CHLORIDE RESPONSE OF PACIFIC NORTHWEST SPRING AND WINTER WHEAT CULTIVARS

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ABSTRACT

Chloride (Cl) deficiency symptoms are exhibited by certain spring and winter wheat cultivars grown in the inland Pacific Northwest. To assess responses to Cl, spring and winter wheat cultivar x chloride rate factorial trials were conducted at multiple eastern Washington locations during the 2001 to 2004 growing seasons. Whole plant samples were collected at early head emergence for Cl determination, and grain yield was measured at maturity. In addition, winter wheat flag leaves were imaged with a flatbed scanner to quantify percent leaf spot severity, and spring and winter wheat grain samples were analyzed for a suite of end-use quality parameters. Chloride application produced higher tissue Cl concentration at early head emergence in all winter and spring cultivars. At most locations, ≥22 kg Cl ha⁻¹ was required to increase tissue Cl concentrations above 0.15%. Spring wheat yields responded to Cl in only one out of five site-years. There were interactions between winter wheat cultivar and Cl rate for leaf spot reduction. Small (2.0 to 3.2% above the control treatment) but statistically significant winter wheat grain yield responses were detected to Cl application. The effects of Cl on milling and flour quality of spring and winter wheat were not consistent. In eastern Washington, winter wheat yield appears to respond to Cl more than spring wheat. While differences exist in winter wheat cultivar leaf spot responses to Cl, yield responses were not cultivar-dependent.

INTRODUCTION

Chloride (Cl) deficiency of wheat has been observed in the Midwest and Great Plains regions of the U.S. and in Canada (Engel et al., 1994; Mohr et al., 1995; Lamond et al., 1999). Deficiency symptoms consist of leaf spotting with spots resembling disease symptoms (Smiley et al., 1993). Symptoms occur when whole-plant Cl concentration at the boot stage is below 0.07% (Engel et al., 1994). Up to 20% increases in grain yield have been reported for winter wheat when Cl was applied at sites with less than 22 kg residual Cl ha⁻¹ in the surface 60 cm of soil (Lamond et al., 1999). Studies have also shown that the magnitude of yield response to Cl fertilization is cultivar-dependant (Fixen, 1993). Few Pacific Northwest winter wheat cultivars, and no spring wheat cultivars, have been tested for Cl response. Soils in eastern Washington State are naturally low in Cl. Due to high soil exchangeable K levels, KCl fertilizers are rarely used. Leaf spotting has been observed in winter and some spring wheat cultivars. The yield potential of wheat grown in the inland Pacific Northwest is much higher than in areas where

This research was funded by a grant from the Potash and Phosphate Institute and the Foundation for Agronomic Research.
much of the Cl research has been conducted; therefore, Cl responses and requirements for optimal production may be different than what has been previously established.

While the potential for profitable responses to Cl fertilization exist in the Pacific Northwest, little research has been done to evaluate spring and winter wheat cultivar responses to Cl. The objectives of this study are to assess the Cl responsiveness of Pacific Northwest-adapted spring and winter wheat cultivars. In addition to yield, the study also included a comprehensive assessment of Cl effects on grain milling properties and end-use quality of the flour.

MATERIALS AND METHODS

Spring Wheat Studies

Experiments were conducted in intermediate (28 to 38 cm) and high (50 to 61 cm) rainfall zones of eastern Washington using a randomized complete block, split plot design with four replications. Wheat cultivar (three in 2001; five in 2002 and 2003) was the whole plot variable and Cl rate (0, 11, 22, and 44 kg ha\(^{-1}\) in 2001; 0, 11, and 22 kg ha\(^{-1}\) in 2002 and 2003) was the subplot variable. All Cl was applied as dry potassium chloride (KCl) deep banded below the seed row at planting. Subplots were 1.7 m wide and 6 to 9 m long. The sites contained less than 20 kg Cl ha\(^{-1}\) in the surface 60 cm prior to planting.

Whole plant samples were collected at head emergence to determine tissue Cl concentration. Chloride was determined by potentiometric titration (LaCroix et al., 1970). At physiological maturity, a plot combine was used to harvest a 1.2 m wide strip from the center of each plot to determine grain yield. Grain milling and flour quality analyses were performed by the USDA-ARS Western Wheat Quality Laboratory located at Pullman, WA. Due to the high cost of these analyses, samples from only two replicates of each treatment were analyzed.

