} \left\{ \sigma_p^2 + \frac{\sigma_s^2}{n_s} \right\}$$

By use of this formula, it is possible to determine the effect upon precision by varying the number of sampling units per plot, when the number of replications is held constant.

Spearmans Coefficient (r_s) and Standard Correlation (r)

Spearman's Coefficient (r_s) was calculated and compared to Standard Correlation (r) to see which one provided an improvement in the correlation coefficient. Spearman's coefficient of rank applies to data in the form of ranks (26). Standard Correlation (r) was calculated using the computer program Turbostat.

CHAPTER IV

RESULTS AND DISCUSSION

Analysis of variance was performed on data collected from Lahoma, Mangum, and laboratory studies. ANOVAs are shown in Appendix Tables I to XX. Least significant differences were used, where appropriate, in comparisons to determine significance.

Lahoma - Field Experiment

Stand Count and Yield

Stand counts were taken once at Lahoma from the limed and unlimed plots in 1985. There were no significant differences in stand count due to liming (Table 2), but there were significant differences in stand count among cultivars (Table 3). There were no significant lime interaction effects on stand count (Table 4).

Yields were harvested at Lahoma in 1986 from the limed and unlimed plots. The data reported is from a one year field study starting in October 1985 and harvested June 1986. Field studies at Lahoma indicate that there were no significant differences in yield due to liming (Table 5). But there were significant differences in yield among cultivars (Table 6) and significant interactions (Table 7). Stand count and yield in limed soils were not significantly different from unlimed soils. This was attributed to the equilibration time required for lime to

Table 2. Main plot stand counts and soil analyses five months after liming at Lahoma.

Main Plot	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g
unlimed	14.3	4.63	3.83	37.32	71.91
limed	13.9	5.72	4.97	1.45	43.66
unlimed vs. limed	NS	*	*	*	NS

* Significant at the 0.05 probability level

Table 3. Cultivar stand counts and soil analyses* five months after liming at Lahoma.

Cultivar	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g
Chisholm	10.3	5.19	4.35	18.45	59.84
Mustang	12.5	5.20	4.29	17.15	61.58
Wrangler	16.1	5.13	4.35	19.45	59.68
Siouxland	14.8	5.19	4.43	22.39	56.45
Tam W-101	12.3	5.36	4.62	19.40	58.86
Tam-107	10.8	5.23	4.46	24.10	53.25
Triumph-64	14.3	5.16	4.40	19.34	56.96
Bounty Exp 2222	11.2	5.11	4.34	21.91	58.84
Quantum XH-551	11.5	5.13	4.36	15.38	55.26
Hybrex-1010	13.3	5.10	4.32	20.23	58.56
Victory	11.3	5.07	4.28	25.35	58.24
Stallion	13.8	5.16	4.39	21.30	58.21
Pioneer-2157	18.0	5.16	4.52	13.64	54.89
Pioneer-2165	15.3	5.12	4.36	18.91	53.96
Pony	20.8	5.12	4.35	18.70	62.11
Garst HR-48	19.1	5.33	4.52	14.46	57.80
LSD (0.05)	3.4	NS	NS	NS	NS

* Values are an average over main plots

Table 4. The effect of lime on stand counts and soil analyses five months after liming at Lahoma.

Cultivars	Limed*					Unlimed*				
	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g	plts/m			ug/g	ug/g
Chisholm	10	5.70	4.88	0.5	46.2	11	4.69	3.83	36.5	73.5
Mustang	12	5.58	4.72	1.5	49.3	13	4.81	3.87	32.9	73.9
Wrangler	16	5.61	4.88	1.1	45.6	16	4.65	3.81	37.8	73.8
Siouxland	14	5.77	5.04	0.7	36.8	16	4.61	3.82	44.1	76.1
Tam W-101	14	6.17	5.45	0.9	40.2	11	4.55	3.80	37.9	77.6
Tam-107	11	5.85	5.17	1.2	34.6	10	4.61	3.76	47.0	72.0
Triumph-64	15	5.76	5.02	1.4	44.0	14	4.56	3.78	37.3	70.0
Bounty Exp 2222	12	5.58	4.87	1.3	43.0	11	4.64	3.81	42.6	74.7
Quantum XH-551	11	5.58	4.15	1.1	48.7	12	4.68	3.87	29.7	61.8
Hybrex-1010	12	5.53	4.80	1.5	38.1	15	4.67	3.84	39.0	79.0
Victory	12	5.59	4.82	1.8	40.6	10	4.55	3.73	48.9	75.9
Stallion	13	5.71	4.99	1.3	46.8	15	4.62	3.79	41.4	69.6
Pioneer-2157	17	5.87	5.09	2.2	42.0	19	4.45	3.96	25.1	67.8
Pioneer-2165	15	5.63	4.87	2.0	42.2	16	4.61	3.84	35.8	65.7
Pony	20	5.60	4.89	2.6	52.0	22	4.64	3.82	34.8	72.3
Garst HR-48	18	5.93	5.12	2.4	48.6	20	4.73	3.91	26.5	67.0

LSD (0.05) = NS, NS, NS, NS, and NS respectively for stand count, pH 1:1 H_2O, pH 1:1 M KCl, Al and Mn.

* Indicates analyses for replications 1 and 4.

Table 5. Main plot yield and soil analyses after harvest at Lahoma.

Main Plot	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g
unlimed	2471.49	4.99	3.74	40.42	65.65
limed	2481.83	6.20	5.12	3.21	20.85
unlimed vs. limed	NS	*	*	*	*

* Significant at the 0.05 probability level

Table 6. Cultivar yield and soil analyses* after harvest at Lahoma.

Cultivar	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g
Chisholm	2204.14	5.61	4.42	21.70	45.45
Mustang	2561.33	5.58	4.42	22.92	46.15
Wrangler	2426.29	5.56	4.39	21.90	44.30
Siouxland	3005.64	5.50	4.37	20.51	46.39
Tam W-101	2548.26	5.50	4.37	22.91	41.21
Tam-107	1860.01	5.64	4.51	23.45	42.20
Triumph-64	1955.84	5.61	4.41	28.83	48.83
Bounty Exp 2222	2857.54	5.56	4.38	24.56	44.55
Quantum XH-551	2439.36	5.64	4.48	18.68	42.84
Hybrex-1010	2400.16	5.51	4.38	25.84	45.35
Victory	2556.97	5.54	4.37	28.29	44.75
Stallion	2613.60	5.61	4.46	22.04	41.06
Pioneer-2157	2844.47	5.69	4.50	22.79	36.11
Pioneer-2165	2456.78	5.60	4.45	17.30	41.93
Pony	2417.58	5.63	4.42	14.29	41.40
Garst HR-48	2478.56	5.70	4.53	13.06	39.51
LSD (0.05)	315.54	NS	NS	NS	NS

* Values are an average over main plots

Table 7. The effect of lime on grain yield and soil analyses after harvest at Lahoma.

