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EFFECT OF CHLORIDE FERTILIZERS AND LIME ON WHEAT GRAIN YIELD AND TAKE-ALL DISEASE*

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ABSTRACT

One experiment was initiated in the fall of 1991 to evaluate the effect of chloride (Cl) fertilizers on the suppression of take-all disease (*Gaeumannomyces graminis* var. *tritici* Walker) in winter wheat (*Triticum aestivum* L.). Preplant and topdress rates of potassium chloride (KCl) and calcium chloride ($CaCl_2$) (0, 34, 67 and 101 kg Cl ha^{-1}) were applied each year. In 1995, plots were split in half whereby one half received 2.24 Mg of 76% ECCE lime ha^{-1} to elevate the pH and potentially increase disease incidence. Wheat grain yield was not affected by lime applications in any year (1995–1999). Plots exhibited visual symptoms of take-all in almost all years, however, grain yields increased in only two of eight years by the application of $CaCl_2$ and KCl. Applied fertilizer Cl for take-all disease suppression

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was inconsistent, even following the application of lime where increased soil pH can increase disease severity.

INTRODUCTION

Take-all (*Gaeumannomyces graminis* var. *tritici* Walker) is a soil-borne fungal pathogen of wheat, often found in conjunction with other root diseases. Few control measures other than crop rotation are available. Take-all is generally more severe where wheat is grown continuously, with little evidence of take-all in years immediately following rotation from a non-host crop (1).

Over the past 50 years, much has been published reporting effects of various fertilizers and soil amendments on crop response to diseases. Garrett (2) reported on some of the first work to demonstrate disease suppression with NH_4-N. Complementary work showed that the nitrification inhibitor nitropyrin improved suppression of take-all when applied with NH_4-N fertilizers (3, 4). Inhibition of nitrification makes fall application of anhydrous ammonia and other NH_4-N fertilizers more feasible for winter wheat production, thus allowing greater flexibility in seeding dates needed for disease control (3). These same authors noted that delayed seeding and adequate nitrogen (N) fertilization are recommended to reduce the severity of take-all, thus the use of nitropyrin (applied with NH_4-N fertilizers) may allow for earlier plantings without increasing the severity of take-all. Furthermore, periods of N stress are known to predispose wheat to take-all, which can in part be alleviated by an adequate supply of N, and/or split N applications (3).

Recent work at Indiana has shown that supplying NH_4-N increases the availability of soil manganese (Mn), which decreases take-all severity (4). Huber and McCay-Buis (5) noted that take-all is severe on soils characteristically low in Mn, and that direct Mn amendment of these soils has been demonstrated to reduce take-all. In this regard, it is important to note that liming an acid soil can reduce Mn availability and increase the severity of take-all (5). Under moderately-severe disease conditions, plants with higher Mn in the seed were more vigorous, and had an average of 11% less take-all (6).

Research results indicate that take-all depresses wheat grain yields when wet and mild fall-winter periods are encountered in winter wheat production systems (R.H. Hunger, 2000, Oklahoma State University, personal communication). This is consistent with work by Engel (7) noting that take-all was commonly observed when wheat was grown under irrigation in Montana and Canada. While the growing conditions are well known concerning where take-all is likely to be encountered, so too are some of the controls, which include crop rotations. Unfortunately, crop rotations are not implemented nor are they popular due to market and equipment constraints. From a farmer survey, Folwell et al. (8)

reported that take-all occurs regardless of the tillage system, however, some farmers indicated that it was more severe with no-till. Coventry et al. (9) demonstrated the importance of crop rotation for disease control (take-all), particularly where soils are limed to amend severe soil acidity.

Application of lime to increase soil pH can favor increased incidence of take-all infection, and as soil pH increases above 4, take-all infection increases substantially (10). Analogous results by Taylor et al. (11) showed reduced grain yield when soil pH increased from 5.6 to 6.2, a result of increased incidence of take-all.

Addition of ammonium chloride fertilizer increased yields 10 to 40 percent over plots with no Cl applied (12). Chloride has been found to slow the disappearance of NH_4-N and appearance of NO_3-N in unlimed soil but not in limed soil (10). This same work noted that NH_4-N:NO_3-N ratio's needed to be greater than 3:1 in order to observe suppression of take-all. Also, it is thought that applied Cl may suppress take-all by inhibiting nitrification in moderately acid (pH 5.3 to 5.8) soils (10). Powelson et al. (1) suggest that this inhibition takes place by Cl^- competing with nitrate (NO_3^-) for plant uptake and by reducing nitrification rates thus leaving more N in the ammonia form. Powelson et al. (1) further note that Cl can enhance plant uptake of NH_4-N which favors the activity of epiphytic bacteria suppressive to G. *Graminis* var. *tritici*. It is suggested that this effect is similar to natural take-all decline and may enhance or encourage this activity. Engel (7) evaluated applied Cl ($45\,kg\,Cl\,ha^{-1}$) on an alkaline soil (pH 7.9) and found that Cl had little effect on take-all severity, but did increase wheat grain yields. Work by LaRuffa et al. (13) noted a significant response to Cl at one location where grain yields were low as a result of N stress (soil pH = 5.9). As was noted earlier, N stress can lead to increased take-all in wheat (3). Brennan (14) reported that Cl containing fertilizers did not control take-all disease of wheat in five experiments in southwestern Australia (soil pH range: 4.7–5.5), however, it should be noted that this was observed where no N stress was present.