Winter Wheat Studies

Winter wheat studies were conducted in intermediate and high rainfall zones in 2002, the high rainfall zone in 2003, and at five intermediate to high rainfall zone locations in 2004. Each experiment was a randomized complete block, split plot design with four replications. Chloride rate (0 or 22 kg ha\(^{-1}\) at two sites in 2002 and one site each in 2003 and 2004; 0 or 11 kg ha\(^{-1}\) at four additional sites in 2004) was the main plot variable and cultivar was the subplot variable. Chloride was applied as dry KCl in a fall broadcast treatment made after planting in the 22 kg Cl ha\(^{-1}\) studies, and as a spring fluid topdress treatment in the 11 kg Cl ha\(^{-1}\) studies. Eight cultivars were included in the 22 kg Cl ha\(^{-1}\) studies; 18 to 20 cultivars were included in the 11 kg ha\(^{-1}\) studies.

Residual soil Cl levels (0 to 60-cm depth) were below 10 kg ha\(^{-1}\) in 2002. Residual Cl data are not available for the 2003 study. Residual soil Cl ranged from 16 to 26 kg ha\(^{-1}\) in 2004. Whole plant samples were collected at head emergence to determine tissue Cl concentration using potentiometric titration (LaCroix et al., 1970). In 2003, ten flag leaf samples were also collected from each treatment and imaged using a flatbed scanner. The images were analyzed with a software program to determine % of the flag leaf area with spots. A plot combine was used to harvest a 1.2 m wide strip from the center of each plot for grain yield determination. In 2002 only, a subsample of grain was retained for milling and flour quality analyses as described previously.
RESULTS AND DISCUSSION

Spring Wheat Studies

Chloride application linearly increased tissue Cl concentration of all cultivars at early head emergence (Figure 1). The rate of increase averaged 0.0057% Cl kg$^{-1}$ Cl applied in 2001, and 0.0099% Cl kg$^{-1}$ Cl applied in 2002 and 2003. In the absence of applied Cl, tissue concentrations were well below the established critical level of 0.15 % (Figure 1) (Fixen, 1993). Even though tissue Cl concentrations were extremely low, few plants in the spring wheat studies exhibited visual leaf spotting symptoms indicative of Cl deficiency.

![Figure 1](image_url)

**Figure 1.** The effect of Cl application on the average tissue Cl concentration of spring wheat at head emergence in 2001-2003. The horizontal line represents the critical tissue Cl concentration according to Fixen (1993). Error bars represent +/- one standard deviation of the mean.

There was a significant cultivar x Cl rate interaction for grain yield in 2001 (Figure 2). The hard red spring wheat cultivar WESTBRED 926 did not respond to Cl, while another hard red (Tara) and a soft white (Zak) cultivar had a significant positive yield response to 11 and 22 kg Cl ha$^{-1}$, respectively. Application of higher rates of Cl significantly reduced the yield of Tara and Zak compared to the maximum. The observed yield decline cannot be explained at this time. There was no effect of Cl on yield at either the intermediate or high rainfall zone locations in 2002 or 2003. Yields during these years, however, were relatively low due to drought, averaging 3,160 and 1,627 kg ha$^{-1}$ for the intermediate and high rainfall sites in 2002, and 1,813 and 3,472 kg ha$^{-1}$ for the intermediate and high rainfall sites in 2003. It is possible that higher yield potentials are required to obtain responses to Cl with spring wheat in eastern Washington.

There were significant effects of Cl on certain grain milling and flour quality parameters in 2001-03 (Table 1). Chloride slightly increased grain test weight, hardness, flour ash content and the retention of various solvents by the flour, but reduced break flour yield. Chloride effects on quality parameters observed in 2001 were generally not repeated in the 2002 and 2003 trials. As
mentioned above, lack of consistent Cl effects may have been due to low yields in 2002 and 2003. The inconsistency of Cl effects on end use quality precludes any definitive conclusions regarding the importance of Cl for grain quality.