Cultivars	Limed*					Unlimed*				
	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g	kg/ha			ug/g	ug/g
Chisholm	2021	6.21	5.13	1.1	22.0	2387	5.01	3.71	42.3	69.0
Mustang	2387	6.18	5.12	1.8	23.2	2736	4.97	3.72	44.1	69.1
Wrangler	2344	6.10	5.05	2.5	21.7	2509	5.02	3.74	41.3	67.0
Siouxland	3206	6.17	5.10	2.2	18.2	2805	4.84	3.65	38.8	74.6
Tam W-101	2448	6.05	5.02	2.1	19.5	2648	4.94	3.72	43.7	62.9
Tam-107	2283	6.39	5.31	2.5	16.0	1437	4.90	3.70	44.4	68.4
Triumph-64	2021	6.23	5.15	2.1	18.3	1891	4.98	3.66	55.6	79.4
Bounty Exp 2222	2570	6.16	5.07	3.4	23.3	3145	4.95	3.70	45.7	65.8
Quantum XH-551	2370	6.26	5.14	2.5	21.7	2509	5.02	3.82	34.9	63.9
Hybrex-1010	2370	6.07	5.06	4.6	23.1	2431	4.95	3.71	47.1	67.6
Victory	2736	6.17	5.07	4.2	23.1	2378	4.91	3.68	52.4	66.4
Stallion	2788	6.23	5.17	1.5	22.4	2439	5.00	3.74	42.6	59.8
Pioneer-2157	2849	6.35	5.21	5.5	16.1	2840	5.03	3.79	40.1	56.1
Pioneer-2165	2448	6.12	5.06	5.3	20.6	2466	5.07	3.84	29.3	63.3
Pony	2500	6.12	5.01	5.8	23.8	2335	5.14	3.82	22.8	59.1
Garst HR-48	2370	6.34	5.26	4.5	20.9	2587	5.06	3.81	21.6	58.2

LSD (0.05) = 1565, NS, NS, NS, and NS respectively for yield, pH 1:1 H_2O, pH 1:1 M KCl, Al, and Mn.

* Indicates analyses for replications 1 and 4.

neutralize the soil. Even though some neutralization of soil occurred by harvest, it was not manifested in yield.

Soil - pH (1:1 H_2O), pH (1:1 M KCl), Al, Mn

Soil samples were taken 5 months after initiating the study at Lahoma from the limed and unlimed plots and pH (1:1 H_2O) and pH (1:1 M KCl) determined. Soil pH (1:1 H_2O) and soil pH (1:1 M KCl) was significantly higher in limed soils than in unlimed soils (Table 2). However, there were no significant differences in pH (1:1 H_2O) and pH (1:1 M KCl) among plots containing cultivars using pH means obtained from averaging limed and unlimed plots (Table 3). There were no significant interactions in soil pH (Table 4). These same soil samples were analyzed for Al and Mn concentrations. Manganese concentrations were higher in both unlimed and limed soils than Al concentrations. Aluminum concentrations were significantly lower in the limed soils than unlimed soils (Table 2). No significant differences were found in Al concentrations in plots containing cultivars (Table 3), nor were there significant interactions (Table 4). There was no difference in Mn concentration between limed and unlimed soils (Table 2) or among plots containing cultivars (Table 3). Interactions were not significant (Table 4).

Soil samples were taken from Lahoma in 1986 after harvest and analyzed for pH (1:1 H_2O), pH (1:1 M KCl), Al and Mn. Again the limed soils were significantly higher in pH (1:1 H_2O) and pH (1:1 M KCl) than unlimed soils (Table 5). Like the samples taken 5 months after liming, there were no significant differences in mean pH (1:1 H_2O) and mean pH

(1:1 M KCl) in plots containing cultivars obtained from averaging across limed and unlimed plots (Table 6). There were no interactions (Table 7). After harvest there were significant differences in Al concentrations between limed and unlimed soils (Table 5). There were no differences in Al concentrations in plots containing cultivars (Table 6) or interactions (Table 7). Manganese concentration in unlimed soil was significantly higher than in limed soil (Table 5). There were no significant differences in Mn concentrations in plots containing cultivars (Table 6) or interactions (Table 7).

Mangum - Field Experiment

Stand Count and Yield

There were no significant differences between stand counts in limed and unlimed soils at Mangum in 1985 (Table 8) or among mean stand counts of cultivars obtained from limed and unlimed plots (Table 9). There were no significant interactions (Table 10).

Yields were harvested at Mangum in 1986 from the limed and unlimed plots and represent a one year study starting in September, 1985 and ending in June, 1986. There were no significant differences in yield among limed and unlimed plots (Table 11). However, there were significant differences in yield among varieties (Table 12) but there were no significant interactions (Table 13).

Soil - pH (1:1 H_2O), pH (1:1 M KCl), Al, Mn

Soil samples were taken from the limed and unlimed plots 5 months after initiation of the study. There were no significant differences in

Table 8. Main plot stand counts and soil analyses five months after liming at Mangum.

Main Plot	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g
unlimed	21.6	6.04	4.77	5.70	14.00
limed	21.8	6.46	5.32	3.76	12.68
unlimed vs. limed	NS	NS	NS	*	NS

* Significant at the 0.05 probability level

Table 9. Cultivar stand counts and soil analyses* five months after liming at Mangum.