Christensen et al. (12) noted that applied Cl reduced the osmotic potential in winter wheat leaves. They further suggested that take-all susceptibility in winter wheat could be reduced by lowering the chemical potential of water in the plant, achieved in part via Cl application. At present, in the Pacific Northwest and in North and South Dakota, researchers generally recommend application of Cl fertilizers to reduce take-all severity (15).

The objective of this experiment was to evaluate Cl fertilizer sources and rates, and applied lime on wheat grain yield and take-all disease in winter wheat.

MATERIALS AND METHODS

One field experiment was initiated in the fall of 1991 to evaluate the effects of Cl fertilizer sources and rates on wheat grain yield and take-all

Table 1. Rate of Applied Chloride, Source, and Method of Application for Take-All Suppression, 1991–1999, Carrier, OK (Plots Split in the Fall of 1995, Half Receiving 2.24 Mg 76% ECCE Lime/ha)

Cl rate kg/ha	Source	Method
0	–	–
34	$CaCl_2$	preplant
67	$CaCl_2$	preplant
101	$CaCl_2$	preplant
101	$CaCl_2$	topdress
34	KCl	preplant
67	KCl	preplant
101	KCl	preplant
101	KCl	topdress

disease in winter wheat at the Ray Nelson farm near Carrier, OK. A randomized complete block experimental design was used with 4 replications. The treatment structure evaluated at this site is reported in Table 1. The wheat variety planted, planting date, topdress date and harvest date for all years are reported in Table 2. Initial soil test results at the time of trial initiation in 1991 are reported in Table 3. Chloride fertilizer rates of 34, 67, and 101 kg Cl ha^{-1} using KCl (0-0-62) and $CaCl_2$ were broadcast preplant and a topdress rate of 101 kg Cl ha^{-1} was also included for both sources. Two completely untreated check plots were included in the experimental design. Annual applications of anhydrous ammonia (AA) have traditionally been used as a management practice, and 90 kg N ha^{-1} as AA was applied in the fall of

Table 2. Planting and Harvest Dates, and Varieties Used, Carrier, OK, 1991–1999

Year	Variety	Fertilizer Application Date	Planting Date	Topdress Date	Harvest Date
1992	2163	October 10, 1991	11-13-91	2-22-92	6-24-92
1993	2163	September 29, 1992	10-12-92	3-9-93	6-24-93
1994	2163	October 16, 1993	late-October	3-17-94	6-13-94
1995	2163	October 16, 1994*	late-October	3-6-95	6-21-95
1996	Jagger	September 4, 1995	mid-October	4-1-96	6-21-96
1997	Custer	September 4, 1996	mid-October	4-1-97	6-21-97
1998	Custer	September 18, 1997	mid-October	2-19-98	6-11-98
1999	2174	September 20, 1998	mid-October	2-2-99	6-16-99

*Plots split in the fall of 1995, half receiving 2.24 Mg ECCE lime ha^{-1}.

Table 3. Initial Surface Soil (0–15 cm) Chemical Characteristics and Classification at Carrier, OK (1991)

		mg kg^{-1}				g kg^{-1}		
Location	pH[a]	NH_4-N	NO_3-N	P[b]	K[b]	Total N	Organic C	Cl[d]
Carrier	6.0	7.4	33	64	470	0.90	8.8	27
Classification: Pond Creek silt loam (fine-silty, mixed, superactive, thermic Pachic Argiustoll)								

[a]pH: 1:1 soil:water.
[b]P and K: Mehlich III.
[c]Organic C and Total N: dry combustion.
[d]Cl determined using Fixen et al. (1988).

