CHLORIDE FERTILITY: SMALL GRAIN VARIETY AND DISEASE RESPONSES

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ABSTRACT

For spring wheat (*Triticum aestivum* L.), chloride fertilizer added to low chloride-testing soil results in a positive yield gain 70 % of the time. Some, but not all, of these yield responses have been attributed to chloride interaction with disease susceptibility. Because soil fertility and disease suppression are among the most important management tools used by farmers, additional research on the interaction between chloride fertility and disease suppression is needed. Our objective was to measure the chloride and disease responses of two hard red spring wheat cultivars under controlled environments. A greenhouse experiment was conducted in which nutrient solutions containing different levels of potassium chloride (0, 20, or 80 mM) were applied to different hard red spring wheat cultivars ('Butte 86' – moderately leaf rust resistant; and 'Ingot' – moderately leaf rust susceptible) that were grown in sand culture for 3 weeks. Plants were subsequently inoculated with leaf rust (*Puccinia triticina* Ericks.) and evaluated for shoot dry weight, shoot chloride, leaf rust severity, and lesion type after two weeks. The cultivar 'Butte 86' had significantly higher shoot dry weight and significantly less shoot chloride, rust severity, and less severe lesion scores than 'Ingot' across all nutrient solution treatments. In both cultivars, shoot dry weight decreased while shoot chloride concentrations increased when the level of chloride provided in the nutrient solution increased. We measured a significant reduction in rust severity in plants receiving the 80 mM chloride when compared to the other nutrient solution treatments. This reduction in leaf rust severity was not accompanied by a consistent change in the lesion type.

INTRODUCTION

Chloride is essential for a diverse set of functions in plants. These functions include biochemical processes (e.g. photosynthesis and enzyme activation) that occur at the intracellular level and physiological processes that occur at the whole plant level. Critical chloride concentrations needed for whole-plant functions (e.g. osmoregulation, plant development, and interactions with other plant nutrients and disease) are in the 2 to 20 mg g^{-1} dry weight concentration range (Fixen, 1993). Plants absorb chloride at a rate proportional to the level of chloride found in the soil solution. Thus, chloride toxicity is a common problem worldwide (Marschner, 1998). Chloride toxicity poses two general stress factors limiting plant growth. The first occurs when highly-negative osmotic potentials of high chloride concentration soil solutions cause tissue desiccation. The second is accumulation of toxic levels of the element in the plant tissues due to increased chloride absorption in an attempt to maintain internal osmotic potentials which are more negative (Epstein, 1972).

Chloride fertilizer added to low chloride-testing soil (< 34 kg ha^{-1} in the top 60 cm of the soil profile) results in a positive yield gain 70 % of the time in spring wheat (Fixen et al., 1986;

Gelderman and Gerwing, 2001). Positive yield gains may result because of alleviation of chloride deficiency, suppression of diseases, or a combination of disease suppression and improved plant water relations (Marschner, 1998). Yield responses of hard red spring wheat to chloride fertilization are often cultivar specific. In a low chloride-testing soil, Fixen (1987) and Bly et al. (2001) found up to a 20% yield increase in certain cultivars while others were unresponsive. Some, but not all, of these yield responses were explainable based on chloride interaction with disease susceptibility (Fixen, 1987; Fixen, 1993).

Because soil fertility and disease suppression are among the most important management tools used by farmers, additional research on the interaction between chloride fertility and disease suppression is needed. The objective of our research was to measure the chloride and disease responses of two hard red spring wheat cultivars under controlled environments.

MATERIALS AND METHODS

Plant Materials

A greenhouse experiment was conducted in which nutrient solutions containing different levels of potassium chloride were applied to different cultivars of hard red spring wheat. Spring wheat cultivars (obtained from Foundation Seed Stocks Division at South Dakota State University in Brookings SD) used in our experiments were: ‘Butte 86’ and ‘Ingot’. Greenhouse conditions during the experiments were: 22 ± 5 ° C, 50 ± 10 % relative humidity, and natural sunlight supplemented with 75 µmol m^{-2} s^{-1} provided by cool white fluorescent and incandescent bulbs for a 14:10 light:dark photoperiod. Seeds of each spring wheat cultivar were planted in 8 ounce Styrofoam™ cups (with 1 cm diam. drain holes) containing industrial quartz sand (2 seeds cup^{-1}; 10 replications per treatment). Cups were watered to saturation with Johnson’s complete nutrient solution (which contained 50 µM chloride; Johnson et al., 1957) plus additional potassium chloride (0, 20, or 80 mM KCl) every other day.

