Effect of Fertilizer Nitrogen Source and Chloride on Take-All of Irrigated Hard Red Spring Wheat

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ABSTRACT

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Field experiments were conducted over 2 yr on an alkaline soil (pH 7.9) to determine the effect of several fertilizer nitrogen (N) sources and chloride (Cl) application methods on irrigated spring wheat inoculated with *Gaeumannomyces graminis* var. *tritici*. The effect of fertilizer N source and Cl on disease severity indices (root disease scores and percent white heads) was not as great as the effect on grain yield and test weight. Application of Cl generally had little effect on disease severity indices. Fertilizer N source did not affect root disease scores but did affect percent white heads. This response was not consistent over the two seasons. In 1985, percent white heads was greater for NH_4OH than for $NaNO_3$. In 1986, percent white heads were greater for $NaNO_3$ than for NH_4NO_3, NH_4OH, or $CO(NH_2)_2$. Disease severity indices did not appear to correlate well with yield results. Grain yield and test weight response to Cl in inoculated wheat was influenced by fertilizer N source applied. Chloride had little effect on grain production and test weight when $NaNO_3$ or no N was applied, but did when NH_4OH or $CO(NH_2)_2$ was applied. Yield and test weight improvements from Cl were as great as 869 and 517 kg/ha and 36 and 24 g/L, respectively, in 1985 and 1986. Differences in the distribution and amount of growing season moisture and indigenous soil NO_3-N levels may have confounded the results from the 2 yr of study.

Additional key words: ammonium, band, broadcast, nitrate, sodium chloride

Take-all of wheat (*Triticum aestivum* L.) caused by *Gaeumannomyces graminis* (Sacc.) Arx & Oliv. var. *tritici* Walker is a severe disease under high moisture conditions. In Montana and neighboring provinces of Canada, the disease is commonly observed when wheat is grown under irrigation. Irrigated wheat producers in Montana often do not utilize crop rotations to control this disease because climatic and market considerations limit alternative crops. Seed treatment with the fungicide triadimenol may provide some control (10), but it is not currently registered for use. Although production of continuous wheat may lead to biological suppression of take-all, or take-all decline (11), the impact to the producer may be severe for several years before this occurs. Therefore, there is great interest in other measures that may control this disease and in the factors that influence its severity.

Results of several studies have shown that fertilizers containing ammonium nitrogen (NH_4-N), in contrast to nitrate nitrogen (NO_3-N), suppress take-all or increase yield of wheat infested with *G. g.* var. *tritici* (1,7,8,14–16). Results of other studies have been somewhat different (3,6). The beneficial effect of NH_4-N fertilization has been attributed to a reduction in soil pH in the rhizosphere (14). The increased acidity may directly reduce the activity of *G. g.* var. *tritici* or stimulate the activity of microorganisms, e.g., *Pseudomonas* spp., that are antagonistic to *G. g.* var. *tritici* (12,13).

Recent reports have shown that fertilizers containing chloride (Cl) were effective in suppressing take-all and increasing yield of soft winter wheat grown on acidic soils in the Pacific Northwest (1,2,15). The mechanism by which Cl controls root diseases is not well understood. Chloride may suppress take-all by decreasing the water potential in the plant (2), or by inhibiting nitrification in unlimed acidic soils.

Little information exists on the effect of fertilizer N source and/or Cl on hard red wheat infected with take-all in the Northern Great Plains. Most information on N source and Cl effects on take-all is

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based on studies with soft winter wheat from humid regions, where soils are more acidic than normally found in the Northern Great Plains. The objectives of this study were to determine under alkaline soil conditions the effect of fertilizer N source, Cl application method, and the interaction of these two factors on disease severity, yield, and test weight of spring wheat infected with take-all.

MATERIALS AND METHODS

Site description. Field experiments were conducted in 1985 and 1986 on two separate areas within the same field near Huntley, MT. The soil at this site is a Fort Collins, silty clay loam (Ustollic Haplargids). Soil properties in the surface (0–15 cm) were as follows: pH 7.9, organic matter 1.7%, 621 ppm ammonium acetate extractable K, and 10 ppm sodium bicarbonate extractable P. Chloride levels extractable in 0.004 M $CaSO_4 \cdot 2H_2O$ were 3.1 and 2.4 ppm in the 0–30 and 30–60 cm zones. Oat kernels (0.65 and 1.0 g/m row in 1985 and 1986, respectively) infested with *G. g.* var. *tritici* were added with the wheat seed and used to inoculate the field site. The procedure for production of the inoculum has been described by Garcia and Mathre (5).