**Figure 2.** The effect of Cl application on the grain yield of three spring wheat cultivars in 2001. The LSD bar is for comparing any two points on the figure.
Table 1. Interpretation of grain milling and flour quality statistical analyses for spring wheat. Note: Cl had no effect on the following parameters so they were omitted from the table: mill score, wheat protein, flour protein, baking absorption, loaf volume, bread crumb and grain.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2001</th>
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<th>2003</th>
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<tbody>
<tr>
<td>Test weight</td>
<td>++⁴</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Grain hardness score</td>
<td>+</td>
<td>++</td>
<td>NS</td>
</tr>
<tr>
<td>Flour yield</td>
<td>NS</td>
<td>NS</td>
<td>++</td>
</tr>
<tr>
<td>Break flour yield</td>
<td>-</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Flour ash</td>
<td>+++</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Rapid visco-analyzer</td>
<td>NS</td>
<td>*</td>
<td>NS</td>
</tr>
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<td>Carbonate solvent retention²</td>
<td>++</td>
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<td>Sucrose solvent retention²</td>
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<tr>
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<td>--</td>
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<tr>
<td>Cookie diameter²</td>
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<td>*</td>
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<td>+</td>
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<tr>
<td>Mix time³</td>
<td>NS</td>
<td>++</td>
<td>NS</td>
</tr>
</tbody>
</table>

¹+, ++, +++ indicate a significant positive effect of Cl on the parameter; -, --, --- indicate a significant negative effect on the parameter at the 0.10, 0.05, or 0.01 level, respectively; NS = not significant; *= significant interaction between Cl and cultivar or location. 
²Soft white wheat cultivars only. 
³Hard red and white wheat cultivars only.

Winter Wheat Studies
Chloride application significantly increased winter wheat tissue Cl concentration in all site-years (Figure 3), but there was no significant interaction between Cl and cultivar. Tissue Cl concentrations in the 0 Cl treatments were well below the critical level of 0.15%. Application of 22 kg Cl ha⁻¹ increased tissue concentrations to near or above the critical level in 2002 and 2003. Application of 11 kg Cl ha⁻¹ failed to increase tissue concentrations to critical levels at three out of four sites in 2004.

There was a significant cultivar x Cl interaction for % flag leaf spot in 2003 (Figure 4). In the 0 kg Cl ha⁻¹ treatment, Weatherford and Madsen had a greater percentage of the flag leaf with spots than other cultivars. With 22 kg Cl ha⁻¹, the cultivar WESTBRED 470 (WPB470) had significantly more flag leaf tissue affected by spots than all of the other cultivars except Beamer.
Figure 3. The effect of Cl on tissue Cl concentration at head emergence. Data for 2002 are averaged over two locations and eight cultivars; 2003 are averaged over eight cultivars at one location; 2004 are four locations, each representing an average over 18 to 20 cultivars. There were significant (p < 0.001) effects of Cl on tissue Cl concentration in all site-years.

Figure 4. The effect of Cl application and cultivar on % of flag leaf tissue with spots in 2003.

Averaged over location and cultivar, a small but significant yield response to Cl fertilization was observed in studies using either 11 (average yield response 2.0% above control) or 22 (average yield response 3.2% above control) kg Cl ha\(^{-1}\) (Figure 5). Comprehensive milling and flour quality analyses of winter wheat samples from 2002 revealed only minor effects of Cl on these parameters. Flour ash content was the only parameter increased by Cl (data not presented).
Grain yield (kg ha\(^{-1}\))

5000 6000 7000 8000 9000 10000

-Cl +Cl

22 kg Cl ha\(^{-1}\) sites 11 kg Cl ha\(^{-1}\) sites

***

Figure 5. The effect of Cl application on winter wheat yield. The 22 kg Cl ha\(^{-1}\) data are the average of two locations in 2002 and one location in 2004. The 11 kg Cl ha\(^{-1}\) data are the average of four locations in 2004. *** denotes significant difference at p < 0.001.

SUMMARY AND CONCLUSIONS

This research suggests a greater potential for Cl responses in winter wheat than in spring wheat grown in eastern Washington. However, additional research with spring wheat may be warranted since yields were lower than normal in two of the three study years. Winter wheat yield responses, though small, were similar in magnitude to responses observed in the Midwest and Great Plains. Unlike results from previous research, winter wheat yield responses to Cl did not vary with cultivar. The effects of Cl on grain milling and flour quality parameters were inconsistent and may be less important than Cl effects on yield. This research is being used to develop a Cl recommendation for eastern Washington winter wheat.

REFERENCES