Chloride, Nitrogen Form, Lime, and Planting Date Effects on Take-All Root Rot of Winter Wheat

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ABSTRACT

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Field experiments conducted in western Oregon showed that losses caused by take-all root rot of wheat (*Gaeumannomyces graminis* var. *tritici*) could be significantly reduced through crop management and fertilization practices. Improved crop performance resulted from seeding late and using fertilizers containing ammonium nitrogen (NH_4-N), phosphorus (P), and chloride (Cl). Increased grain yield of take-all-infected plants was greatest in response to delayed seeding and Cl fertilization, whereas root infection was most effectively suppressed by NH_4-N. The potential for take-all was lower when the soil pH was between 5.6 and 6.0. Lime and P applications on a strongly acid (pH 5.2), P-deficient soil reduced the incidence of whiteheads associated with take-all, whereas previous lime treatments on a moderately acid (pH 5.6), high P status soil favored attack by take-all and caused yields to decline. Although the influence of seeding date, N form, lime, and P on take-all severity have been studied extensively, the involvement of Cl in take-all suppression has only recently been demonstrated.

Wheat production in Oregon's Willamette Valley has expanded in recent years, with the number of harvested hectares more than doubling in the past decade according to the Extension Economic Information Office, Oregon State University, Corvallis. Land that previously remained in wheat for only one season is now seeded to wheat for the second and third consecutive year or longer. As a consequence, diseases favored by wheat monoculture constitute a problem of increasing importance. Notable among these is take-all, caused by *Gaeumannomyces graminis* (Sacc.) Arx & Oliv. var. *tritici* Walker.

Previous research has demonstrated that proper use of fertilizers and crop management practices can limit losses caused by take-all in consecutive wheat crops. Late seeding, the ammonium (NH_4-N) form of nitrogen, moderate soil acidity, and balanced mineral nutrition of the host plant all have been reported (5,6,8,11,12,19,21,22) to lessen the severity of take-all. There was reason to suppose, based on the reported suppression by chloride (Cl) of certain other diseases such as corn stalk rot (*Gibberella zeae* and *G. fujikuroi*) (23,24) and downy mildew (*Sclerophthora macrospora*) of pearl millet (10), that Cl might also reduce the severity of take-all. To evaluate this possibility, experiments were established during the 1976–1977 and 1977–1978 cropping seasons in fields where take-all had occurred in wheat grown the previous year. Form of N and lime were included as variables in the 1976–1977 experiment to test the nature of their interactions with Cl (17). The study was expanded at the same site in 1977–1978 to include seeding date and phosphorus (P) as variables, whereas at a second location, the effects of lime and P on take-all development in a strongly acid soil of low P status were examined.

MATERIALS AND METHODS

Plots of soft white winter wheat (*Triticum aestivum* L. 'Hyslop') were established on a Willamette series soil (Table 1) at the North Willamette Experiment Station (NWES), Aurora, OR, on 19 October 1976. The field had been in a wheat/bean or wheat/summer fallow cropping sequence for 10 yr; wheat/summer fallow/wheat had been the sequence during the previous 3 yr. Lime had been applied in 1969 at rates of 0, 9, and 18 metric tons per hectare on plots 6 × 61 m. In 1976, the pH values of soil from these plots were 5.6, 6.0, and 6.2 (1:2 soil to water solution), respectively. The direction of plowing was reversed each year to minimize movement of topsoil between plots. Subplots 1.5 × 6 m were laid out within the limed and unlimed plots for comparing effects of different fertilizer treatments at different soil pH levels. The experimental design was a randomized complete block with three replicates. Fertilizer sources, rates, and time of application are presented in Table 2.

Roots of wheat plants selected randomly from within the plot showed symptoms of take-all infection, which grew increasingly severe as the cropping season progressed. The effect of take-all on the wheat was evaluated by harvesting two 60-cm sections of row per plot at the soft-dough stage, then determining total fresh weight, number of heads per tiller, and plant height.

In the fall of 1977, plots of winter wheat (cultivar Yamhill) were established in the same field. Two dates, 4 and 27 October, were selected to evaluate the influence of planting date on the severity of take-all. Plots measuring 1.5 × 6 m were replicated three times in a randomized complete block design.