Field study in 1985. Nine inoculated treatments, involving a complete factorial with two N fertilizer sources ($NaNO_3$ and NH_4OH or aqua ammonia) and four Cl treatments (no Cl, surface broadcast, seed-band, and deep-band 15 cm below surface), plus a control treatment without N and Cl were evaluated. Two noninoculated treatments, both receiving N as $NaNO_3$ and one receiving seed-band Cl, were also included. The study was replicated four times in a randomized complete block design. The inoculated treatments were arranged as a split-plot design, with N and Cl treatments as the main plot and subplot, respectively.

Fertilizer N sources were applied as liquids at 90 kg/ha of N in a deep band 15 cm below the soil surface. Soil analyses before seeding showed NO_3-N levels of 8.2, 19.1, and 9.2 ppm within the 0–15, 15–30, and 30–60 cm zones, respectively. Soil NH_4-N levels were 7.0, 4.7, and 4.1 ppm, respectively. The Cl was applied as NaCl at a rate of 75 kg/ha (45 kg/ha of Cl).

On 18 April, the hard red spring wheat cultivar Newana was seeded in rows spaced 30 cm apart and at a rate of 100 kg/ha. Fertilizer N and the Cl deep-band treatments (approximately 10 cm below and to the side of seed) were applied the day before seeding. Seed-band Cl was placed with the seed, and surface-broadcast Cl was applied immediately after planting. All plots received 10 kg/ha of seed-band P. Individual plots were 4.9 × 1.8 m.

Sprinkler irrigation was applied at a uniform rate across the entire study area to ensure there was no crop moisture stress. Crop water use was anticipated to be greater in the noninoculated area, where take-all disease was minimal. Therefore, application rates and timing were based on plant water use rates in this area. Irrigation was applied five times, for a total of 281 mm. Rainfall totaled 96 mm between 1 April and 1 August.

Field study in 1986. Twenty inoculated treatments in a 5 × 4 complete factorial arrangement involving five fertilizer N and four Cl treatments were evaluated. The fertilizer N treatments were $NaNO_3$, NH_4NO_3, $CO(NH_2)_2$, NH_4OH, and no N. The four Cl treatments were no Cl, broadcast Cl, shallow-band Cl, and deep-band Cl. Six noninoculated treatments receiving one of the five N sources and one treatment receiving NH_4OH plus deep-band Cl were included. The experiment was replicated six times in a randomized complete block design. The 20 inoculated treatments were analyzed as a split-plot, with N and Cl treatments as the main plot and subplot, respectively.

Fertilizer N sources were applied as a liquid at 156 kg/ha of N in a deep band. The fertilizer N rate was higher than in 1985 because of lower residual soil NO_3-N. Soil analyses before seeding showed 5.9, 2.3, and 0.3 ppm NO_3-N in the 0–15, 15–30, and 30–60 cm zones, respectively. Soil NH_4-N levels were 7.1, 4.6, and 3.9 ppm, respectively. Chloride application rate, methods, and source were the same as in 1985, with one exception. A shallow-band (equidistant between alternate wheat rows, 5 cm below the soil surface) placement was evaluated instead of the seed-band Cl. Phosphorus was broadcast and incorporated into the top 10 cm of soil at a rate of 20 kg/ha before seeding.

Fertilizer N and Cl deep-band treatments were applied 22 April. Seeding of spring wheat cultivar Newana was delayed until 2–3 May because of rainfall (34 mm) during the final week of April. A seed-row spacing of 15 cm and seeding rate of 110 kg/ha were used. Individual plots were 4.9 × 1.5 m. Irrigation (240 mm total) was applied on five dates according to the method used in 1985.

