Effect of Chloride Fertilizers on Development of Powdery Mildew of Winter Wheat

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ABSTRACT

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The role of spring-applied fertilizers containing the chloride (Cl) anion on the development of the powdery mildew (PM) disease of winter wheat was studied over three seasons. Additional factors included in the study were resistant and susceptible cultivars and conventional and intensive nitrogen fertilization. Plots were naturally infected with *Erysiphe graminis* f. sp. *tritici*. Single point-in-time disease assessments showed that Cl reduced powdery mildew severity but was significant only for the potassium (K) source. Area under the disease progress curve analysis of subsequent data showed a significant reduction of powdery mildew development due independently to K and Cl. The magnitude of the PM reduction varied with cultivar and leaf position within the canopy. Because of the lack of significant disease reduction with $CaCl_2$ and the high experimental rates used, reductions of PM due only to the Cl portion of some fertilizers may be too small to be of practical value. Yield increases were not directly associated with PM reductions.

Powdery mildew of wheat (*Triticum aestivum* L.) has been a significant problem in the Middle Atlantic states since the 1940s when new races of the causal agent, *Erysiphe graminis* DC. f. sp. *tritici* Em. Marchal were first identified in the region (13). Utilization of disease-resistant cultivars and fungicide treatments are the primary control methods presently in use. In this region, fungicidal controls for conventionally managed wheat have rarely been economical, and resistant cultivars have been short-lived because of the genetic variability in the pathogen population (10).

It has long been known that macronutrients can alter disease severity. High nitrogen (N) levels can increase powdery mildew (5), but phosphorus is generally noted to decrease mildew (3,7). Reports of potassium (K) effects on powdery mildew are more variable and include increasing, decreasing, or not affecting the disease severity, although the majority of the reports indicate a decrease in disease development (9). More recent work suggests that micronutrients, such as chloride (Cl), may protect wheat against certain fungal diseases. Christensen et al (1) reported that Cl applied to wheat with ammonium-N was associated with higher grain yields and less severe take-all root rot caused by *Gaeumannomyces graminis* (Sacc.) Arx & Oliv. var. *tritici* Walker. Sheyer et al (12) also reported reduced rates of development of stripe rust, caused by *Puccinia striiformis* West., with spring Cl applications.

Chloride is an inexpensive soil amendment that is often applied along with K, as KCl, as part of normal fertility practices. Deliberate use of Cl to protect wheat against severe powdery mildew development, therefore, would be a simple and convenient disease control tactic. Furthermore, greater use of intensive cereal management practices, in particular, higher nitrogen fertility regimes and narrow row spacing, is likely to increase the severity of powdery mildew epidemics unless counteracting measures are found. Preliminary efforts to determine the effect of Cl on powdery mildew development did not show significant disease suppressive effects (14). We report on continued efforts to characterize the effect of Cl on powdery mildew of wheat.

Objectives of this study were to evaluate the effect of Cl-containing soil amendments on: 1) powdery mildew development under conventional and high nitrogen conditions, 2) grain yield, and 3) differences in disease and yield response between resistant and susceptible cultivars.

MATERIALS AND METHODS

Field experiments were conducted at the University of Maryland Wye Research and Education Center near Queenstown during 1983–1984, 1984–1985, and 1985–1986. All subsequent reference to the individual trials will be by their respective harvest years: 1984, 1985, and 1986. The soil type is a Mattapex silt loam, pH 6.6, with 117 kg ha^{-1} and 281 kg ha^{-1} double-acid extractable P_2O_5 and K_2O, respectively.

Agronomic practices. Plots were sown on 11 October 1983, 26 October 1984, and 29 October 1985 with a five-row double-disk drill at 101 kg seed ha^{-1}. Plot areas were 0.9 × 4.9 m. Experimental units were separated by barley buffer plots of the same dimensions except in 1986. No fall fertilizer, herbicides, or fungicides were applied except in 1984, when the herbicide dicamba (2-methoxy-3,6-dichlorobenzoic acid) was applied at 0.14 kg a.i. ha^{-1}. All experimental fertility treatments were hand-applied on 5 April 1984, 2 April 1985, and 26 March 1986 except for the high rate of nitrogen in 1986, which was applied half on 26 March and half on 24 April. Ammonium nitrate was used as the nitrogen source in all studies, and natural inoculum was relied upon for infection. The entire plot area was harvested with a small-plot combine on 11 July 1984, 24 June 1985, and 1 July 1986. Total grain weight and grain moisture content were determined. All yields were corrected to 13.5% moisture content.