Root samples were taken in the spring (24 May) from the early seeded plots; soil was washed from the roots, which were visually rated for the percent of root area (PA) displaying symptoms of take-all (black roots). These data were linearized

Table 1. Location, soil classification, lime rates, and soil analysis values of the experimental sites[a]

Location	Soil series	Lime (metric tons/ha)	pH	P[b] (ppm)	K[c] (ppm)
North Willamette Experiment Station	Willamette[d]	0	5.6	126	201
		9	6.0	128	216
		18	6.2	122	196
Douglas County	Nonpareil[e]	0	5.2	12	467
		4.5	6.4	10	458

[a] Averaged over four replicates.
[b] Determined by Bray 1 method.
[c] Determined by ammonium acetate method.
[d] Pachic Ultic Argixerolls, fine, silty, mixed, and mesic.
[e] Dystric Xerochrepts, fine, loamy, mixed, mesic, and shallow.

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using a logit transformation:

$$[\ln (\frac{PA}{1-PA})]$$

for purposes of statistical analysis. Plots were harvested the first week in August.

A separate experiment was established on a Nonpareil series soil (Table 1) in a farmer's field in Douglas County, OR. This field had been in wheat for the previous 2 yr, and before that, in a ryegrass (*Lolium perenne*) and subclover (*Trifolium subterraneum*) pasture. Eight wheat cultivars were seeded on 11 October 1977 in plots measuring 3 × 12 m. The experimental design employed was a split-split plot arrangement with cultivars as main plots, lime vs. no lime as subplots, and P vs. no P as sub-subplots (Table 2). Entire plots were harvested the first week in August with a plot combine after the severity of take-all infection was assessed based on the percentage of bleached, white, empty spikes (whiteheads) per plot.

RESULTS

North Willamette Experiment Station. *1976–1977.* Fresh weight yields from plots treated with 168 kg N/ha were highest for NH_4Cl, followed by $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ (Fig. 1). The same trend held for the other parameters measured (results not reported). Fresh weight of the plants was significantly less in limed plots (Fig. 1). Lime is well known to favor take-all (6,22); however, differences between treatments in this first experiment were not significant at $P=0.05$. We now know that more extensive subsampling is required to reduce experimental error associated with the large variation occurring within plots of wheat with take-all.

1977–1978. Grain yields from wheat plots established the following season in the same field were influenced most dramatically by seeding date. The early seeded wheat, which displayed a greater incidence and severity of take-all (short-statured plants of uneven height, blackened roots, and whiteheads), produced substantially lower yields than late seeded wheat. The average yield for all treatments seeded on 27 October was 4,260 kg/ha compared with 2,940 kg/ha for the 4 October seeding (Table 3). Statistical comparisons (*t* tests) of individual fertilizer treatments between seeding dates showed that except for the $NH_4Cl + NaCl$ and $NH_4Cl + KCl + P$ treatments, yields were significantly ($P=0.05$) increased by delayed seeding.

Lime-induced changes in soil pH from 5.6 to 6.2 markedly influenced yields of both the early and late seedings. Wheat grown on nonlimed plots (pH 5.6) had significantly higher yields ($P<0.01$) than wheat from plots limed at the high rate (pH 6.2) (Table 4). However, the more modest differences in soil reaction failed to have as consistent an effect. In comparisons between plots with soil pHs of 5.2 vs. 6.0 and 6.0 vs. 6.2, yields were significantly higher at the lower pH for the late seeding but did not differ for the early seeding (Table 4).

At a given soil pH, plants that received NH_4Cl generally had higher yields (but not significantly so at $P=0.05$) than those treated with $(NH_4)_2SO_4$ or $Ca(NO_3)_2$ (Table 3). The failure to obtain statistical significance between treatments was due in part to a relatively large experimental error caused by variability in soil conditions, microclimate effects, and the variable pattern of disease common with take-all.

Use of orthogonal comparisons permitted the testing of fertilizer treatment main effects. Plants that received NH_4Cl had significantly higher yields than those given either $(NH_4)_2SO_4$

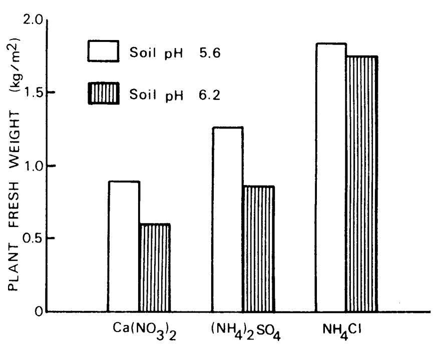

Fig. 1. Effect of soil pH and different nitrogen sources on the fresh weight of take-all infected wheat at the North Willamette Experiment Station in 1977.