Table 1. Effect of fertilizer N source on total heads, percent white heads, and root disease score of spring wheat cultivar Newana inoculated with *Gaeumannomyces graminis* var. *tritici*

		Not inoculated	Inoculated		
Year	N source	Total heads/m²	Total heads/m²	Percent white heads	Root disease score[y]
1985	No N	...	297 a[z]	21.5 ab	...
	$NaNO_3$	376	338 a	16.5 a	...
	NH_4OH	...	344 a	27.8 b	...
1986	No N	341 a	241 a	25.6 ab	2.2 a
	$NaNO_3$	440 b	273 a	30.6 b	2.1 a
	NH_4NO_3	486 bc	343 b	21.7 a	2.2 a
	$CO(NH_2)_2$	496 bc	349 b	22.7 a	2.1 a
	NH_4OH	511 c	349 b	20.9 a	2.0 a

[y] Disease severity classes: 0 = 0%, 1 = 1–25%, 2 = 26–50%, 3 = 51–75%, and 4 = 76–100% of roots with one or more lesions.
[z] Means within a column followed by the same letter are not significantly different according to the protected LSD comparison test ($P = 0.05$).

Table 2. Effect of fertilizer N source and Cl application method on grain yield of spring wheat cultivar Newana inoculated with *Gaeumannomyces graminis* var. *tritici*

		Chloride application method[x]				Contrasts (*P*)		
Year	N source	No Cl	BC	SB	DB	No Cl vs. rest	BC vs. B, DB	SB vs. DB
1985	No N	2,880 a[y]	...	...	...	...	...	...
	$NaNO_3$	3,433 b	3,313 a	3,666 a	3,260 a	ns[z]	ns	0.05
	NH_4OH	2,860 a	3,460 a	3,729 a	3,683 b	0.01	ns	ns
1986	No N	1,714 a	1,250 a	1,572 a	1,727 a	ns	0.01	ns
	$NaNO_3$	1,707 a	1,633 b	1,754 ab	1,969 a	ns	ns	ns
	NH_4NO_3	2,251 b	2,393 c	2,144 b	2,654 b	ns	ns	0.01
	$CO(NH_2)_2$	2,305 b	2,433 c	2,822 c	2,735 b	0.01	0.02	ns
	NH_4OH	2,372 b	2,708 c	2,770 c	2,630 b	0.02	ns	ns

[x] BC = broadcast, SB = seed-band in 1985 and shallow-band in 1986, DB = deep-band.
[y] Means within a column followed by the same letter are not significantly different according to the protected LSD comparison test ($P = 0.05$).
[z] ns = Not significant at 0.10 probability level.

Rainfall totaled 198 mm during 1 April–1 August.

Field measurements and laboratory methods. Disease severity was rated in both 1985 and 1986 by counting white heads from a 1.8-m^2 area approximately 3 wk before harvest, and in 1986 by inspecting plant roots at Feekes growth stage 10–10.2. White heads were expressed as a percentage of the total heads (percent white heads). Root disease scores were determined by removing 15–20 plants from two rows of each plot. The roots were examined after washing and assigned to one of five disease severity classes as follows: 0 = 0%, 1 = 1–25%, 2 = 26–50%, 3 = 51–75%, and 4 = 76–100% of the roots with one or more lesions. Grain harvest was performed with a small-plot combine on 8 August 1985 and 18 August 1986.

Soil samples were collected in the spring before fertilization in both 1985 and 1986 and after harvest in 1986 only. Samples were dried and ground to pass a 2-mm sieve, then analyzed for NO_3-N and NH_4-N by copperized Cd reduction and indophenol blue methods (9).

RESULTS

Head counts and disease severity. Evidence of take-all was apparent in all inoculated plots in both 1985 and 1986. Early symptoms were yellowing of lower leaves (apparent by late tillering) and fewer tillers per plant compared with the noninoculated treatments. No evidence of take-all was apparent in the non-inoculated portion of the study area (i.e., no black lesions on roots or white heads).

Total heads were increased by N fertilization in 1986, reflecting the low soil N status for this season (Table 1). Inoculation reduced the head counts by approximately 10% in 1985 and 30–38% in 1986. Within the inoculated plots, total heads were similar for $NaNO_3$ and NH_4OH in 1985 and lower for $NaNO_3$ than for the other N sources in 1986.

