# Effects of Chloride Fertilizer and Systemic Fungicide Seed Treatments on Common Root Rot of Barley

P. A. SHEFELBINE, Former Graduate Student, and D. E. MATHRE, Professor, Department of Plant Pathology, Montana State University, Bozeman 59717, and G. CARLSON, Agronomist, Northern Agricultural Research Center, Havre, MT 59270

**ABSTRACT**

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Two chloride fertilizers and six systemic fungicides, which inhibit ergosterol biosynthesis, were tested for efficacy in controlling *Cochliobolus sativus* of spring barley in Montana in 1981 and 1982. Nuarimol and imazalil seed treatments increased emergence compared with that observed in uninoculated plots, whereas chloride fertilizers had no effect on plant emergence. Common root rot (CRR) was controlled only with fertilizers containing chloride, indicating that the chloride anion was the probable effective agent. Although most of the fungicides reduced disease ratings, only nuarimol was statistically significant in disease reduction. Significant disease control effected by chloride or nuarimol use did not increase grain yield. Overall, the results suggest that healthy plants in a diseased plant population may compensate for stand reduction by an increase in other yield components. These results would render apparent disease control economically unfeasible under conditions of mild or moderate CRR disease.

Additional key words: *Helminthosporium sativum*

Common root rot (CRR), a disease complex of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L. emend. Bowden), is characterized by blighting, stunting, and death of seedlings, stunting of mature plants, and necrotic lesions on seminal and crown roots, subcrown internode (SCI), and crown and basal stem tissues (8,12). The anamorph of *Cochliobolus sativus* (Ito & Kurib) Drechs. ex Dastur (*Bipolaris sorokiniana* (Sacc.) = *Helminthosporium sativum* P.K.B.) is considered the primary pathogen, but *Fusarium culmorum* (W. G. Smith) Sacc. and *F. graminearum* Schwabe have been reported as secondary incitants (17).

CRR severity has been evaluated by rating SCI necrosis as none, slight, moderate, or severe (19). By integrating the incidence and relative yield loss of each severity class, a disease rating has been obtained. This rating is a relative number, expressed as a percentage; it represents disease intensity and is useful in predicting yield loss (19). The percent disease rating has been used to measure disease progression (18,22), cultivar resistance to CRR (3,11), and the efficacy of cultural practices (2,15).

For barley in the prairie provinces of Canada, an annual yield loss of 10.3%, totaling 18 million bushels, has been attributed to CRR (12). Yield loss was determined from the yield reduction of individual diseased plants in a diseased plant population and was attributed to fewer harvestable tillers for severely diseased plants. However, Piening (11) observed earlier that yield loss of individual barley plants in a diseased plant population was not correlated with disease intensity. Recently, Grey and Mathre (3) showed that the grain yield of a diseased plant population was not reduced by significantly increasing disease intensity. They attributed this lack of yield reduction to barley's ability to compensate for initial yield component reduction with an increase in later-formed yield components. Several researchers suggest that healthy plants may yield more than normal in a diseased plant population because of reduced competition for water and nutrients from neighboring diseased plants (9,20).

Crop rotation (6), residue management (7,13,16), seeding date and depth, and seed size (2) all affect CRR severity but do not provide adequate control of the disease. Although cultivars differ greatly in mature plant resistance, no commercial cultivars have a high level of resistance to CRR (10). Adequately fertilized barley has less CRR than overfertilized or underfertilized barley. Yield response, however, is related to fertility level and not to CCR control (7,15). Recently, several systemic fungicides have been shown effective in reducing disease intensity, but yields have not usually been increased (14,20).

In Oregon, increased yields in winter wheat have resulted where chloride fertilizer has been applied to wheat soils infested with the take-all root rot pathogen *Gaeumannomyces graminis* var. *tritici* (1).

In this paper, we report how chloride fertilizers and several systemic fungicides affect disease levels, grain yield, and yield components of CRR-diseased barley.

## MATERIALS AND METHODS

**1981 Tests.** Oat kernels colonized by *C. sativus* were produced as described previously (3) for use as inoculum. In addition, colonized oat kernels were autoclaved for 60 min at 121 C and added to control plots. Infested or uninfested oat kernels were packaged in 20-g lots and added with the seed at the time of planting.

Two potassium (K) fertilizers were used: 100% pure potassium chloride (KCl) and 43% pure potassium sulfate ($K_2SO_4$). Rate of application was 22.4 kg of K/ha. Fertilizer and seed were placed simultaneously in the furrow.