Cultivar	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g
Chisholm	21.6	6.28	5.14	2.90	14.16
Mustang	21.6	6.20	5.07	4.59	13.42
Wrangler	22.8	6.17	4.98	5.79	12.72
Siouxland	21.2	6.18	4.95	4.93	12.49
Tam W-101	22.2	6.17	4.93	5.10	12.59
Tam-107	21.4	6.13	4.87	4.74	13.39
Triumph-64	22.0	6.28	5.03	3.97	12.76
Bounty Exp 2222	22.8	6.26	5.06	5.21	13.70
Quantum XH-551	21.4	6.31	5.10	4.56	12.86
Hybrex-1010	22.1	6.30	5.10	3.57	13.09
Victory	21.6	6.23	5.05	4.08	13.12
Stallion	21.5	6.20	5.02	5.55	14.29
Pioneer-2157	20.8	6.27	5.02	5.45	13.50
Pioneer-2165	21.8	6.29	5.12	5.55	14.19
Pony	21.7	6.27	5.07	3.93	13.34
Garst HR-48	20.1	6.40	5.18	5.08	13.59
Tam-108	22.9	6.30	5.10	5.44	13.59
LSD (0.05)	NS	NS	NS	NS	NS

* Values are an average over main plots

Table 10. The effect of lime on stand counts and soil analyses five months after liming at Mangum.

Cultivars	Limed					Unlimed				
	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn	Stand Count	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	plts/m			ug/g	ug/g	plts/m			ug/g	ug/g
Chisholm	21	6.50	5.46	1.7	13.2	22	6.07	4.82	4.1	15.2
Mustang	22	6.35	5.24	3.9	12.9	21	6.05	4.89	5.2	13.9
Wrangler	22	6.32	5.24	5.5	12.1	23	6.02	4.72	6.1	13.3
Siouxland	22	6.30	5.15	4.5	11.4	21	6.06	4.75	5.4	13.6
Tam W-101	23	6.50	5.26	4.2	11.7	22	5.84	4.60	6.1	13.5
Tam-107	22	6.34	5.13	3.9	13.1	21	5.92	4.61	5.6	13.7
Triumph-64	22	6.46	5.33	3.8	11.7	22	6.10	4.73	4.2	13.8
Bounty Exp 2222	22	6.48	5.31	5.1	12.8	23	6.04	4.81	5.3	14.6
Quantum XH-551	21	6.57	5.43	3.4	12.5	21	6.05	4.78	5.7	13.2
Hybrex-1010	21	6.57	5.44	2.3	12.4	23	6.04	4.76	4.8	13.7
Victory	23	6.47	5.37	3.7	12.8	21	5.98	4.72	4.4	13.4
Stallion	22	6.41	5.31	3.6	13.6	21	5.99	4.74	7.5	15.0
Pioneer-2157	22	6.59	5.34	3.0	12.4	20	5.96	4.70	7.9	14.6
Pioneer-2165	22	6.47	5.38	3.6	13.4	22	6.10	4.85	7.5	15.0
Pony	22	6.49	5.36	3.5	13.0	22	6.05	4.77	4.4	13.6
Garst HR-48	21	6.53	5.35	4.6	13.6	19	6.27	5.00	5.6	13.6
Tam 108	23	6.49	5.31	3.6	12.9	23	6.10	4.90	7.3	14.2

LSD (0.05) = NS, NS, NS, NS, and NS respectively for stand counts, pH 1:1 H_2O, pH 1:1 M KCl, Al, and Mn.

Table 11. Main plot yield and soil analyses after harvest at Mangum.

Main Plot	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g
unlimed	1748.58	6.29	4.88	3.14	14.32
limed	1479.07	6.78	5.62	2.58	9.69
unlimed vs. limed	NS	*	*	*	*

* Significant at the 0.05 probability level

Table 12. Cultivar yield and soil analyses* after harvest at Mangum.

Cultivar	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g
Chisholm	1663.64	6.65	5.42	1.84	11.48
Mustang	1623.39	6.53	5.21	2.23	12.01
Wrangler	1313.72	6.53	5.20	2.01	12.52
Siouxland	1522.04	6.45	5.10	2.78	11.51
Tam W-101	1570.95	6.53	5.23	2.46	12.14
Tam-107	1136.62	6.46	5.16	2.83	12.84
Triumph-64	1392.87	6.50	5.25	2.48	12.16
Bounty Exp 2222	2049.06	6.55	5.30	2.38	12.28
Quantum XH-551	1667.79	6.62	5.40	2.73	11.13
Hybrex-1010	1880.75	6.58	5.30	2.57	12.08
Victory	1713.65	6.51	5.18	2.96	11.74
Stallion	1685.60	6.53	5.25	3.09	12.14
Pioneer-2157	1858.79	6.50	5.20	3.21	11.65
Pioneer-2165	1372.51	6.50	5.22	3.39	12.24
Pony	1602.66	6.59	5.25	4.04	11.74
Garst HR-48	1845.38	6.56	5.30	4.01	11.91
Tam 108	1535.58	6.54	5.30	3.61	12.48
LSD (0.05)	409.24	NS	NS	0.99	NS

* Values are an average over main plots

Table 13. The effect of lime on grain yield and soil analyses after harvest at Mangum.

	Limed					Unlimed				
Cultivars	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn	Yield	pH 1:1 H_2O	pH 1:1 M KCl	Al	Mn
	kg/ha			ug/g	ug/g	kg/ha			ug/g	ug/g
Chisholm	1715	6.88	5.79	1.7	8.9	1612	6.41	5.05	2.0	14.0
Mustang	1669	6.79	5.60	2.2	10.3	1578	6.27	4.81	2.3	13.7
Wrangler	1159	6.81	5.57	2.1	10.2	1468	6.26	4.82	1.9	14.9
Siouxland	1216	6.70	5.50	2.6	10.1	1828	6.20	4.69	2.9	13.0
Tam W-101	1447	6.80	5.62	2.5	10.2	1695	6.26	4.85	2.5	14.1
Tam-107	882	6.77	5.60	2.1	10.4	1392	6.16	4.73	3.6	15.3
Triumph-64	1198	6.68	5.68	2.2	9.7	1588	6.31	4.83	2.8	14.6
Bounty Exp 2222	1769	6.82	5.71	2.3	9.6	2330	6.28	4.89	2.5	15.0
Quantum XH-551	1667	6.95	5.90	2.4	8.1	1669	6.30	4.91	3.0	14.2
Hybrex-1010	1769	6.81	5.61	2.3	9.5	1993	6.34	4.98	2.8	14.6
Victory	1593	6.77	5.51	2.7	10.2	1834	6.25	4.86	3.2	13.3
Stallion	1573	6.76	5.64	3.0	9.6	1798	6.30	4.87	3.2	14.7
Pioneer-2157	1781	6.77	5.61	2.7	8.6	1937	6.24	4.80	3.8	14.7
Pioneer-2165	1074	6.72	5.52	2.9	10.0	1671	6.29	4.91	3.9	14.5
Pony	1529	6.77	5.51	3.7	9.9	1676	6.41	4.99	4.4	13.6
Garst HR-48	1827	6.78	5.61	2.9	9.4	1864	6.35	5.00	5.2	14.4
Tam 108	1278	6.74	5.59	3.7	10.2	1793	6.33	5.01	3.5	14.8