Table 2. Fertilizer treatments and rates

Treatment	Rate (kg/ha) Fall[a] N	P	K	Cl	Spring[b] N	Cl
North Willamette Experiment Station						
Check	···	···	···	···	···	···
NH_4Cl	34	···	···	86	134	342
$NH_4Cl + KCl$	34	···	37	126	134	342
$NH_4Cl + K_2SO_4$	34	···	37	86	134	342
$NH_4Cl + NaCl$	34	···	···	126	134	342
$NH_4Cl + KCl + Ca(H_2PO_4)_2$	34	30	37	126	134	342
$(NH_4)_2SO_4$	34	···	···	···	134	···
$(NH_4)_2SO_4 + KCl$	34	···	37	40	134	···
$(NH_4)_2SO_4 + K_2SO_4$	34	···	37	···	134	···
$(NH_4)_2SO_4 + NaCl$	34	···	···	40	134	···
$(NH_4)_2SO_4 + KCl + Ca(H_2PO_4)_2$	34	30	37	40	134	···
$Ca(NO_3)_2$	34	···	···	···	134	···
$Ca(NO_3)_2 + KCl$	34	···	37	40	134	···
Douglas County						
$(NH_4)_2SO_4$	23	···	···	···	134	···
$(NH_4)_2SO_4 + Ca(H_2PO_4)_2$	23	30	···	···	134	···

[a] All fall fertilizers were banded with the seed at planting, and plots not receiving either $(NH_4)_2SO_4$ or K_2SO_4 were topdressed with gypsum to avoid sulfur deficiency.
[b] Spring fertilizers were applied as a topdressing.

Table 3. Yield of take-all infected wheat in response to seeding date, soil pH, and different nitrogen sources in combination with potassium chloride, potassium sulfate, sodium chloride, and phosphorus at the North Willamette Experiment Station, 1978

Treatment	Yield (kg/ha)[a] Seeded 4 October pH 5.6	pH 6.0	pH 6.2	Seeded 27 October pH 5.6	pH 6.0	pH 6.2
Check	890	860	640	1,890	1,380	840
NH_4Cl	3,740	3,060	3,120	5,820	4,510	4,430
$NH_4Cl + KCl$	4,210	4,240	2,440	5,540	5,580	4,330
$NH_4Cl + K_2SO_4$	···	2,900	4,000	···	···	···
$NH_4Cl + NaCl$	···	3,670	3,900	···	5,070	4,890
$NH_4Cl + KCl + P$	···	4,900	4,920	···	5,400	5,640
$(NH_4)_2SO_4$	2,850	3,310	2,320	4,270	3,940	4,170
$(NH_4)_2SO_4 + KCl$	3,270	3,190	2,270	4,800	4,120	4,070
$(NH_4)_2SO_4 + K_2SO_4$	···	3,240	2,370	···	4,410	4,010
$(NH_4)_2SO_4 + NaCl$	···	3,670	2,720	···	4,980	4,450
$(NH_4)_2SO_4 + KCl + P$	···	2,480	2,890	···	4,580	4,190
$Ca(NO_3)_2$	3,140	2,970	2,420	4,180	3,720	3,130
$Ca(NO_3)_2 + KCl$	2,940	1,840	2,760	4,230	5,130	4,460

[a] LSD ($P=0.05$) for comparing treatment means within columns and between rows: 1,890 kg/ha (4 October) and 900 kg/ha (27 October).

or $Ca(NO_3)_2$, whereas $(NH_4)_2SO_4$ was not superior to $Ca(NO_3)_2$ (Table 4), indicating a significant yield response to Cl but not to NH_4-N. Chloride in combination with $(NH_4)_2SO_4$ as either KCl or NaCl did not increase the yield above that obtained with $(NH_4)_2SO_4$ + K_2SO_4 (Table 4).

Phosphorus, which has been implicated in the suppression of take-all (1,7), produced mixed results in this experiment. When added in combination with NH_4Cl and KCl, application of P resulted in significantly greater yields (Table 4) and was the highest-yielding treatment for both seeding dates (Table 3). Plots treated with $(NH_4)_2SO_4$ + KCl + P, however, did not have higher yields than those treated with $(NH_4)_2SO_4$ + KCl (Table 4).