Six experimental fungicides were tested as seed treatments (Table 1). Seed lots (500-g) were treated either with fungicide or distilled water. Fungicides were applied at 110% of the recommended rate to compensate for adherence of fungicide to equipment (4). Seed was treated as it tumbled in a rotating drum.

Washonupana, a two-row, hull-less waxy, Smyrna-type barley, was chosen for this study because it was being considered for use in Montana for malt syrup production. This cultivar is hull-less and susceptible to mechanical damage during threshing, thus it has only a moderate germination potential. Seed remaining on a mesh screen 0.22 × 1.9 cm after passage through a mesh screen 0.26 × 1.9 cm was used for planting.

The experimental plot was located on the Arthur H. Post Research Farm, five miles west of Bozeman. The plot had a small-grain/fallow cropping history and an Amsterdam silty clay loam (fine silty mixed typic cryoborall) soil type. Moisture and nutrients were not limiting.

Twenty-four treatment combinations from two factors were planted in a completely randomized block design and replicated four times. Factor 1 contained three fertilizer treatments (no fertilizer,

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KCl fertilizer, and $K_2SO_4$ fertilizer). Factor 2 contained eight fungicide-inoculum treatments (untreated seed plus autoclaved inoculum, untreated seed plus inoculum, and inoculated seed treated with one of six fungicides).

On 22 May 1981, the experimental plot was planted with a four-row plot seeder. Seed, fertilizer, and inoculum were drilled together (4 cm deep) in four-row, 3-m plots with rows spaced 30 cm apart. The middle two rows were sown with 150 seeds; the outer two rows were sown with 7 g of seed. Data were collected from only three of the four replicated blocks because of rodent destruction of the fourth block.

At the three-leaf stage (1 on the Feekes scale [5]), plants in the center two rows of each plot were counted. Yield and the following component data were obtained from the middle two rows of each plot: harvestable tillers per row, number of kernels per spike, total grain yield per row, and 1,000-kernel weight. Harvestable tillers, counted during the soft-dough stage (11.2 on the Feekes scale), were those with spikes in the upper one-third of the plant canopy. During the hard-dough stage (11.3 on the Feekes scale), 20 harvestable spikes per row were randomly collected for determining the number of kernels per spike. At harvest, all remaining plants were threshed with a Vogel grain thresher. Grain harvested, plus kernels obtained from the kernel number per spike determination, constituted total grain yield per row. Thousand-kernel weight was determined by weighing 250 machine-counted kernels.

After harvest, we discovered that the cultivar selected produced very short SCIs that were difficult to evaluate for disease symptoms. For this reason, a minimum of 50 SCIs from each replicate were rated with a two-class system where SCIs with no discoloration or only pinpoint lesions were rated healthy and SCIs with moderate or severe necrosis were rated diseased. Percent diseased SCIs equals percent disease rating.

Plant stand and yield data obtained from each of the two middle rows were averaged to obtain one value per plot. An analysis of variance on plot means was performed on plant stand, percent disease ratings, 1,000-kernel weight, and kernel number per spike. Covariance analysis indicated that plant stand differences accounted for a significant ($P = 0.01$) amount of grain yield and harvestable tiller number differences between treatments. Therefore, an analysis of variance on plot means was performed for grain yield and harvestable tillers per row after adjustment for plant stand of the two middle rows.

**1982 Tests.** In 1982, additional tests were conducted in a number of locations to determine the effect of several systemic seed treatments on yield. These tests were conducted in fields with a history of small-grain cereal production and a low to moderate level of *C. sativus* inoculum. No additional inoculum was added. Clark barley (CI 15857), a two-row, high-yielding malting barley widely grown in Montana, was used. The seed was treated with either triadimenol, imazalil, or nuarimol. The tests were planted at the Montana Agricultural Research centers at Moccasin and Havre and at the A. H. Post farm near Bozeman. With one exception, the plots consisted of three rows 6.1 m long with at least four replicates. The exception was an experiment conducted on the Northern Agricultural Research Center at Havre, where large (0.53 ha/treatment) plots were seeded and harvested with commercial equipment. Here, the test area was divided into two areas, one having been summer-fallowed, the other having been in barley the previous year. Clark barley was used with and without treatment with 0.05 g a.i./kg of imazalil. Random selections of plants were pulled 3 wk postanthesis (10.5 on the Feekes scale) and the SCI rated for root rot according to the method developed by Ledingham et al (8). A four-class system was used that year because we felt that an additional two classes would increase the precision of the experiment.