LSD (0.05) = NS, NS, NS, NS, and NS respectively for yield, pH 1:1 H_2O, pH 1:1 M KCl, Al, and Mn.

pH (1:1 H_2O) and pH (1:1 M KCl) between limed and unlimed soils (Table 8) or in plots containing cultivars (Table 9), or interactions (Table 10). Overall, soil Al concentrations were lower at Mangum compared to soil Al concentrations at Lahoma. Soil analysis showed only Al was significantly different between limed and unlimed soils (Table 8). There were no significant differences in soil Al concentrations in plots containing cultivars (Table 9). Also, there were no significant interactions regarding Al concentration (Table 10). There were no significant differences in soil Mn concentrations among limed and unlimed soils (Table 8), in plots containing cultivars (Table 9), or interactions (Table 10).

Soil samples were taken after harvest and pH (1:1 H_2O) and pH (1:1 M KCl) were significantly different between limed and unlimed soils (Table 11). Like soil samples taken 5 months after liming, there were no significant differences in pH (1:1 H_2O) and pH (1:1 M KCl) in plots containing cultivars (Table 12) or interactions (Table 13). Aluminum concentrations in soil after harvest decreased slightly from observed concentrations 5 months after liming. However, there were significant differences in Al concentrations among limed and unlimed soils (Table 11). There were significant differences in yield of cultivars (Table 12), but there were no significant interactions (Table 13). Manganese concentrations were higher than Al concentrations in soil samples taken 5 months after liming and after harvest. Concentrations of manganese after harvest were almost the same between unlimed soils five months after initiation of the study and in unlimed soils after harvest. There were significant differences in Mn concentrations between limed and unlimed soils (Table 11). No significant differences were found in soil Mn concentrations in plots containing cultivars (Table 12) and there were no significant interactions (Table 13).

Because Al and Mn concentrations were much lower at Mangum than Lahoma, only data from Lahoma was used to compute mean variance, single degree of freedom contrasts and differences in Spearmans Coefficient (r_s) and Standard Correlations (r).

Visual Ratings of Cultivar Tolerance to Al

Twenty wheat cultivars were tested for Al tolerance using hematoxylin stain and three concentrations of Al^{3+} (Table 24). Visual ratings were used to evaluate stained roots based on a numerical score starting with 5 for no staining, 10 for partial staining and 15 as complete staining of the root. The roots of all these cultivars developed a common pattern of staining as the Al^{3+} concentration was increased. There were significant differences in staining among cultivars. Also, there were significant differences in staining among the three Al^{3+} concentrations used. Finally, there were significant cultivars x Al^{3+} concentration interactions on staining.

Four distinct groups of cultivars were identified by the hematoxylin staining method at the 0.18 mmol/L Al^{3+} concentrations (Table 24). Group 1, which included 'Mustang', 'Garst HR48', 'Wrangler', 'Fronteira', 'Atlas 66', and 'McNair 1003' was shown to be the most tolerant to low concentrations of Al. Group 2 included 'Triumph 64', 'Tam W-101', 'Chisholm', and 'Bounty Hybrid 122' and was

Table 14. Visual ratings of cultivar tolerance to Al^{3+} concentrations using hematoxylin dye.

Wheat Cultivars	Al Concentration* (mmol/L)		
	0.18	0.36	0.72
	rating index		
Mustang	5	9	14
Arthur 71	12	15	15
Triumph 64	9	14	15
Garst HR48	5	9	14
Pioneer 2165	11	13	15
Siouxland	11	14	15
Stallion	14	15	15
Pony	14	15	15
Wrangler	5	6	13
Fronteira (CI 12019)	5	5	6
Tam W-101	8	13	15
Atlas 66	5	5	8
Victory	14	15	15
McNair 1003	5	9	14
Quantum XH-551	11	14	15
Chisholm	9	13	15
Pioneer 2157	10	14	15
Tam 107	14	14	15
Hybrex 1010	10	13	15
Bounty Hybrid 122	7	11	14

LSD (0.05) = 1.98 for comparison of cultivars.
LSD (0.05) = 0.77 for comparison of Al concentrations.
LSD (0.05) = 3.43 for comparison of cultivars vs. Al concentrations.
*Root staining ratings based on 5-15 visual scale where 5 = no staining, 10 = partial staining, and 15 = complete staining of the root.

shown to be tolerant to low concentrations of Al. 'Arthur 71', 'Pioneer 2165', 'Siouxland', 'Quantum XH-551', 'Pioneer 2157', and 'Hybrix 1010' make up Group 3 as being semi-tolerant to low concentrations of Al. Finally, Group 4 is comprised of 'Stallion', 'Pony', 'Victory', and 'Tam 107' and are ranked as the least tolerant to low concentrations of Al.

Four distinct groups of cultivars were also identified at the 0.36 mmol/L Al^{3+} concentration level also (Table 24). Group 1 consists of 'Wrangler', 'Fronteira' and 'Atlas 66' as being the most tolerant to medium concentrations of Al. 'Mustang', 'Garst HR48' and 'McNair 1003' make up Group 2 and are tolerant to medium concentrations of Al. Group 3 only consists of 'Bounty Hybrid 122' as being semi-tolerant to medium concentrations of Al. Group 4, which includes 'Arthur 71', 'Triumph 64', 'Pioneer 2165', 'Siouxland', 'Stallion', 'Pony', 'Tam W-101', 'Victory', 'Quantum XH-551', 'Chisholm', 'Pioneer 2157', 'Tam 107', and 'Hybrix 1010' was shown to be the least tolerant to medium concentrations of Al.