Experimental design. A randomized complete block design with four blocks and a factorial set of treatments was set up each season. The factors and levels in 1984 and 1985 were: two soft red winter wheat cultivars, Blueboy and Severn; two nitrogen rates, 67 and 168 kg ha^{-1}; and three Cl levels, none and 280 kg Cl ha^{-1} from either $CaCl_2$ or KCl sources. Blueboy has no known resistance to powdery mildew, whereas Severn has a race-specific resistance mechanism that is no longer effective against the prevalent mildew population. A third cultivar, Massey, with effective powdery mildew resistance was included in 1986, and nitrogen rates on all plots were reduced to 56 and 112 kg ha^{-1} to reduce the risk of lodging. The Cl treatments in 1986 were modified on the basis of previous results into a 2 × 2 factorial set of K rate, 28 and 280 kg ha^{-1}, and K source, KCl and K_2SO_4, treatments.

Data collection and analysis. Powdery mildew was scored visually on a whole-plot basis at the Zadoks et al (16) decimal growth stage code (DC) 68 using a 0–9 scale on 31 May 1984 and the Horsfall-Barratt scale (4) on 14 May 1985. Disease assessments in 1986 were made on four dates: 1 May, 9 May, 15 May, and 21 May, corresponding to DC 37, 52, 64, and 72, respectively. Separate disease assessments were made at four consecutive canopy heights, flag leaf (L1) through

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flag leaf−3 (L4). Each canopy height disease assessment was the mean of visual assessments of six leaves per plot and was recorded as a percentage of leaf area diseased using the diagrams of James (6). Area under the disease progress curve (AUDPC) was calculated as described by Shaner and Finney (11) for each canopy height. A mean canopy AUDPC was calculated using the mean of the disease assessments for L1 through L4. The L3, L4, and mean canopy AUDPCs were calculated over the first three assessment periods because of leaf senescence that occurred by the fourth assessment. All data were subjected to an analysis of variance. Mean separations for significant factors or interactions having two or more degrees of freedom were calculated using Duncan's multiple range test.

RESULTS

Nitrogen. Powdery mildew significantly increased in response to increased N fertility in every trial (Tables 1 and 2). In 1986, however, the increase of PM due to increased N fertility was significant only at the L1 canopy height (Table 3). Significant treatment interactions with N occurred only in 1984 (Table 1). The interaction with the factor cultivar was due to a greater increase of PM in response to N on the susceptible cultivar, Blueboy, than on Severn. Increased N fertility also significantly increased yields in every trial (Tables 4 and 5). There were no significant interactions with N fertility affecting yield. Therefore, the addition of 101 kg N ha^{-1} over the conventional N fertility level significantly increased the overall mean grain yields from 4,550 to 5,474 kg ha^{-1} in 1984 and from 5,227 to 5,554 kg ha^{-1} in 1985. The addition of 56 kg N ha^{-1} over the conventional fertility level in 1986 significantly increased the overall mean grain yields from 5,391 to 5,800 kg ha^{-1}.

Cultivar. Cultivar differences in disease development were significant in all trials and at all canopy heights in 1986 (Tables 1–3). Where significant fertility interactions with cultivar occurred, only the magnitude of the disease levels was affected, and not the treatment or cultivar ranks (Tables 1–3). Disease development was greatest on Blueboy (the suscept), reduced on Severn, and, in 1986, lowest on Massey. Cultivar yields were significantly different in all but the 1984 trial (Tables 4 and 5).

Chloride. The severity of PM at DC 68 was significantly reduced with KCl but not $CaCl_2$ in 1984 and 1985 (Table 1). The reduction of PM below the no Cl level with KCl in 1984 was, furthermore, only significant at the high rate of N and was not significantly different from the reduction due to $CaCl_2$. There were no interactions with Cl in 1985. Therefore, over all other treatment combinations the mean PM severities in 1985 were 6.7, 6.4, and 5.8 for the no Cl, $CaCl_2$, and KCl treatments, respectively.