The interaction of chloride fertilizers

**Table 1.** Active ingredients, formulations, and application rates of six systemic fungicide seed treatments

| Active ingredient | Chemical name | Formulation (% a.i.) | Application rate (a.i./kg seed) |
|---|---|---|---|
| | **Triazoles** | | |
| Etaconazole (CGA-64251) | 1-[2-(2,4-dichlorophenyl)-4-ethyl-1,3-dioxolan-2-yl)methyl]-1*H*-1,2,4-triazole | 13.5L[a] | 0.015 ml |
| Triadimenol (Baytan 150FS) | *β*-(4-chlorophenyl)-*α*-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol | 14.0FL | 0.150 ml |
| Furmecyclox (GUS 215) | 2,5-dimethyl-*N*-cyclohexyl-*N*-methoxy-3-furan-carboxamide | 50.0L | 0.980 ml |
| | **Imidazoles** | | |
| Imazalil (Fungaflor) | 1-{2-(2,4-dichlorophenyl)-2-(2-propenyloxy)ethyl}-1*H*-imidazole | 5.0FL | 0.100 ml |
| Prochloraz (BTZ 40502) | *N*-propyl-*N*-(2-(2,4,6-trichlorophenoxy)ethyl)imidazole-1-carboxamide | 40.0L | 1.200 ml |
| | **Pyrimidine** | | |
| Nuarimol (EL 228) | *α*-(2-chlorophenyl)-*α*-(4-fluorophenyl)-5-pyrimidinemethanol | 98.0P | 0.300 g |

[a] L = liquid, FL = flowable, and P = powder.

**Table 2.** Effects of fertilizer and fungicide-inoculum treatments on plant stand, disease ratings, grain yield, and yield components of common root rot-diseased Washonupana barley in 1981

| Treatment | Plant stand (no./3 m) | Disease ratings (%) | Grain yield (g/2.4 m) | Harvestable tillers (no./3 m) | 1,000-Kernel wt (g) | Kernels/spike (no.) |
|---|---|---|---|---|---|---|
| Fertilizer | | | | | | |
| None | 52.2 a[z] | 54.6 b | 206.1 a | 199.6 a | 38.8 a | 19.8 ab |
| KCl | 47.9 a | 36.9 a | 199.7 a | 198.1 a | 40.3 b | 19.4 a |
| $K_2SO_4$ | 49.5 a | 57.2 b | 207.3 a | 192.0 a | 39.6 ab | 19.9 b |
| Fungicide-inoculum | | | | | | |
| Uninoculated | 64.9 e | 56.8 bc | 188.3 a | 177.9 a | 39.5 ab | 19.5 ab |
| Inoculated | 45.5 bc | 53.3 bc | 212.0 a | 188.9 a | 39.2 ab | 20.0 ab |
| Imazalil | 62.6 de | 45.4 ab | 202.5 a | 207.2 ab | 39.8 ab | 19.8 ab |
| Triadimenol | 53.7 cd | 49.4 abc | 196.0 a | 187.7 a | 40.7 b | 19.4 ab |
| Prochloraz | 43.6 ab | 47.2 ab | 198.1 a | 189.0 a | 39.1 a | 19.2 a |
| Nuarimol | 55.8 de | 36.0 a | 219.2 a | 235.7 b | 39.2 a | 19.7 ab |
| Furmecyclox | 35.4 a | 64.3 c | 208.3 a | 193.9 a | 39.6 ab | 20.5 b |
| Etaconazole | 37.6 ab | 44.1 ab | 210.4 a | 192.5 a | 39.4 ab | 19.6 ab |

[z] Column means followed by common letters are not significantly ($P = 0.05$) different according to the Student-Newman-Keuls multiple comparison test. Letters indicating significance are valid only within either the fertilizer or fungicide-inoculum sections of this table.

and imazalil seed treatment was investigated further in 1982 on two farms with histories of low to moderate levels of CRR near Hardin, MT. Various levels of $NH_4Cl$ or KCl were banded with the seed or broadcast over the soil surface before seeding. Clark barley, with and without 0.05 g a.i./kg of imazalil, was seeded with a cone-type plot seeder in a randomized complete block design. Each plot was 6.1 m long by 3.7 m wide and replicated four times. At the milky dough stage (11.2 on the Feekes scale), at least 100 plants were dug and the SCIs rated for severity of CRR according to the method developed by Ledingham et al (8). Yield, test weight, and percent plump kernels were determined using standard small-plot equipment and techniques.