Finally, three distinct groups of cultivars were identified at the 0.72 mmol/L Al^{3+} concentration level (Table 24). 'Fronteira' was the only variety that made up Group 1 and was the most tolerant to high Al^{3+} concentrations. In Group 2, 'Atlas 66' was the only variety found to be tolerant to high concentrations of Al. Finally in Group 3, 'Mustang', 'Arthur 71', 'Triumph 64', 'Garst HR48', 'Pioneer 2165', 'Siouxland', 'Stallion', 'Pony', 'Wrangler', 'Tam W-101', 'Victory', 'McNair 1003', 'Quantum XH-551', 'Chisholm', 'Pioneer 2157', 'Tam 107', 'Hybrix 1010', and 'Bounty Hybrid 122' all were shown to be the least tolerant to high Al concentrations.

'Frontiera' is Al tolerant at all the concentrations used as indicated by lack of linearity in increased staining with increased Al^{3+} concentrations (Table 25). There were no quadratic effects in staining of cultivars with increasing Al^{3+} concentrations. Many of the cultivars used in the laboratory experiment showed a lack of linearity (Table 25), indicating that for these cultivars increasing Al^{3+} concentrations had no effect on staining. The cultivars that showed some degree of staining linearity ($P = 0.05$) to the increasing Al^{3+} concentrations were 'Mustang', 'Garst HR-48', 'Wrangler', and 'McNair'. 'Tam W-101' and 'Bounty Exp 2222' showed a linear effect ($P = 0.10$) with increasing Al^{3+} concentrations also (Table 25).

Mean Variance from Data Collected at Lahoma

Data from Lahoma and the lab study using hematoxylin were used to calculate mean variance (14). Because lime had been applied before on the land used at Lahoma, only two replications were used.

It was important to better understand factors affecting the mean variance used in this experiment for more precision in the area of sampling for future experiments. Laboratory experiments using hematoxylin stain (Table 14) showed that the mean variance was reduced more by increasing replications than with increasing subsamples. For example, when two replications were used with one subsample, the mean variance was reduced by 50% compared to only one replication with one

Table 15. Single degree of freedom contrasts of effects of Al on cultivars.

Cultivar	F Value	Cultivar	F Value
1. Mustang		11. TAM W-101	
Linear	5.28***	Linear	3.19*
Quad	0.02	Quad	0.20
>2. Arthur-71		>12. Atlas-66	
Linear	0.58	Linear	0.58
Quad	0.20	Quad	0.20
3. Triumph-64		13. Victory	
Linear	2.35	Linear	0.07
Quad	0.35	Quad	0.02
4. Garst HR48		>14. McNair	
Linear	5.38***	Linear	5.28***
Quad	0.02	Quad	0.02
5. Pioneer-2165		15. Quantum XH-551	
Linear	1.04	Linear	1.04
Quad	0.09	Quad	0.09
6. Siouxland		16. Chisholm	
Linear	1.04	Linear	2.35
Quad	0.09	Quad	0.09
7. Stallion		17. Pioneer-2157	
Linear	0.07	Linear	1.63
Quad	0.02	Quad	0.02
8. Pony		18. TAM-107	
Linear	0.07	Linear	0.07
Quad	0.02	Quad	0.02
9. Wrangler		19. Hybrex-1010	
Linear	4.17**	Linear	1.63
Quad	0.78	Quad	0.02
>10. Fronteira (CI 12019)		20. Bounty Hybrid 122	
Linear	0.07	Linear	3.19*
Quad	0.02	Quad	0.02

*, **, *** Significant at the 0.10, 0.05, and 0.025 probability levels, respectively.

> Used as checks in laboratory.

subsample. Also, when replications were increased to three and the subsamples were held constant at three, the mean variance was decreased by 67%. But, when replications were held constant at three and subsamples were increased to four, the mean variance was reduced only by 34%.

The effect of increasing subsamples on the mean variance of stand counts taken five months after liming was studied and is shown in Table 15. There was evidence that the mean variance was reduced more by increasing replications than with increasing subsamples. In this experiment, four replications were used with five subsamples. This shows the mean variance was reduced 73% by increasing subsamples. But, the mean variance could have been reduced by 50% by using four replications and one subsample or it could have been reduced by 67% if six replications with only one subsample were used.

The effect of increasing subsamples on the mean variance of pH (1:1 M KCl) and pH (1:1 H_2O) in soil samples taken five months after liming (Tables 16 and 17) shows that the mean variance was reduced by increasing replications, but not with increasing subsamples. The mean variance was reduced by 50% when replications were increased to two and subsamples were held constant at one. But, if the replications were increased to five and subsamples held constant at one, the mean variance would be reduced by 80%. This shows a reduction in mean variance by 30% just by increasing replications from two to five and keeping subsamples at one.

Looking at the effect of increasing subsamples on the mean variance of Al (Table 18) and Mn (Table 19) in soil samples taken five

Table 16. The effect of increasing subsamples and replications on the mean variance of scores from hematoxylin staining for Al.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	3.9800	1.9900	1.3267	0.9950	0.7960
2	3.0685	1.5343	1.0228	0.7671	0.6137
3	2.7647	1.3823	0.9216	0.6912	0.5529
4	2.6128	1.3064	0.8709	0.6532	0.5226
5	2.5216	1.2608	0.8405	0.6304	0.5043

Table 17. The effect of increasing subsamples and replications on the mean variance of stand counts taken five months after liming.

	Number of Replications		
Number of Subsamples	2	4	6
1	10.2297	5.1149	3.4099
2	5.5662	2.7831	1.8554
3	4.0117	2.0059	1.3372
4	3.2345	1.6172	1.0782
5	2.7681	1.3841	0.9227

Table 18. The effect of increasing subsamples and replications on the mean variance of pH (1:1 M KCl) in soil samples taken five months after liming.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	0.0202	0.0101	0.0067	0.0051	0.0041
2	0.0201	0.0100	0.0067	0.0050	0.0040
3	0.0200	0.0100	0.0067	0.0050	0.0040
4	0.0200	0.0010	0.0067	0.0050	0.0040
5	0.0200	0.0010	0.0067	0.0050	0.0040

Table 19. The effect of increasing subsamples and replications on the mean variance of pH (1:1 H_2O) in soil samples taken five months after liming.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	0.0272	0.0136	0.0091	0.0068	0.0054
2	0.0264	0.0132	0.0088	0.0066	0.0053
3	0.0261	0.0131	0.0087	0.0065	0.0053
4	0.0260	0.0130	0.0087	0.0065	0.0052
5	0.0259	0.0130	0.0086	0.0065	0.0052