each year to all plots. Plots were planted with a conventional grain drill at an 84 kg ha^{-1} seeding rate using a 21 cm row spacing. Twenty-two kg ha^{-1} of P_2O_5 using diammonium phosphate (DAP, 18-46-0) was banded with the seed at planting. Plot size was 4.88 m × 15.24 m. In 1995, plots were split in half and 2.24 Mg lime ha^{-1} (76% ECCE) was applied to the east half of each plot. Wheat grain was harvested from a strip 2 m wide in the center of each plot using a self-propelled conventional combine in June of each year. Following the completion of the experiment, sixteen soil cores 0–15 cm were taken from each plot, air dried, mixed, ground to pass a 100-mesh sieve ($<$ 0.15 mm), and analyzed for pH, NH_4-N, NO_3-N, phosphorus (P), potassium (K), total N, organic carbon (C) and Cl. Total N and organic C analyses were determined using a Carlo-Erba (Milan, Italy) NA 1500 dry combustion analyzer (16). NH_4-N and NO_3-N were determined following a 2 *M* KCl (17) extraction and analyzed using an automated flow injection analysis system. Soil pH was determined using a glass electrode and a soil/water ratio of 1:1. Extractable P and K were determined using the Mehlich III procedure (18). Soil test Cl was determined as per the methods described by Fixen et al. (19) on the 0–15 and 15–60 cm depths.

RESULTS AND DISCUSSION

Since 1992, a significant wheat grain yield increase as a result of applying Cl has only been observed three times (Table 4). A significant increase in wheat grain yield was found when KCl was applied in 1992 and 1994. Since 1994, no yield increases due to annual applications of KCl have been observed. Grain yields also increased in 1993 and 1994 as a result of applying $CaCl_2$. A linear

Table 4. Mean Yields, Corresponding Treatments, and Significant Effects, 1991–1999, Carrier, OK

Cl rate $kg\,ha^{-1}$	Source	Method	Mg ha^{-1} 1992	1993	1994	1995	1996	1997	1998	1999
0	–	–	1.73	2.68	3.06	1.11	2.64	3.22	3.54	4.17
34	$CaCl_2$	preplant	1.82	2.96	3.02	1.07	2.66	3.18	3.65	4.31
67	$CaCl_2$	preplant	1.74	2.94	3.22	1.13	2.73	3.13	3.51	4.13
101	$CaCl_2$	preplant	1.78	2.76	3.29	1.07	2.69	3.11	3.45	4.07
101	$CaCl_2$	topdress	1.72	2.68	3.18	1.08	2.67	3.29	3.46	4.08
34	KCl	preplant	1.97	2.76	3.11	1.04	2.55	3.22	3.45	4.07
67	KCl	preplant	2.07	2.87	3.19	1.09	2.60	3.21	3.65	4.31
101	KCl	preplant	1.96	2.67	3.27	1.16	2.56	3.12	3.56	4.20
101	KCl	topdress	1.97	2.79	3.22	1.10	2.62	3.12	3.59	4.23
SED			0.06	0.12	0.15	0.07	0.13	0.12	0.42	0.51
Contrasts										
$CaCl_2$-linear			ns	ns	*	ns	ns	ns	ns	ns
$CaCl_2$-quadratic			ns	*	ns	ns	ns	ns	ns	ns
KCl-linear			**	ns	@	ns	ns	ns	ns	ns
KCl-quadratic			**	ns	ns	ns	ns	ns	ns	ns
$CaCl_2$-101 preplant vs $CaCl_2$-101 topdress			ns	ns	ns	ns	ns	*	ns	ns
KCl-101 preplant vs KCl-101 topdress			ns	ns	ns	ns	ns	ns	ns	ns
$CaCl_2$ vs check			ns	*	ns	ns	ns	ns	ns	ns
KCl vs check			**	ns	ns	ns	ns	ns	ns	ns

**, *, @-Significant at the 0.01, 0.05, and 0.10 probability levels, respectively.
SED-Standard error of the difference between two equally replicated means.

increase was observed over all rates evaluated in the 1994 crop year. In 1998 the 34 $kg\,ha^{-1}$ rate of Cl had the highest yield. Yields decreased with increasing rates of applied Cl at rates above 34 $kg\,Cl\,ha^{-1}$. Differences between preplant incorporated and topdress (KCl and $CaCl_2$) were generally small. A significant increase in wheat grain yield was observed in 1997 when $CaCl_2$ was applied topdress at a rate of 101 $kg\,Cl\,ha^{-1}$ compared to preplant (Table 4). In 1993, the overall effect of $CaCl_2$ treatment did produce significantly higher yields when compared to the check with no Cl applied.

Over the four years since lime was applied to the east half of each plot, no significant differences in yield have been observed in either the treated or untreated plots. No significant effect of lime application was noted in grain yield in any year (means not reported). It was anticipated that the elevated pH would induce take-all, therefore, allowing better evaluation of Cl treatments for possible disease suppression. However, the severity of take-all in these plots was minimal since lime was applied in 1995. Average surface (0–15 cm) soil pH was only slightly higher in limed plots (pH = 6.1) compared to plots not receiving lime (pH = 5.8) (samples collected following 1999 harvest).