## RESULTS

**1981 Tests.** Significant ($P = 0.05$ unless otherwise noted) interactions between the fertilizer factor and the fungicide-inoculum factor were not detected for any of the measured parameters. Therefore, reported data for each factor were averaged across the other factor.

Less than 50% of planted seed emerged, regardless of treatment; however, inoculation significantly reduced emergence an additional 30% (Table 2). Emergence was increased significantly by seed treatment with imazalil or nuarimol compared with uninoculated plots but was not affected by seed treated with triadimenol, etaconazole, or prochloraz. Furmecyclox was phytotoxic and significantly reduced emergence below that observed for inoculated plots (Table 2). Fertilization with KCl or $K_2SO_4$ did not affect emergence (Table 2).

CRR was moderate in both uninoculated and inoculated plots; however, disease was not increased by artificial inoculation. Because the pathogen could not be isolated from the autoclaved inoculum added to control plots, the presence of a residual pathogen population was indicated (Table 2).

Fertilization with KCl significantly reduced disease ratings, but fertilization with $K_2SO_4$ had no effect, indicating that the chloride anion was probably the effective agent controlling CRR (Table 2). Although all fungicides except furmecyclox had lower disease ratings than the check, only nuarimol was significant (Table 2).

Grain yield and yield components were not affected by inoculation, reflecting similar disease pressure in both inoculated and uninoculated plots (Table 2).

Even though disease ratings were significantly reduced with KCl fertilization, grain yield was not subsequently increased. KCl, but not $K_2SO_4$, significantly increased 1,000-kernel weight compared with the unfertilized check. There was a significant difference in kernel number per spike between KCl and $K_2SO_4$ treatments but not compared with the unfertilized check. None of the fertilizer treatments affected harvestable tillers per row. These effects were observed across both inoculated and uninoculated rows (Table 2).

Grain yield was not affected by any fungicide treatment (Table 2). This lack of effect on grain yield by any fungicide treatment was reflected by a general lack of effect on yield components. With the exception of imazalil-treated plots, rows planted with nuarimol-treated seed had significantly more harvestable tillers than did the other treatments. Plots treated with furmecyclox had a significantly greater kernel number per spike than plots treated with prochloraz, and plots treated with triadimenol had a significantly greater 1,000-kernel weight than plots treated with prochloraz or nuarimol. However, 1,000-kernel weight and kernel number per spike were not increased or decreased by any fungicide treatment compared with either the inoculated or uninoculated plots (Table 2).

**1982 Tests.** In the small-plot tests, seed treatment alone did not result in significant yield increases at any of the three locations (Table 3). Because of shallow seeding, there were no SCIs available to score for disease.

In the large-plot test at Havre, imazalil treatment reduced the severity of disease but had a nonsignificant effect on yield or test weight (Table 4).

In the tests studying the interaction of chloride fertilizer and imazalil seed treatment on CRR, imazalil reduced the disease score significantly at one of the two sites, but no yield response to treatment was noted at either site. However, there was a significant response to fertilizer treatment at site 1, where both $NH_4Cl$ and KCl reduced the severity of CRR and increased yield (Table 5). At site 2, the severity of CRR was lower and although both $NH_4Cl$ and KCl reduced disease severity, the differences were not significant and no yield response was observed.

## DISCUSSION

CRR severity was reduced only with KCl but not $K_2SO_4$ fertilization. Similar effects of the chloride anion have been

**Table 3.** Effect of systemic seed treatment on yield of Clark barley at three Montana locations in 1982 in small-plot tests

| Treatment | Dose (g a.i./kg) | Yield (kg/ha) Bozeman | Moccasin | Havre |
|---|---|---|---|---|
| Untreated | ··· | 4,356 a[z] | 2,571 a | 3,962 a |
| Triadimenol | 0.05 | 4,048 a | 2,564 a | 4,110 a |
| | 0.10 | 3,739 a | ··· | ··· |
| Imazalil | 0.04 | 4,088 a | ··· | ··· |
| | 0.08 | 4,001 a | 2,625 a | 3,962 a |
| Nuarimol | 0.08 | 3,981 a | ··· | ··· |
| | 0.15 | 3,920 a | 2,135 a | 3,478 a |

[z] Column means followed by a common letter are not significantly ($P = 0.05$) different according to the Student-Newman-Keuls multiple comparison test.