Table 20. The effect of increasing subsamples and replications on the mean variance of Al in soil samples taken five months after liming.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	33.0521	16.5261	11.0174	8.2630	6.6104
2	29.9546	14.9773	9.9849	7.4887	5.9909
3	28.9221	14.4611	9.6407	7.2305	5.7844
4	28.4059	14.2029	9.4686	7.1015	5.6812
5	28.0961	14.0481	9.3654	7.0240	5.6192

Table 21. The effect of increasing subsamples and replications on the mean variance of Mn in soil samples taken five months after liming.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	64.2391	32.1196	21.4130	16.0598	12.8478
2	45.3896	22.6948	15.1299	11.3474	9.0779
3	39.1064	19.5532	13.0355	9.7766	7.8213
4	35.9649	17.9824	11.9883	8.9912	7.1930
5	34.0799	17.0400	11.3600	8.5200	6.8160

months after liming, the mean variance was reduced at a higher percentage when the replications were increased. In the Al samples when one replication was used with two subsamples the mean variance was reduced by 0.09%, but when the replications were increased to two and the subsamples dropped to one the mean variance was reduced by 50%. In the Mn samples the mean variance was reduced by 39% when replications were held constant at three and subsamples were increased to three, but instead the mean variance of the Mn samples was reduced by 67% when the replications were increased to three and subsamples were constant at three. A 28% reduction in the mean variance was achieved by increasing the replications and keeping subsamples constant.

The mean variances of soil pH (1:1 M KCl) and pH (1:1 H_2O) taken after harvest were affected to a greater extent by increasing replications than by increasing subsamples (Table 20 and 21). When replications were increased and subsamples were held constant, the reduction in mean variance increased. In pH (1:1 M KCl) when two replications were used with one subsample, the reduction was 50% and increased to 80% when replications were increased to five and subsamples were held constant at one.

The mean variance of soil samples taken after harvest testing for Al (Table 22) and Mn (Table 23) showed a greater reduction by increasing replications. The variance was reduced by 80% when replications were increased to five and subsamples stayed constant at one.

In all cases previously described the mean variance was reduced by greater percentages when increasing replications rather than increasing subsamples.

Table 22. The effect of increasing subsamples and replications on the mean variance of pH (1:1 M KCl) in soil samples taken after harvest.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	0.0127	0.0064	0.0042	0.0032	0.0025
2	0.0126	0.0063	0.0042	0.0031	0.0025
3	0.0125	0.0063	0.0042	0.0031	0.0025
4	0.0125	0.0062	0.0042	0.0031	0.0025
5	0.0125	0.0062	0.0042	0.0031	0.0025

Table 23. The effect of increasing subsamples and replications on the mean variance of pH (1:1 H_2O) in soil samples taken five months after harvest.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	0.0190	0.0095	0.0063	0.0047	0.0038
2	0.0374	0.0093	0.0062	0.0047	0.0037
3	0.0186	0.0093	0.0062	0.0047	0.0037
4	0.0185	0.0093	0.0062	0.0046	0.0037
5	0.0185	0.0093	0.0062	0.0046	0.0037

Table 24. The effect of increasing subsamples and replications on the mean variance of Al in soil samples taken after harvest.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	72.8015	36.4008	24.2673	18.2005	14.5604
2	65.8405	32.9205	21.9468	16.4603	13.1682
3	63.5202	31.7603	21.1736	15.8802	12.7041
4	62.3605	31.1803	20.7868	15.5901	12.4721
5	61.6644	30.8322	20.5548	15.4161	12.3329

Table 25. The effect of increasing subsamples and replications on the mean variance of Mn in soil samples taken after harvest.

	Number of Replications				
Number of Subsamples	1	2	3	4	5
1	39.6595	19.8298	13.2198	9.9149	7.9319
2	33.1010	16.5505	11.0337	8.2753	6.6202
3	30.9148	15.4574	10.3049	7.7287	6.1830
4	29.8218	14.9109	9.9406	7.4554	5.9644
5	29.1659	14.5830	9.7220	7.2915	5.8332

Differences in Spearmans Coefficient (r_s) and Standard Correlation (r)

Spearmans Coefficient of rank correlation (r_s) applies to data in the form of ranks and measures correspondence between ranks (26). The data may be collected as ranks or may be ranked after observation on some other scale. Standard correlation (r) is a measure of the degree to which variables vary together or a measure of the intensity of association. It is independent of the units of measurement and is an absolute or dimensionless quantity. Overall, comparing limed plots with unlimed plots, the correlation coefficient for staining and yield is greater in the limed plots with one exception when Spearmans Coefficient is used (Table 26).

Lab and field data had a correlation in stand count when Spearmans Coefficient (r_s) was used at Al concentrations of 0.36 and 0.72 for limed plots and limed and unlimed plots and for the difference (Limed - Unlimed) only for Al concentrations at 0.72.

In limed and unlimed plots there was no correlation improvement in yield except for concentrations of 0.36 and 0.72 using Spearmans Coefficient (r_s), but in the difference (limed - unlimed) the yield correlation coefficient improved when using Spearmans Coefficient.

Overall the use of Spearmans Coefficient showed an improvement in the correlation coefficient and may be beneficial to use.

Table 26. Differences in Spearmans Coefficient of rank correlation (r_s) and Standard Correlation Coefficient (r) between visual detection, stand count, and yield.

	Al Concentrations							
	0.18		0.36 mmol/L		0.72		Total	
	r	r_s	r	r_s	r	r_s	r	r_s
Limed								
Stand Count p/m	-0.08	-0.11	-0.12	0.03	-0.16	0.09	-0.11	-0.07
Yield kg/ha	0.25	0.36	0.21	0.41	0.12	0.33	0.23	0.42
Unlimed								
Stand Count p/m	-0.02	-0.06	-0.07	-0.04	-0.09	-0.10	-0.05	-0.05
Yield kg/ha	-0.44	-0.51	-0.29	-0.43	-0.31	-0.13	-0.38	-0.47
Limed and Unlimed								
Stand Count p/m	-0.05	-0.07	-0.10	0.02	-0.12	0.10	-0.08	-0.03
Yield kg/ha	-0.11	-0.08	-0.05	0.03	-0.10	0.05	-0.09	-0.00
Difference (Limed-Unlimed)								
Stand Count p/m	-0.08	-0.21	-0.06	-0.13	-0.08	0.05	-0.08	-0.23
Yield kg/ha	0.61	0.60	0.44	0.55	0.38	0.52	0.54	0.60

CHAPTER V

SUMMARY AND CONCLUSIONS

Lime applications increased pH (1:1 H_2O), pH (1:1 M KCl), and decreased Al concentrations, but had no effect on stand count and Mn concentrations in main plot means five months after liming at the North Central Research Station at Lahoma, Oklahoma. Lime applications caused significant differences in stand counts among cultivars, but no significant differences were found in pH (1:1 H_2O), pH (1:1 M KCl), Al, and Mn in soil analyses for plots containing cultivars using means obtained from limed and unlimed plots five months after liming. Also, there were no interaction effects on stand count, pH (1:1 H_2O), pH (1:1 M KCl), Al, and Mn five months after liming.