Experimental Treatments

After growing for three weeks, plants were inoculated with uredospores of the leaf rust pathogen, *Puccinia triticina* Ericks. Spores were suspended in inoculating oil (Soltrol 170) then applied to wheat plants using compressed air to atomize the suspension. After the carrier oil was allowed to evaporate, the plants were placed under ideal conditions for infection (100% RH; 20 to 23ºC) for 24 hours. Plants were returned to ambient conditions in the greenhouse for the remainder of the procedure. After 14 days, plants were evaluated for host response to infection (infection type lesion scores) and rust infection severity. Infection types (Roelfs, et al 1992) include resistant, moderately resistant, moderately susceptible, and susceptible and are based on the pustule development (size) and spore production (estimated visually using a 1 to 4 rating scale; Figure 1). Rust severity, expressed as a percentage of leaf area (Figure 1) was based on a modified Cobb scale (Peterson et al. 1948). Shoots of plants were then harvested and dried to constant weight in a forced air oven (60° C). The tissue was then ground to pass a 60 mesh sieve with a Wiley mill and measured for chloride concentration.

Chloride Measurement and Statistical Analysis

Chloride was extracted from shoot tissue (0.1 mM nitric acid, shaken for ten minutes on a rotary shaker and then filtered through Whatman #1 filter paper) and measured using the mercuric thiocyanate colormetric method (Frankenberger et al., 1996). Shoot dry weight, shoot chloride concentration, and rust severity were analyzed using PROC ANOVA in SAS software. Data mean separations were calculated using the LSD test. Rust lesion categorical scores, which consist of ordinal data, cannot be analyzed using quantitative comparisons (Zar, 1974). For rust lesion scores, the most frequently occurring measurement in data sets (the mode) was calculated and presented. The mode is an unbiased and consistent estimate of the data mean and median (Zar, 1974).

RESULTS AND DISCUSSION

Statistical analysis revealed significant effects of cultivar and nutrient solution chloride treatments on dependent variables (Tables 1 and 2) but no significant two-way cultivar x nutrient solution chloride interactions. These results suggest that the two cultivars studied did not differ from each other in their responses to nutrient solution chloride treatments. Therefore, presentation of results will be based upon data that were pooled across main effect treatments (cultivar and nutrient solution chloride concentration).

The cultivar 'Butte 86' had significantly higher shoot dry weight and significantly less shoot chloride, rust severity, and less severe lesion scores than did 'Ingot' across all nutrient solution treatments (Table 1). It is possible that these differences between cultivars were the result of different genetic makeup of each cultivar. Hall et. al (2000) reported that 'Butte 86' was moderately resistant to leaf rust while 'Ingot' was moderately susceptible. Our results confirm that 'Ingot' is slightly more susceptible to leaf rust than in 'Butte 86' (Table 1).

Shoot dry weight decreased while shoot chloride concentrations increased when the level of chloride provided in the nutrient solution increased from 0 to 80 mM (Table 2). Plants grown using 80 mM chloride nutrient solution had reduced tiller number and a wilted appearance (data not shown) suggesting that this level of chloride in the nutrient solution caused toxicity symptoms in the spring wheat plants. Of interest was the significant reduction in rust severity as measured in plants receiving the 80 mM chloride when compared to the other nutrient solution treatments (Table 2). This reduction in leaf rust severity was not accompanied by a consistent change in the lesion score (Table 2). Sweeny et al. (2000) found that, under field conditions, potassium chloride fertilizer application to susceptible winter wheat cultivars resulted in a 10 % reduction in the amount of leaf area infected by leaf rust. Resistant winter wheat cultivars did not show this same chloride response. Engle et al. (1994) also found that chloride fertilizer suppressed leaf rust severity from 18 % to less than 1 %. Neither of these two authors presented lesion score data from their field studies.

In conclusion, the results of our experiment indicate that the leaf rust severity (but not the lesion score) is reduced in plants given nutrient solutions containing 80 mM potassium chloride. This reduction, which was seen in both moderately resistant and moderately susceptible cultivars, occurred at levels of potassium chloride that caused toxicity to the plants. Additional studies are needed before any conclusions can be reached concerning the practical application of chloride for rust management under field situations.

REFERENCES

Bly, A, H.J. Woodard, and D. Winther, 2001, Chloride effect on hard red spring wheat grain yield and protein near Aurora SD in 2000. 2000 Progress Report #SOIL PR 00-12. Ag. Exp. Stn., Plt. Sci. Dep. South Dakota State Univ. Brookings SD 57007.

Engel, R.E., J. Eckhoff, and R.K. Berg, 1994, Grain yield, kernel weight, and disease responses of winter wheat cultivars to chloride fertilization. Agron. J. 86:891-896.

Epstein, E., 1972, Mineral nutrition of plants: Principles and perspectives. John Wiley and Sons, Inc. New York.

Fixen, P.E., 1987, Chloride fertilization? Recent research gives new answers. Crops Soils 39:14-16.

Fixen, P.E., 1993, Crop responses to chloride. Advances Agron. 50:107-150.