**Table 4.** Effect of imazalil seed treatment of Clark barley in large plots at Havre, MT, in 1982

| Treatment | Dose (g a.i./kg) | Disease score[y] (%) | Yield (kg/ha) | Test weight (kg/hl) |
|---|---|---|---|---|
| Untreated | ··· | 40 | 3,472 a[z] | 66.3 a |
| Imazalil | 0.05 | 35 | 3,532 a | 65.9 a |

[y] Plants with moderate or severe rotting of the subcrown internode.
[z] Column means followed by a common letter are not significantly ($P = 0.05$) different according to the Student-Newman-Keuls multiple comparison test.

**Table 5.** Effect of chloride fertilizer on common root rot of Clark barley near Hardin, MT, in 1982[x]

| Fertilizer | Root rot score[y] (%) | Yield (kg/ha) | Test weight (kg/hl) |
|---|---|---|---|
| Site 1 | | | |
| $NH_4Cl$ | 1.7 a[z] | 3,396 a | 70.8 a |
| KCl | 1.4 a | 3,412 a | 70.0 a |
| None | 8.4 b | 2,663 b | 70.0 a |
| Site 2 | | | |
| $NH_4Cl$ | 4.3 a | 4,098 a | 68.8 a |
| KCl | 2.3 a | 4,063 a | 68.8 a |
| None | 6.4 a | 3,986 a | 70.6 b |

[x] Averaged across imazalil-treated and untreated seed treatments and across three fertilizer treatments of 16.8 kg/ha banded, 16.8 kg/ha broadcast, and 50.4 kg/ha broadcast.
[y] Percentage of plants with severe rot on the subcrown internode.
[z] Column means for each site followed by a common letter are not significantly ($P = 0.05$) different according to the Student-Newman-Keuls multiple comparison test.

observed for take-all disease (1). Although chloride fertilizers reduced disease ratings under moderate disease conditions, yield was only significantly increased at site 1 in 1982 (Table 5). Grain yield and yield components were not increased by KCl even though it significantly reduced disease severity (Table 2). Additionally, under the low disease pressure observed at site 2, yield was not increased by chloride fertilization even though disease was reduced (Table 5). Thus, chloride added at the rates used in this study reduced CRR severity, but positive effects on yield or yield components were the exception, not the rule.

Treatment with all of the systemic, ergosterol biosynthesis-inhibiting fungicides except furmecyclox reduced disease ratings. Even though only nuarimol was statistically significant in disease reduction, our results support previous reports (14,20, 21) that indicate that nuarimol, imazalil, and triadimenol all reduce CRR.

Emergence varied significantly among fungicide treatments (Table 2). Visual observations indicated no apparent plant death between emergence and harvest. Thus, initial plant emergence mirrored final plant stand. Of the factors in 1981 influencing yield and harvestable tiller number, covariance statistics indicated that plant stand had a highly significant ($P = 0.01$) impact. Therefore, we removed this variable to increase precision in determining if reduced disease affected yield and harvestable tiller number. Grain yield was not increased when disease ratings were significantly reduced by nuarimol (Table 2). Similarly, grain yield was not reduced when disease ratings were significantly increased by furmecyclox. Compared with all other treatments, an increase in harvestable tillers per row occurred with nuarimol, but a decrease in other yield components (kernels per spike and 1,000-kernel weight) resulted in a lack of a significant yield increase.

In 1982, seed treatment with triadimenol, imazalil, or nuarimol had no effect on grain yield at any of the three locations. Similarly, even though seed treatment with imazalil reduced CRR severity in the large-plot Havre test (Table 4), yield, or test weight were not significantly increased.

These collective results suggest that under Montana conditions, plants in a population are capable of responding to CRR-induced stress, or lack of such stress, in adjacent plants. Healthy plants next to diseased plants would yield more than normal because of reduced competition. However, the yield for the population of plants would not change. The exception may be where severe disease conditions exist, the relatively few healthy plants would be unable to compensate to overcome the yield losses caused by CRR. Therefore, in situations where CRR is not abnormally severe, use of protective measures such as systemic seed treatments or chloride fertilizer may not be cost-effective. Where the disease situation is more severe, their use may be justified.


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