Analytical results of soil samples taken after harvest showed lime significantly increased pH (1:1 H_2O), pH (1:1 M KCl), and decreased Mn, but had no effect on yield. However, there were significant differences in yield among cultivars. There were no interaction effects.

Lime application decreased Al, but had no effect on stand count, pH (1:1 H_2O), pH (1:1 M KCl), and Mn in main plot means five months after liming at the Sandy Land Research Station at Mangum, Oklahoma. Lime application had no effect among cultivars on stand count, pH (1:1 H_2O), pH (1:1 M KCl), Al, and Mn in means for cultivars obtained from averages across limed and unlimed plots five months after liming at Mangum.

Also, no significant interactions were found in stand count, pH (1:1 H_2O), pH (1:1 M KCl), Al, and Mn five months after liming.

Lime applications increased pH (1:1 H_2O), pH (1:1 M KCl), and decreased Al, and Mn, but had no effect on yield in main plot means after harvest at Mangum. Lime application showed significant differences among cultivars in yield and Al concentrations in soils, but had no effect on pH (1:1 H_2O), pH (1:1 M KCl), and Mn in plots containing cultivars at Mangum. There were no interaction effects on yield, pH (1:1 H_2O), pH (1:1 M KCl), Al, and Mn after harvest at Mangum.

The lab study using twenty wheat cultivars testing for Al tolerance using hematoxylin stain and increasing concentrations of Al^{3+} showed significant differences among cultivars, among the three Al^{3+} concentrations and among cultivar x Al^{3+} concentration interactions. The cultivars showing some degree of staining linearity to the increasing Al^{3+} concentrations include: Mustang, Garst HR-48, Wrangler, Tam W-101, McNair, and Bounty Hybrid 122.

Differences in Spearmans Coefficient (r_s) and Standard Correlation (r) showed overall the use of Spearmans Coefficient (r_s) showed an improvement in the correlation coefficient.

The data from Lahoma and the lab study using hematoxylin used to calculate mean variance showed that the mean variance was reduced by greater percentages when replications were increased rather than increasing subsamples.

In conclusion, the results of this study show that liming increases the pH of the soil and decreases Al and Mn concentrations. There were no responses in stand count or yield due to lime. But, this is a one year study and this information will be of importance after the lime has had more time to react in the soil.

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Appendix

Table I. Analysis of variance of the effect of lime on stand counts five months after application at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replication	1	1197.456	1197.456	
Treatment	1	17.588	17.588	1.12
Main plot error (a)	1	15.744	15.744	
Cultivar	15	2908.570	193.905	7.01*
Treatment x Cultivar	15	228.995	15.266	0.55
Subplot error (b)	30	830.424	27.681	
Sampling error	256	4775.352	18.654	
Total	319	9974.129		

* Significant at 0.05 probability level

Table II. Analysis of variance of the effect of lime on pH (1:1 H_2O) five months after application at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	0.586	0.586	
Treatment	1	37.736	37.736	54.90
Main plot error (a)	1	0.687	0.687	
Cultivar	15	0.757	.050	0.96
Treatment x Cultivar	15	1.386	0.092	1.75
Subplot error (b)	30	1.581	0.053	
Sampling error	64	0.102	.002	
Total	127	42.835		

Table III. Analysis of variance of the effect of lime on pH (1:1 M KCl) five months after application at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	0.046	0.046	
Treatment	1	41.473	41.473	136.34
Main plot error (a)	1	0.304	0.304	
Cultivar	15	1.052	0.070	1.75
Treatment x Cultivar	15	1.059	0.071	1.76
Subplot error (b)	30	1.203	0.040	
Sampling error	64	0.021	0.0003	
Total	127	45.159		

Table IV. Analysis of variance of the effect of lime on Al concentration in soil five months after application at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	526.501	526.501	
Treatment	1	41162.978	41162.978	988.71*
Main plot error (a)	1	41.633	41.633	
Cultivar	15	1260.016	84.001	1.40
Treatment x Cultivar	15	1462.790	97.519	1.63
Subplot error (b)	30	1797.261	59.909	
Sampling error	64	396.470	6.195	
Total	127	46647.649		

* Significant at 0.05 probability level

Table V. Analysis of variance of the effect of lime on Mn concentration in soil five months after application at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	13392.707	13392.707	
Treatment	1	25535.175	25535.175	97.28
Main plot error (a)	1	262.491	262.491	
Cultivar	15	772.255	51.484	0.57
Treatment x Cultivar	15	1957.804	130.520	1.44
Subplot error (b)	30	2723.374	90.779	
Sampling error	64	2412.715	37.699	
Total	127	47056.521		

Table VI. Analysis of variance of the effect of lime on yield after harvest at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	308458.052	308458.052	
Treatment	1	1712.470	1712.470	<0.01
Main plot error (a)	1	407240.528	407240.528	
Cultivar	15	5348442.042	356562.803	7.47*
Treatment x Cultivar	15	1890979.497	126065.300	2.64*
Error (b)	30	1432696.929	47756.564	
Total	63	0.0000094		

* Significant at 0.05 probability level

Table VII. Analysis of variance of the effect of lime on pH (1:1 H_2O) after harvest at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	0.315	0.315	
Treatment	1	46.815	46.815	244.56*
Main plot error (a)	1	0.191	0.191	
Cultivar	15	0.460	0.031	0.82
Treatment x Cultivar	15	0.467	0.031	0.83
Subplot error (b)	30	1.123	0.037	
Sampling error	64	0.036	0.0006	
Total	127	49.407		