Table 4. Orthogonal comparisons of yield main effects for take-all-infected wheat at the North Willamette Experiment Station, 1978

	Seeded 4 October			Seeded 27 October		
Treatment comparison	Yield (kg/ha)	Variance ratio	Probability level[a]	Yield (kg/ha)	Variance ratio	Probability level[a]
NH_4Cl	3,758			5,122		
vs. $(NH_4)_2SO_4$	2,882	10.31	0.01	4,357	29.00	0.01
NH_4Cl	3,468			5,035		
vs. $Ca(NO_3)_2$	2,673	8.49	0.01	4,142	23.73	0.01
$(NH_4)_2SO_4$	2,868			4,228		
vs. $Ca(NO_3)_2$	2,678	0.51	NS	4,142	0.22	NS
Soil pH 5.6	3,006			4,382		
vs. soil pH 6.2	2,281	4.12	0.05	3,633	19.46	0.01
Soil pH 5.6	3,006			4,382		
vs. soil pH 6.0	2,777	0.41	NS	4,054	3.73	0.10
Soil pH 6.0	2,777			4,054		
vs. soil pH 6.2	2,281	1.93	NS	3,633	6.15	0.05
$(NH_4)_2$ + K_2SO_4	2,803			4,210		
vs. $(NH_4)_2SO_4$ + KCl	2,730	0.01	NS	4,095	0.04	NS
$(NH_4)_2SO_4$ + K_2SO_4	2,803			4,210		
vs. $(NH_4)_2SO_4$ + NaCl	3,197	0.34	NS	4,715	2.53	NS
NH_4Cl + KCl + P	4,910			5,525		
vs. NH_4Cl + KCl	3,340	5.52	0.05	4,955	3.22	0.10
$(NH_4)_2SO_4$ + KCl + P	2,690			4,385		
vs. $(NH_4)_2SO_4$ + KCl	2,730	0.01	NS	4,095	0.83	NS

[a]NS = not significantly different ($P = 0.10$).

Table 5. Orthogonal comparisons of root infection main effects at the North Willamette Experiment Station, 1978

Treatment comparison	Infection (%)	Variance ratio	Probability level[a]
NH_4Cl vs.	26.7		
$(NH_4)_2SO_4$	36.6	2.33	NS
NH_4Cl vs.	26.7		
$Ca(NO_3)_2$	70.2	29.69	0.01
$(NH_4)_2SO_4$ vs.	36.6		
$Ca(NO_3)_2$	70.2	15.36	0.01
Soil pH 6.0 vs.	46.5		
soil pH 6.2	50.0	0.002	NS
KCl vs.	43.0		
no KCl	46.1	0.008	NS

[a]NS = not statistically significant ($P = 0.10$).

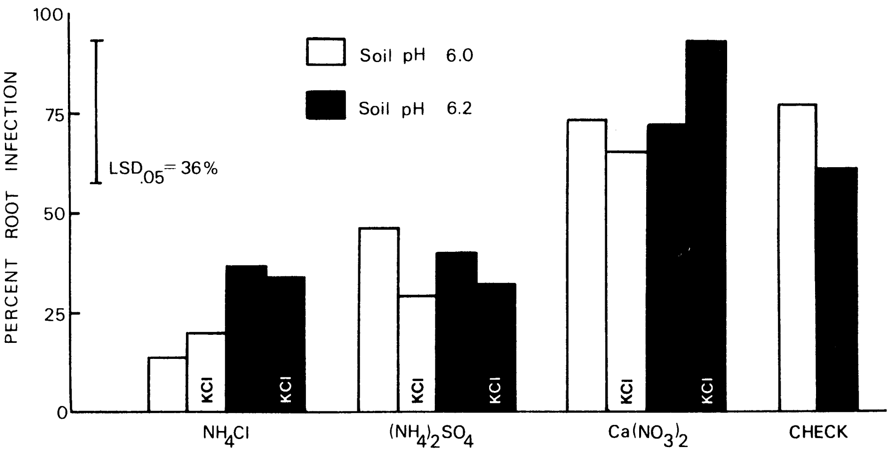

Fig. 2. Severity of take-all root infection as influenced by soil pH, potassium chloride, and different nitrogen sources at the North Willamette Experiment Station in 1978.