Table 1. Effect of nitrogen rate, chloride rate, chloride source, and cultivar on severity of powdery mildew (PM) of winter wheat in 1984 and 1985

Nitrogen (kg ha^{-1})	Chloride[w] (kg ha^{-1})	PM severity 1984[x]			PM severity 1985[y]		
		Blueboy	Severn	Mean	Blueboy	Severn	Mean
67	0	2.2	1.2	1.8 c[z]	7.0	5.8	6.4
67	280 (Ca)	2.8	2.0	2.4 c	6.5	5.8	6.2
67	280 (K)	3.5	1.2	2.4 c	6.0	4.8	5.4
168	0	7.2	3.8	5.5 a	7.8	6.3	7.0
168	280 (Ca)	5.5	3.8	4.6 ab	6.8	6.5	6.6
168	280 (K)	5.5	2.5	4.0 b	7.0	5.5	6.2

[w] Chloride source in parentheses; Ca = calcium chloride, K = potassium chloride.

[x] Based on a mean of four replicates using a 0–9 scale where 0 = no infection and 9 = severe infection throughout plant canopy. Assessment was made at anthesis on 31 May 1984. Significant main effects and interactions were: cultivar ($P = 0.001$), nitrogen ($P = 0.001$), cultivar × nitrogen ($P = 0.025$), and nitrogen × chloride ($P = 0.025$).

[y] Based on a mean of four replicates using the Horsfall-Barratt scale. Assessment was made at anthesis on 14 May 1985. Significant main effects were: cultivar ($P = 0.001$), nitrogen ($P = 0.01$), and chloride ($P = 0.025$). There were no significant ($P = 0.05$) interactions.

[z] Values followed by the same letter do not differ significantly ($P = 0.05$) based on Duncan's multiple range test.

Table 2. Effect of nitrogen rate, potassium rate, potassium source, and cultivar on mean canopy area under disease progress curve (AUDPC) for powdery mildew in 1986

Nitrogen (kg ha^{-1})	Potassium (kg ha^{-1})	Mean canopy AUDPC (% severity-days)[z]					
		Blueboy		Severn		Massey	
		KCl	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4
56	28	63.7	70.7	46.7	48.1	10.5	19.4
56	280	38.0	51.7	35.3	55.7	11.4	14.2
112	28	59.7	79.9	46.3	51.8	15.4	16.7
112	280	41.7	65.8	35.3	53.8	15.6	14.6

[z] Calculated for 1–15 May 1986, using the mean of disease severity values over four canopy positions (L1, L2, L3, and L4), each consisting of four replicates of six individual leaf disease assessments at each assessment period. Significant main effects and interactions were: potassium rate ($P = 0.001$), potassium source ($P = 0.001$), cultivar ($P = 0.001$), and potassium rate × cultivar ($P = 0.002$).

Powdery mildew development as measured by the mean canopy AUDPC in 1986 was significantly reduced by Cl (Table 2). There were no significant interactions with Cl, so the overall mean reduction of PM due to Cl was 10.2% severity-days (units). The rate of K also significantly reduced PM development, but the magnitude of the reduction depended on the cultivar. The mean difference in AUDPC between low and high rates of K was 19.2, 3.2, and 1.5 units for Blueboy, Severn, and Massey, respectively.

The significant reduction in PM development in response to Cl in 1986 occurred at the L3 and L4 canopy heights but not at the L1 and L2 heights (Table 3). The mean reduction in AUDPC due to Cl at L4 depended on the culitvar and was 60, 34, and 6 units for Blueboy, Severn, and Massey, respectively. The magnitude of the response at L3 was not significantly affected by other factors and averaged 5.9 units. The rate of K also significantly reduced PM development at L1, L3, and L4 (Table 3). The magnitude of the reduction due to rate of K at L3 and L4 but not L1 depended on the cultivar. The AUDPCs were reduced at the high rate of K by 13, 0, and 0 units at L3 and by 58, 12, and 6 units at L4 for Blueboy, Severn, and Massey, respectively. The overall mean reduction of the AUDPC at L1 was small, from 25 to 22 units by using the high rate of K.

A significant Cl effect on yield occurred in 1984 and 1985 but not in 1986 (Tables 4 and 5). There were no significant interactions with Cl in 1984, when $CaCl_2$ significantly improved yields over no Cl but yields were not significantly different from those produced with KCl. The cultivar by chloride interaction in 1985 resulted from Severn yields that were not affected by either source of Cl, but Blueboy yields were significantly improved with the addition of Cl regardless of source.