Fixen, P.E., G.W. Buchenau, R.H. Gelderman, T.E. Schumacher, J.R. Gerwing, and F.A. Cholick. 1986. Influence of soil and applied chloride on several wheat parameters. Agron. J. 78:736-740.

Frankenberger, W.T. Jr., M.A. Tabatabai, D.C. Adriano, H.E. Doner. 1996. Bromine, Chlorine, & Fluorine. p. 833 – 867. In: Methods of soil analysis. Part 3. Chemical methods. Book series no. 5. Soil Science Society of America, Madison, WI

Gelderman, R., and J. Gerwing. 2001. A summary of soil test results (Sep. 1999 – June 2000). 2000 Progress Report #SOIL PR 00-11. Ag. Exp. Stn., Plt. Sci. Dep. SDSU. Brookings SD 57007.

Hall, R.G., C. Stymiest, J. Rickertsen, P.D. Evenson. 2000. Small Grains - South Dakota Test Results, Characteristics, and Yield Averages. South Dakota Cooperative Extension Service Pub. # EC774, Brookings, SD. http://www.abs.sdstate.edu/abs/EC774/swheat.htm

Johnson, C.M., P.R. Stout, T.C. Broyer, and A.B. Carlton. 1957. Comparative chloride requirements of different plant species. Plant and Soil 8:337-353.

Marschner, H. 1998. Mineral nutrition of higher plants. Second Edition. Academic Press, London.

Peterson, R.F., A.B. Campbell, and A.E. Hannah. 1948. A diagrammatic scale for estimating rust severity on leaves and stems of cereals. Can. J. Res. Sect. C. 26:496-500.

Roelfs, A.P. , R.P. Singh, and E.E. Saari. 1992. Rust diseases of wheat: Concepts and methods of disease management. CIMMYT, Mexico City.

Sweeney, D.W., G.V. Granade, M.G. Eversmeyer, and D.A. Whitney. 2000. Phosphorus, potassium, chloride, and fungicide effects on wheat yield and leaf rust severity. J. Plant Nutrit. 23:1267-1281.

Zar, J.H. 1974. Biostatistical analysis. Prentice-Hall, Inc. Englewood Cliffs, NJ

Table 1. Main effects of spring wheat variety on shoot chloride concentration, leaf rust percent severity, and leaf lesion score to the rust pathogen. Values represent data averaged across all nutrient solution chloride treatments.

Cultivar	Shoot dry weight	Shoot chloride	Rust severity	Lesion score†
	(g shoot $^{-1}$)	(mg g $^{-1}$ DW)	(% of leaf area)	(1 to 4 scale)
Butte 86	0.773	8.6	44	3 ‡
Ingot	0.715	10.6	62	4
Prob. > *F* §	0.03	0.0003	0.002	

† Lesion score numerical score scale: 1 = resistant; 2 = moderately resistant; 3 = moderately susceptible; 4 = susceptible. See Figure 1.

‡ Values represent the most frequently occurring measurement (mode) in the data set.

§ Values represent probability associated with the *F* value generated in the ANOVA analysis ($\alpha = 0.05$).

Table 2. Effects of nutrient solutions with different levels of potassium chloride on shoot chloride concentration, leaf rust percent severity, and leaf lesion score to the rust pathogen. Values represent data averaged across both wheat cultivars.

Nutrient solution chloride	Shoot dry weight	Shoot chloride	Rust severity	Lesion score†
(mM)	(g shoot $^{-1}$)	(mg g $^{-1}$ DW)	(% of leaf area)	(1 to 4 scale)
0	1.023 a ‡	3.4 a	68 a	4 §
20	0.803 b	8.5 b	54 a	3
80	0.405 c	16.9 c	38 b	4
Prob. > *F* ¶	0.0001	0.0001	0.0002	

† Lesion score numerical score scale: 1 = resistant; 2 = moderately resistant; 3 = moderately susceptible; 4 = susceptible. See Figure 1.

‡ Values within columns followed by the same letter are not significantly different (LSD, $\alpha = 0.05$)

§ Values represent the most frequently occurring measurement (mode) in the data set.

¶ Values represent probability associated with the *F* value generated in the ANOVA analysis ($\alpha = 0.05$).

Rust Severity in Percentage of Leaf Area Covered

5 %	30 %	30 %	30 %	10 %	30 %	20 %	10 %

Resistant Lesions Rating Score = 1	Intermediate Lesions Rating Score = 2 to 3	Susceptible Lesions Rating Score = 4

Figure 1. Examples of wheat leaf rust severity (top) and lesion scores (bottom). The amount of leaf area covered by leaf rust is expressed as percent severity. Lesions are classified as resistant (rating score = 1), intermediate [moderately resistant (rating score = 2) to moderately susceptible (rating score 3)], or susceptible (rating score 4) depending on sporulation, size, and halo prominence.