Effects of soil pH, N form, and Cl on take-all, based on severity of root symptoms, were evaluated for selected treatments from the 4 October seeding. Although the overall percentage of root area with take-all symptoms (PA) increased slightly with pH (Table 5), this difference was not significant ($P = 0.05$), and except for plants fertilized with either NH_4Cl or NH_4Cl + KCl, PA was not consistently reduced by the more acid soil pH (Fig. 2). A comparison of the yield and root infection data in Tables 4 and 5 for the three N sources indicate that the influence exerted by N form and Cl on PA were inconsistent with their effect on yield. Whereas yields were significantly improved by Cl (Table 4) but not by NH_4-N, root infection was suppressed by NH_4-N (Table 5) but only marginally reduced by Cl.

Douglas County. *1977–1978.* At this site, the grain yield of eight different cultivars was increased and take-all infection (percentage of tillers with heads that were dead or whiteheads) decreased by either lime, P, or the combination of lime and P (Table 6). The lime response was opposite that at NWES. Plots receiving 168 kg N/ha as $(NH_4)_2SO_4$ averaged 1,100 kg of grain per hectare, with a 78% incidence of whiteheads. Comparatively, the average grain yield rose to 3,000, 3,740, and 4,830 kg/ha when P alone, lime alone, and lime plus P, respectively, were added to the nitrogen, with a corresponding decline in the percentage of whiteheads from 78 to 48, 16, and 11 for the same sequence of treatments.

DISCUSSION

Results obtained during the two cropping seasons indicated that management practices known to suppress take-all were the same practices that resulted in increased fresh weight and grain yields. Late seeding, for example, increased grain yields, markedly at NWES in 1977–1978 (Table 3). Glynn (8) in England and Butler (1) in Australia reported similar experiences with seeding date in the presence of take-all. Apparently, late seeding reduces the severity of take-all by extending the period during which the fungus must survive in the soil as a saprophyte exposed to microbial competition. In addition, lower temperatures associated with late seeding (8–16 C) favor development of a more vigorous wheat plant, which can better tolerate infection (1,4,16).

Reductions in grain yield at NWES associated with increases in soil pH from 5.6 to 6.2 were consistent with reports by others of an increased incidence of take-all after liming (6,22). The fact that root infection was not significantly influenced by soil pH (Table 5) probably indicates that the pH difference between soils limed at the low (pH 6.0) and high (pH 6.2) rates was too small to appreciably influence take-all development in the more severely infected plants of the early seeding. Grain yields of the early seeded wheat also failed to respond to liming over this range. Unfortunately, roots were not sampled from plots where grain yield responded significantly to differences in soil pH.

Liming improved grain yield and significantly reduced the percentage of tillers with whiteheads where soil pH and P were limiting (Table 5), in contrast to the negative yield response to lime where soil pH and P were adequate (Table 2). Liming the more acid soil possibly had a positive influence on host performance because of decreased toxicity from excessive Al and Mn (20). The contrasting results obtained at these two locations indicate that the response of plants with take-all to liming is related to the existing pH and fertility status of the soil and should be evaluated on a site-specific basis.

The tendency of P to suppress take-all has been linked to increased root growth in the presence of this element (1). At the Douglas County site (11 ppm average soil P), fertilization with P and $(NH_4)_2SO_4$ reduced the incidence of whiteheads and increased yields significantly over those obtained with $(NH_4)_2SO_4$ alone (Table 6). At NWES (125 ppm average soil P), P increased yields when combined with NH_4Cl + KCl but not with $(NH_4)_2SO_4$ + KCl (Table 4). The differential response to P at NWES suggests a positive P × Cl interaction because the NH_4Cl + KCl + P treatment contained the equivalent of 428 kg Cl/ha, compared with 40 kg Cl/ha for the $(NH_4)_2SO_4$ + KCl + P treatment. The possibility of a synergistic interaction between P and Cl is difficult to explain, however, considering the demonstrated antagonism between these two ions (13,14). It is more likely that addition of P overcame the competitive inhibition of P uptake caused by the high Cl concentration in the root zone.

The lower percentage of root attack (Fig. 2, Table 5) obtained with NH_4Cl and $(NH_4)_2SO_4$ fertilization compared with $Ca(NO_3)_2$ supports the theory advanced originally by Huber et al (9) that NH_4-N suppresses and NO_3-N stimulates take-all. Currently, there is no consensus as to the mechanism(s) involved. Smiley and Cook (19) suggested that the downward shift in rhizosphere pH that occurs when plants absorb NH_4-N produces a more favorable niche for microbes antagonistic to *G. graminis*. Alternatively, Huber and Watson (12) contended that the suppression of take-all by NH_4-N is directed through a change in host physiology, leading to increased disease tolerance.