Treatment means for soil test parameters from samples collected following the 1999 harvest are reported in Table 5. No treatment differences were detected for soil pH, NO_3-N, P, Cl, organic C, and total N. As was expected, soil pH

Table 5. Mean Soil Test Levels from Surface Samples (0–15 cm) Collected Following the Completion of the Experiment, and Mean Treatment Levels for Limed Versus Non-limed Plots, 1999, Carrier, OK

Cl rate kg ha^{-1}	Source	Method	pH	mg kg^{-1} NH_4-N	NO_3-N	P	K	Cl†	g kg^{-1} OC	TN
0	–	–	5.8	9.3	5.8	34	418	26	8.9	0.91
34	$CaCl_2$	preplant	5.9	10.3	6.1	34	418	24	9.1	0.90
67	$CaCl_2$	preplant	5.9	7.9	5.5	33	414	26	9.1	0.93
101	$CaCl_2$	preplant	5.9	10.6	6.6	33	420	26	9.1	0.92
101	$CaCl_2$	topdress	5.9	10.2	6.2	34	426	26	8.9	0.88
34	KCl	preplant	5.9	7.2	5.7	34	421	27	9.0	0.94
67	KCl	preplant	5.9	8.5	6.2	33	436	31	8.9	0.90
101	KCl	preplant	5.9	9.1	6.0	35	471	29	9.1	0.93
101	KCl	topdress	6.0	9.1	6.1	34	498	29	9.1	0.93
Limed			6.1	9.5	5.9	34	433	29	9.2	0.93
Not Limed			5.8	8.8	6.1	33	435	26	8.9	0.90
SED			0.1	1.3	0.7	1.7	19	5	0.2	0.03
Contrasts										
$CaCl_2$-linear			ns	ns	ns	ns	ns	ns	ns	ns
$CaCl_2$-quadratic			ns	@	ns	ns	ns	ns	ns	ns
KCl-linear			ns	ns	ns	ns	ns	ns	ns	ns
KCl-quadratic			ns	ns	ns	ns	**	ns	ns	ns
$CaCl_2$-101 preplant vs $CaCl_2$-101 topdress			ns	ns	ns	ns	*	ns	ns	ns
KCl-101 preplant vs KCl-101 topdress			ns	ns	ns	ns	ns	ns	ns	ns
$CaCl_2$ vs check			ns	ns	ns	ns	ns	ns	ns	ns
KCl vs check			ns	ns	ns	ns	**	ns	ns	ns
KCL-101 topdress vs check			ns	ns	ns	ns	**	ns	ns	ns

†Average for 0–60 cm, **, *, @-Significant at the 0.01, 0.05 and 0.10 probability levels, respectively.

SED–Standard error of the difference between two equally replicated means, OC–organic carbon, TN–total nitrogen.

remained somewhat higher in the limed plots in 1995 when compared to the unlimed plots (Table 5). Soil test NH_4-N was generally higher where $CaCl_2$ was applied annually compared to KCl (Table 5). However, NH_4-N levels were never high enough (or NO_3-N levels low enough) to result in a critical NH_4-N:NO_3-N ratio of 3:1 (ratio averaged 1.5 for all plots in this experiment) where suppression of take-all would likely be realized as a result of applying Cl fertilizers (10). As was expected, soil test K levels were greater where KCl was applied as the Cl source.

Data from soil samples (0–15 and 15–60 cm) taken at the conclusion of the experiment for soil test Cl resulted in small differences. Soil test Cl ranged from 26–31 mg kg^{-1}, or approximately 232–277 kg Cl ha^{-1} in the 0–60 cm depth, and was high at this site (Table 5). As a result, a nutritional yield response due to applied Cl was not expected. If applied Cl in this experiment were to have increased yields, it would have been the result of disease suppression, or an alternative nutrient interaction as a result of applying KCl and/or $CaCl_2$. Soil test Cl levels reported here were notably higher than that reported by Fixen et al. (20) who showed a yield response to applied Cl (range of 20–95 kg Cl ha^{-1}, 0–60 cm), and markedly higher than soil test Cl levels noted by Engel et al. (21).

In summary, wheat grain yields were not affected by lime applications from 1995 to 1999. Several plots exhibited visual symptoms of take-all in almost all years, however, grain yields increased in only two of eight years by the application of $CaCl_2$ and KCl. At this site where soil test Cl levels were relatively high, applied fertilizer Cl for take-all disease suppression was inconsistent, even following the application of lime where increased soil pH was expected to increase disease severity.

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