* Significant at 0.05 probability level

Table VIII. Analysis of variance of the effect of lime on pH (1:1 M KCl) after harvest at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	0.00005	0.00005	
Treatment	1	61.245	61.245	1921.22*
Main plot error (a)	1	0.032	0.032	
Cultivar	15	0.332	0.022	0.88
Treatment x Cultivar	15	0.309	0.021	0.82
Subplot error (b)	30	0.751	0.025	
Sampling error	64	0.02	0.0003	
Total	127	62.689		

* Significant at 0.05 probability level

Table IX. Analysis of variance of the effect of lime on Al concentration in soil after harvest at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	160.272	160.272	
Treatment	1	44294.413	44294.413	254.39*
Main plot error (a)	1	174.121	174.121	
Cultivar	15	2289.806	152.654	1.16
Treatment x Cultivar	15	3109.800	207.320	1.57
Subplot error (b)	30	3950.471	131.682	
Sampling error	64	891.037	13.922	
Total	127	54869.920		

* Significant at 0.05 probability level

Table X. Analysis of variance of the effect of lime on Mn concentration in soil after harvest at Lahoma.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	1	22.386	22.386	
Treatment	1	64240.065	64240.065	256.60*
Main plot error (a)	1	250.348	250.348	
Cultivar	15	1151.521	76.768	1.16
Treatment x Cultivar	15	1423.223	94.882	1.43
Subplot error (b)	30	1986.053	66.202	
Sampling error	64	839.512	13.117	
Total	127	69913.108		

* Significant 0.05 probability level

Table XI. Analysis of variance of the effect of lime on stand counts five months after application at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	338.134	112.711	
Treatment	1	6.213	6.213	0.10
Main plot error (a)	3	181.734	60.578	
Cultivar	16	329.103	20.569	1.23
Treatment x Cultivar	16	210.562	13.160	0.79
Subplot error (b)	96	1600.782	16.675	
Sampling error	544	6494.400	11.938	
Total	679	9160.928		

Table XII. Analysis of variance of the effect of lime on pH (1:1 H_2O) five months after application at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	3.700	1.233	
Treatment	1	12.198	12.198	42.96*
Main plot error (a)	3	0.852	0.284	
Cultivar	16	1.162	0.073	0.77
Treatment x Cultivar	16	0.914	0.057	0.60
Subplot error (b)	96	9.066	0.094	
Sampling error	136	0.269	0.002	
Total	271	28.161		

* Significance at 0.05 probability level

Table XIII. Analysis of variance of the effect of lime on pH (1:1 M KCl) five months after application at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	4.525	1.508	
Treatment	1	20.143	20.143	30.78*
Main plot error (a)	3	1.963	0.654	
Cultivar	16	1.630	0.102	0.76
Treatment x Cultivar	16	0.798	0.050	0.37
Subplot error (b)	96	12.828	0.134	
Sampling error	136	0.466	0.003	
Total	271	42.353		

* Significance at 0.05 probability level

Table XIV. Analysis of variance of the effect of lime on Al concentration in soil five months after application at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	63.477	21.159	
Treatment	1	255.188	255.188	13.48*
Main plot error (a)	3	56.807	18.936	
Cultivar	16	166.362	10.398	1.31
Treatment x Cultivar	16	134.118	8.382	1.06
Subplot error (b)	96	761.557	7.933	
Sampling error	136	527.770	3.881	
Total	271	1965.280		

* Significance at 0.05 probability level

Table XV. Analysis of variance of the effect of lime on Mn concentration in soil five months after application at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	234.427	78.142	
Treatment	1	119.780	119.780	5.16
Main plot error (a)	3	69.587	23.196	
Cultivar	16	78.736	4.921	0.87
Treatment x Cultivar	16	28.287	1.768	0.31
Subplot error (b)	96	541.175	5.637	
Sampling error	136	140.125	1.030	
Total	271	1212.117		

Table XVI. Analysis of variance of the effect of lime on yield after harvest at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	1341736.171	447245.390	
Treatment	1	2469542.718	2469542.718	1.50
Main plot error (a)	3	4925464.891	1641821.630	
Cultivar	16	6690077.283	418129.830	2.46*
Treatment x Cultivar	16	1741772.809	108860.801	0.64
Error	96	0.00000016	169980.187	
Total	135	0.0000003		

* Significant at 0.05 probability level

Table XVII. Analysis of variance of the effect of lime on pH (1:1 H_2O) after harvest at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	1.211	0.404	
Treatment	1	16.484	16.484	162.95*
Main plot error (a)	3	0.304	0.101	
Cultivar	16	0.688	0.043	0.75
Treatment x Cultivar	16	0.393	0.025	0.43
Subplot error (b)	96	5.524	0.058	
Sampling error	136	0.126	0.0009	
Total	271	24.729		

* Significance at 0.05 probability level

Table XVIII. Analysis of variance of the effect of lime on pH (1:1 M KCl) after harvest at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	3.050	1.017	
Treatment	1	37.340	37.340	131.39*
Main plot error (a)	3	0.853	0.284	
Cultivar	16	1.695	0.106	0.70
Treatment x Cultivar	16	0.956	0.050	0.40
Subplot error (b)	96	14.449	0.151	
Sampling error	136	0.777	0.006	
Total	271	59.119		

* Significance at 0.05 probability level

Table XIX. Analysis of variance of the effect of lime on Al after harvest at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	59.561	19.854	
Treatment	1	21.012	21.012	0.33
Main plot error (a)	3	193.481	64.494	
Cultivar	16	104.532	6.533	3.30*
Treatment x Cultivar	16	26.069	1.629	0.82
Subplot error (b)	96	190.025	1.979	
Sampling error	136	48.450	0.356	
Total	271	643.131		

* Significance at 0.05 probability level

Table XX. Analysis of variance of the effect of lime on Mn after harvest at Mangum.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F Ratio
Replications	3	339.595	113.198	
Treatment	1	1438.265	1458.265	53.18*
Main plot error (a)	3	82.270	27.423	
Cultivar	16	47.124	2.945	0.63
Treatment x Cultivar	16	55.860	3.491	0.75
Subplot error (b)	96	445.496	4.641	
Sampling error	136	48.450	0.356	
Total	271	2477.059		

* Significant at 0.05 probability level

VITA 2

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