Neither theory explains why plants receiving NH_4Cl should outyield those receiving $(NH_4)_2SO_4$ (Table 4). It is doubtful that the added response to NH_4Cl was a direct nutritional response to Cl. Although Cl is an essential nutrient, plants extract sufficient amounts from the soil solution and atmosphere to satisfy physiological demands (18), and positive yield responses to Cl as a nutrient are seldom encountered (15). There are, however, nonspecific ion functions performed by Cl that influence plant physiological processes and may in turn affect development of take-all.

Christensen et al (2) obtained higher grain and fresh weight yields when plants with take-all were fertilized with NH_4Cl compared with $(NH_4)_2SO_4$. They found lower osmotic potentials in the Cl-fertilized plants, which they concluded might influence host colonization by the fungus. Chloride also increases the ratio of NH_4- to NO_3-N, which plants assimilate by slowing the rate of nitrification (9) and competitively inhibiting NO_3 absorption (15), raising the possibility that the yield response to Cl was a consequence of that ion's ability to increase the negative influence NH_4-N has on take-all.

As with the P × Cl interaction, high rates of Cl were required to increase yields. Neither NaCl nor KCl, when added to $(NH_4)_2SO_4$ at a rate equivalent to 40 kg Cl/ha (compared with 428 kg Cl/ha for the NH_4Cl treatment), increased yields over those obtained with $(NH_4)_2SO_4$ + K_2SO_4 (Table 4).

Although reduction in severity of root symptoms where Cl was applied was not as significant as the yield response to this element, it should be recognized that large within-plot variability and small sample sizes reduced the precision of those statistics associated with the root disease data. This is confirmed by the coefficients of variation (CVs) for the 4 October seeding. For treatments containing either NH_4Cl or $(NH_4)_2SO_4$, the CVs were 38.2 and 56.5% for the yield and

Table 6. Effects of lime and phosphorus treatments on yield and severity of take-all root rot infection of eight winter wheat cultivars in Douglas County, 1978

	Treatments			
Cultivar	Lime (metric tons/ha)	P (kg/ha)	Yield (kg/ha)	Whiteheads (%)
Hyslop	0	0	1,050	90.8
	0	30	2,500	62.5
	4.5	0	3,960	7.5
	4.5	30	4,150	7.5
McDermid	0	0	1,180	69.8
	0	30	2,940	33.8
	4.5	0	3,610	15.0
	4.5	30	4,470	12.5
Daws	0	0	750	96.8
	0	30	3,040	73.8
	4.5	0	4,040	17.5
	4.5	30	6,170	12.5
Stephens	0	0	530	96.5
	0	30	1,630	82.5
	4.5	0	4,210	22.5
	4.5	30	4,560	16.2
R9401	0	0	1,340	57.5
	0	30	3,280	28.8
	4.5	0	3,950	6.2
	4.5	30	4,830	5.0
IM6 Ymh/Hys	0	0	1,150	77.2
	0	30	3,540	36.2
	4.5	0	3,140	20.0
	4.5	30	4,940	15.0
2M6 Ymh/Hys	0	0	1,470	66.2
	0	30	4,040	23.8
	4.5	0	3,740	18.8
	4.5	30	5,520	5.0
Entry 6 Nugaines	0	0	1,300	72.5
	0	30	2,990	38.8
	4.5	0	3,240	18.8
	4.5	30	3,980	16.2
P			*[a]	*
$LSD_{0.05}$			1,030	22.4

[a] * = Highly significant ($P = 0.01$).

disease data, respectively, indicating a 50% greater variation in root infection data. Also, questions have arisen concerning the propriety of using root discoloration as an indicator of the severity or time of take-all infection. Other research (3) has shown that the main damage done to plants by take-all involves disorganization and subsequent dysfunction of the stele, which cannot always be determined by measuring blackened roots.

It appears that Cl can be added to the already extensive list of factors that influence take-all development (22). This study shows that fertilizers containing Cl significantly increased the yield of take-all-infected wheat and produced slight reductions in root infection if supplied in sufficient quantity. It was also apparent that the capacity of Cl to suppress take-all was influenced by other variables. Take-all was less severe on late seeded wheat planted in moderately acid soil (pH 5.6-6.2) and adequately fertilized with N, P, and K. The value of Cl may be to provide an increment of disease control beyond what can now be accomplished with fertilizer and crop management practices known to suppress take-all.

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