DISCUSSION

Nitrogen. A primary component of intensive management of wheat is increased N fertility. These data support the previously established findings that increased N fertility can increase PM severity (5). Recently, split applications of N have received more attention in agronomic studies as a means of reducing N losses and optimizing yields. Split applications of N and somewhat lower rates were used in 1986 to conform with evolving refinements in intensive management practices in Maryland. The lack of N-mediated increase in PM at all but the L1 height in 1986 may have been a result of the changes in the rate and timing of fertilizer applications. The base N level was applied to all the plots in March with all the K rate and source treatments, and then additional N was applied to produce the high N rate treatments almost 1 mo later. The overall magnitude of the response may thus have been reduced by the combination of reduced N rate and decreased time for epidemic development at high N.

Cultivar. All fertility effects on mildew were more readily apparent on the susceptible cultivar, Blueboy, and were virtually undetectable on Massey, the cultivar with an effective resistance mechanism. Severn, with the defeated race-specific resistance mechanism, was consistently intermediate in response. The intermediate level of response suggests that either Severn possesses a previously unknown general race-nonspecific resistance mechanism or some residual effect of the race-specific resistance mechanism may be active as discussed by Nass et al (8). Although the magnitude of the disease reactions to fertility varied with cultivars, the pattern was the same. Thus, use of a susceptible cultivar is indicative of the type of response and makes it easier to detect the effect.

Chloride. Chloride soil amendments can, under certain conditions, reduce the development of powdery mildew. The 1984 and 1985 results, using single point-in-time disease assessments, showed that significant reductions in PM could be achieved in some seasons with spring-applied KCl. This is in agreement with Trolldenier, who recently demonstrated the effect of KCl on powdery mildew of barley (15). Powdery mildew in our studies was also reduced with $CaCl_2$, but the reductions were not statistically significant. Thus, it appeared that K, either alone or combined with Cl, was required to reduce mildew to a level we could statistically resolve.

Further work was designed to examine and potentially separate the K and Cl effects and to improve the resolution of the experiments. Shaner and Finney (11) believe that AUDPC analysis is sensitive to slow-mildewing or rate-reducing type of responses. Fry (2) found that AUDPC could also reflect differences in epidemic onset. AUDPC analysis was therefore chosen as a simple procedure with the potential to detect differences in epidemic development regardless of mode. Using AUDPC analysis, we confirmed in 1986 that increasing K fertility decreases powdery mildew development. This is not inconsistent with most of the literature reports on K, since most do not directly compare sources

Table 3. Effect of nitrogen rate, potassium rate, potassium source, and cultivar on area under the disease progress curve (AUDPC) for powdery mildew at individual canopy positions in 1986

		AUDPC (% severity-days)					
		Blueboy		Severn		Massey	
Nitrogen ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)	KCl	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4
L1[w]							
56	28	32.3	31.4	27.1	29.9	8.3	11.2
56	280	27.6	27.6	25.7	28.5	8.1	12.8
112	28	39.4	37.5	30.3	29.4	11.2	16.4
112	280	29.9	33.7	27.0	29.5	10.4	9.0
L2[x]							
56	28	56.5	55.9	54.7	56.5	19.4	27.5
56	280	52.9	52.5	50.1	60.2	24.0	24.6
112	28	59.8	58.2	54.8	55.3	22.6	23.6
112	280	50.4	55.2	48.0	57.7	29.0	23.5
L3[y]							
56	28	76.8	66.1	43.2	47.4	12.6	21.3
56	280	45.2	56.3	42.4	54.2	14.4	19.2
112	28	63.2	70.6	48.6	51.1	19.9	18.4
112	280	53.8	67.4	37.4	57.6	19.2	18.1
L4[z]							
56	28	127.2	163.7	90.9	94.3	17.3	35.2
56	280	57.6	103.3	52.6	114.5	16.0	19.2
112	28	116.3	196.4	84.3	106.7	25.2	27.8
112	280	66.2	144.8	55.8	103.8	22.6	22.8

[w] L1 (flag leaf) AUDPC was calculated for 1–21 May. Significant main effects were: nitrogen ($P = 0.015$), potassium ($P = 0.011$), and cultivar ($P = 0.001$). There were no significant ($P = 0.05$) interactions.