Root disease scores within the inoculated plots were not affected by fertilizer N or Cl in 1986. Disease severity estimates as expressed by percent white heads were affected by fertilizer N source in 1985 and 1986. The response from the fertilizer N sources was not consistent over the two seasons, however. In 1985, percent white heads was greater in treatments with NH_4OH than in those with $NaNO_3$. In 1986, percent white heads was greater for $NaNO_3$ than for the other N sources tested.

Application of Cl had no effect on total heads in either the inoculated or noninoculated treatments in 1985 or 1986. The percent white heads was not reduced significantly by Cl, with the exception of seed-banded Cl in 1985. In 1985, percent white heads averaged 11.4% for seed-banded Cl and 21.8% for the other Cl treatments (mean of no Cl, broadcast, and deep band).

Grain yield and test weight. Grain production levels in 1985 for non-inoculated $NaNO_3$ and $NaNO_3$ plus Cl treatments were 4,269 and 4,415 kg/ha, respectively. Grain production in 1986 for noninoculated no N, $NaNO_3$, NH_4NO_3, $CO(NH_2)_2$, NH_4OH, and NH_4OH plus Cl treatments were 3,236, 4,572, 4,605, 5,114, 5,338, and 5,002 kg/ha (LSD = 672 kg/ha at $P = 0.05$ level), respectively. Grain yield was improved by N fertilization, and NH_4OH yielded more than $NaNO_3$ in 1986. No significant yield response from Cl was observed either year.

Inoculation reduced yield by approximately 18% in 1985 and 43–63% in 1986. Yield within the inoculated plots was affected by N source and the interaction of fertilizer N source and Cl ($P < 0.01$ in 1985 and $P < 0.02$ in 1986) (Table 2). Without Cl, grain yield was greater for $NaNO_3$ than for NH_4OH in 1985. In 1986, grain production for $NaNO_3$ was similar to no N and significantly below the other treatments that received N. Application of Cl did not improve yield where fertilizer N was applied as $NaNO_3$ or, in 1986, without fertilizer N. Where N was applied as $CO(NH_2)_2$ or NH_4OH, there was a general improvement in yield from Cl in both years. Application of Cl only improved yield ($P = 0.05$ level) with NH_4NO_3 when applied together in a deep band.

Within the inoculated plots, application of Cl improved test weight for wheat fertilized with NH_4OH, $CO(NH_2)_2$, and NH_4NO_3 ($P < 0.10$) (Table 3). The method of Cl application generally had no effect on the test weight level. No significant improvement in test weight was observed from Cl where $NaNO_3$ was applied and without N fertilization. The magnitude of test weight response to Cl where NH_4OH was applied was greater in 1985 than in 1986.

Rainfall amounts were considerably greater during 1986 than during 1985, particularly early in the growing season. During the month after N fertilization, rainfall totaled 11 mm in 1985 and 99 mm in 1986. To determine if this may have caused NO_3 leaching, soil samples were collected after harvest in 1986. These analyses revealed (Table 4) that NO_3-N movement into the 30–60 and 60–90 cm zones was greater with $NaNO_3$ than with NH_4OH within the inoculated plots.

DISCUSSION

The effect of fertilizer N source and Cl on disease severity was not clear from the results of this study. Root disease scores, based on percentage of roots with black lesions, were not affected by the applied treatments. Percent white heads, however, were affected by fertilizer N source, but

Table 3. Effect of fertilizer N source and Cl application on grain test weight of spring wheat cultivar Newana inoculated with *Gaeumannomyces graminis* var. *tritici*

Year	N source	Test weight (g/L) No Cl	Test weight (g/L) With Cl	Contrasts (*P*) No Cl vs. with Cl[x]
1985	No N	882 b[y]	...	...
	$NaNO_3$	884 b	884 a	ns[z]
	NH_4OH	845 a	881 a	0.01
1986	No N	867 b	867 a	ns
	$NaNO_3$	847 ab	844 a	ns
	NH_4NO_3	853 ab	869 a	0.03
	$CO(NH_2)_2$	853 ab	865 a	0.10
	NH_4OH	829 a	853 a	0.01

[x] With Cl = mean of three chloride application methods: broadcast, seed-band, and deep-band in 1985 and broadcast, shallow-band, and deep-band in 1986.