[x] L2 (penultimate leaf) AUDPC was calculated for 1–21 May. Significant main effects were: cultivar ($P = 0.001$). There were no significant ($P = 0.05$) interactions.

[y] L3 (second leaf below flag leaf) AUDPC was calculated for 1–15 May. Significant main effects and interactions were: potassium source ($P = 0.015$), cultivar ($P = 0.001$), and potassium × cultivar ($P = 0.033$).

[z] L4 (third leaf below flag leaf) AUDPC was calculated for 1–15 May. Significant main effects and interactions were: potassium source ($P = 0.001$), potassium ($P = 0.001$), cultivar ($P = 0.001$), potassium × cultivar ($P = 0.003$), and potassium source × cultivar ($P = 0.004$).

Table 4. Effect of nitrogen rate, chloride rate, chloride source, and cultivar on mean grain yields of winter wheat in 1984 and 1985

		1984 Yield ($kg\ ha^{-1}$)[y]		1985 Yield ($kg\ ha^{-1}$)[z]	
Nitrogen ($kg\ ha^{-1}$)	Chloride[x] ($kg\ ha^{-1}$)	Blueboy	Severn	Blueboy	Severn
67	0	4,353	4,357	4,750	5,579
67	280 (Ca)	4,732	5,070	5,016	5,584
67	280 (K)	4,475	4,410	5,009	5,413
168	0	5,051	5,591	5,054	5,948
168	280 (Ca)	5,454	5,771	5,373	5,934
168	280 (K)	5,304	5,616	5,332	5,693

[x] Chloride source in parentheses; Ca = calcium chloride, K = potassium chloride.

[y] Based on four replicates at 13.5% moisture. Significant main effects were: nitrogen ($P = 0.001$) and chloride ($P = 0.025$). There were no significant ($P = 0.05$) interactions.

[z] Based on four replicates at 13.5% moisture. Significant main effects and interactions were: cultivar ($P = 0.001$), nitrogen ($P = 0.001$), and cultivar × chloride ($P = 0.025$).

Table 5. Effect of nitrogen rate, potassium rate, potassium source, and cultivar on mean grain yields of winter wheat in 1986

		Yield ($kg\ ha^{-1}$)[z]					
		Blueboy		Severn		Massey	
Nitrogen ($kg\ ha^{-1}$)	Potassium ($kg\ ha^{-1}$)	KCl	K_2SO_4	KCl	K_2SO_4	KCl	K_2SO_4
56	28	4,773	4,879	5,342	5,607	5,916	5,820
56	280	5,199	5,080	5,152	5,310	5,930	5,687
112	28	5,213	5,711	5,568	5,865	6,260	6,034
112	280	5,315	5,406	5,764	5,761	6,412	6,286

[z] Based on four replicates at 13.5% moisture. Significant main effects were: nitrogen ($P = 0.001$) and cultivar ($P = 0.001$). There were no significant ($P = 0.05$) interactions.

of K (9). Furthermore, Cl was not only more effective than the SO_4 source of K, but also reduced PM development regardless of the rate of K applied. The resolution of procedures used in the initial trials apparently limited the detection of PM reduction to the combined effect of K and Cl from KCl and not the effect of Cl from $CaCl_2$. Detailed disease assessments over time and analysis of AUDPC could be used to confirm the effect of Cl from other sources. However, the magnitude of the effect of Cl alone appears to be too small to be of practical value similar to the limited rate reductions achieved for stripe rust (12).

The response to Cl was generally found on the lower canopy leaves. Disease development was limited in the upper canopy because of nonconducive environmental conditions in late spring and early summer. Since K and Cl are known to be very mobile and other studies have demonstrated accumulation of Cl in the flag leaves (14), the higher disease levels at the lower canopy positions allowed a greater range of PM to develop because of treatment effects.

Yield increases, although apparent in 1984 and 1985, did not correspond to the treatment effects on PM, except for the susceptible cultivar in 1985. Because similar magnitude changes in PM also occurred with Severn in 1985, but without an effect on yield, it seems unlikely that the yield response in Blueboy was due to PM control. The environmental conditions were generally not conducive for disease development in the upper canopy where disease-yield relationships are more apparent.

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