[y] Means within a column followed by the same letter are not significantly different according to the protected LSD comparison test ($P = 0.05$).

[z] ns = Not significant at 0.10 probability level.

Table 4. Effect of inoculation with *Gaeumannomyces graminis* var. *tritici* (I) and fertilizer N source (N) on soil NO_3-N levels after harvest in 1986

Depth (cm)	Soil NO_3-N (ppm) No inoculum No N	No inoculum $NaNO_3$	No inoculum NH_4OH	With inoculum No N	With inoculum $NaNO_3$	With inoculum NH_4OH	*P* I	*P* N	*P* I*N	LSD[y]
0–30	4.18	3.55	4.03	6.87	7.82	7.25	0.01	ns[z]	ns	...
30–60	0.83	2.68	0.54	1.90	7.53	4.18	0.01	0.01	0.04	2.41
60–90	1.47	1.37	0.67	1.83	7.22	2.87	0.01	0.03	0.03	2.50

[y] Protected LSD comparison ($P = 0.05$) for I by N interaction.

[z] ns = Not significant at 0.10 probability level.

the responses differed for the two seasons. Application of Cl, with one exception, did not reduce the disease severity indices. The reduction in percent white heads from seed-band Cl in 1985 may have been related to its placement close to the inoculum. This may have affected the inoculum's virulence.

In general, disease severity indices (root scores and white heads) did not correlate well with the yield results. In many instances, yield was affected more by the applied treatments than was disease severity. Disease severity indices used in this study may not be accurate or precise measures of plant vigor. White head numbers changed rapidly during the ripening stages and were sometimes difficult to differentiate from healthy heads. Disease severity estimates were based on samples collected at specific points in time, whereas yield was influenced by factors occurring over the entire season. Deacon and Henry (4) noted in studies with wheat infected with take-all that the extent of root discoloration was not a good index of plant disease resistance. Taylor et al (15) found that Cl had a greater effect on yield than on the percentage of root area displaying take-all symptoms. They noted that within-plot variability and small sampling areas reduce the precision of root disease data relative to yield measurements.

The effect of Cl on grain yield and test weight in wheat infected with take-all depended on the fertilizer N source applied in both 1985 and 1986. The method of Cl placement was not as important. General yield and test weight improvements from Cl (no Cl vs. mean of three Cl placements) occurred with NH_4OH or $CO(NH_2)_2$. Yield increased when Cl was banded with NH_4NO_3 in 1986. The Cl responses with NH_4OH were greater in 1985 than in 1986. Inoculation reduced yield and head counts more in 1986 because of the higher inoculum rate used and greater early season moisture. These results suggest that Cl may exert its greatest effect on wheat with moderate levels of take-all infection. The response to Cl may become smaller and/or less consistent under several disease conditions.

Differences between 1985 and 1986 with respect to soil N levels and early-season rainfall may have confounded our results and affected the response to the fertilizer N sources. Low indigenous soil NO_3-N levels and fertilizer NO_3-N leaching, resulting in N deficiency, was probably a major cause of the low head counts and grain production levels for $NaNO_3$ and no N in 1986. This was evident in both the inoculated and noninoculated areas. Soil analyses after harvest confirm that NO_3-N movement into the 60–90 cm zone was greater with $NaNO_3$ than NH_4OH, particularly in the inoculated plots. During 1986, N deficiency symptoms (general plant chlorosis) were very apparent in the no N and $NaNO_3$ noninoculated plots. These symptoms were masked somewhat in the inoculated areas because of the presence of take-all disease. Although postharvest soil N levels were not measured in 1985, the lower rainfall early in the growing season should have minimized NO_3-N leaching and helped maintain the positional availability of N from $NaNO_3$ and NH_4OH.

Although disease severity indices were not greatly affected by Cl, this does not preclude the possibility that Cl increased yield by improving plant resistance to take-all. Yield improvements from Cl were only observed here in the presence of disease. Application of Cl increased grain yield by as much as 869 kg/ha in 1985 and 517 kg/ha in 1986. Yield improvements from Cl reported here were generally not as great as reports from Oregon on acidic soils (1,2). Nevertheless, the Cl responses in wheat infected with take-all on this alkaline soil (pH 7.9) may be of both biological and potential economic significance.

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