Progress report to Potash and Phosphate Institute - 1994 research

# Effect of chloride fertilization on wheat and cereal grains

## PERSONNEL

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## BACKGROUND AND JUSTIFICATION

Chloride has been recognized as an essential plant nutrient since 1954 (Broyer et al., 1954). Initially, Cl was classified as a micronutrient with plants requiring only trace amounts for their physiological functions. Until recently comparatively little attention was given to Cl as a fertilizer because soil Cl levels and inputs from rain were considered adequate to meet this requirement. During the mid-1980's agronomists in the Great Plains redirected investigations into Cl fertilization. This interest can be attributed to two factors: i) studies in the Pacific Northwest indicated that Cl fertilization increased yield and suppressed take-all root rot in winter wheat caused by *Gaeumannomyces graminis* var. *tritici* (Taylor et al., 1981; Christensen et al., 1981); and ii) previous studies in the region documented significant yield and quality responses by wheat and barley to KCl or potash, 0-0-60, on soils with seemingly abundant supplies of available K (Zubriski et al., 1970; Schaff and Skogley, 1982). Current, Great Plains research indicates that yield responses to Cl are economical, provided they can be predicted (Fixen et al., 1986a). A survey of wheat and barley Cl fertility studies in this region found significant yield improvements from Cl at 72 of 166 episodes (Engel et al., 1992). Yield responses averaged 302 kg/ha and maximum responses were frequently obtained from inexpensive and low Cl application rates (< $9/ha material cost).

Soil and plant analyses are potentially useful tools in fertilizer Cl response prediction provided critical levels and/or ranges can be established. Published reports of critical soil and/or plant Cl levels have been prepared (Fixen et. al, 1986, Engel et al., 1994), but the data-base from which this information was derived is small. More research is needed to broaden our Cl data-base, and better define the soil and plant Cl level over which responses occur. Inaddition, there is need to better understand the processes involved and the yield components most affected by Cl fertilizer applications. It is the objective of this study to address these issues.

## OBJECTIVES

1. To determine the effect of Cl fertilization on grain yield, yield components, kernel weight and rate of kernel growth in several spring and winter wheat cultivars under a wide range of environments.

2. To provide a Cl fertilizer recommendation program to Montana producers by developing a data-base on yield response frequency to Cl as affected by soil and plant Cl levels.

3. To determine the effect of Cl on leaf spots in susceptible wheat cultivars, and to verify the origin as being physiological or microbial.

4. To include a final report at the conclusion of this project to address each of the objectives

## Materials and Methods

### Experimental design - winter wheat studies

Two dryland field experiments were established at site 1, south of Lodgegrass, Montana in the Bighorn Mountain foothills. 'Experiment I' was a factorial study that included five cultivars ('Redwin', 'Tiber', 'Manning', 'Kestrel', and 'Stephens'), propiconazole foliar fungicide (Tilt+) and untreated control (Tilt-), and two Cl levels (0 and 67 kg/ha). The 20 treatments were replicated six times. The study was arranged as a strip-split-block design with cultivars and Tilt(-,+) treatments oriented in perpendicular strips and Cl level sub-plots. 'Experiment ii' treatments included two cultivars, 'Redwin' (leaf spot susceptible) and 'Tiber' (a 'Redwin' selection with leaf spot tolerance), and four Cl levels (0, 22.5, 45, 90 kg/ha) in factorial arrangement. Treatments were replicated six times. Propiconazole was applied to Tilt+ plots in 'Experiment i' and all plots in 'Experiment ii' at Feekes growth stage 4 and 10. A 300 ml/ha rate (4 fluid oz/acre) was used.

A dryland field experiment was established at the Post Farm near Bozeman, Montana (site 2). The experiment consisted of five cultivars ('Redwin', 'Tiber', 'Manning', 'Kestrel', and 'Stephens') and two Cl levels (0 and 67 kg/ha) in factorial combination. The treatments were arranged as a split-plot design with cultivars main-plots and Cl level sub-plots, and five replications. Two propiconazole foliar applications were applied to the study at Feekes growth stage 4-5 and 9.

### Experimental design - spring wheat and durum studies

Spring wheat studies were established at four locations in 1995. Sites 4, 5, and 6 were conducted in dryland summer-fallow fields and site 3 was irrigated. Three experiments were run at each site. 'Experiment i' was a factorial study that included six cultivars ('Amidon', 'Newana', 'Pondera', 'Rambo', 'Marshall', and 'Lew'; 'WB926' substituted for 'Lew' at site 3) and two Cl fertilizer levels (0 and 50 kg/ha). The treatments were arranged as a split-plot design, with cultivars main-plots and Cl sub-plots, and five replications at site 4,5, and 6, and six replications at site 3. In 'experiment ii' Rambo spring wheat was grown under four Cl fertilizer levels (0, 22, 45, and 67 kg/ha). Treatments were arranged as a latin-square with five replications. In 'experiment iii' 'WB881' durum wheat was fertilized at two Cl fertilize levels (0 and 50 kg/ha). Treatments were replicated five times in a randomized complete block design.

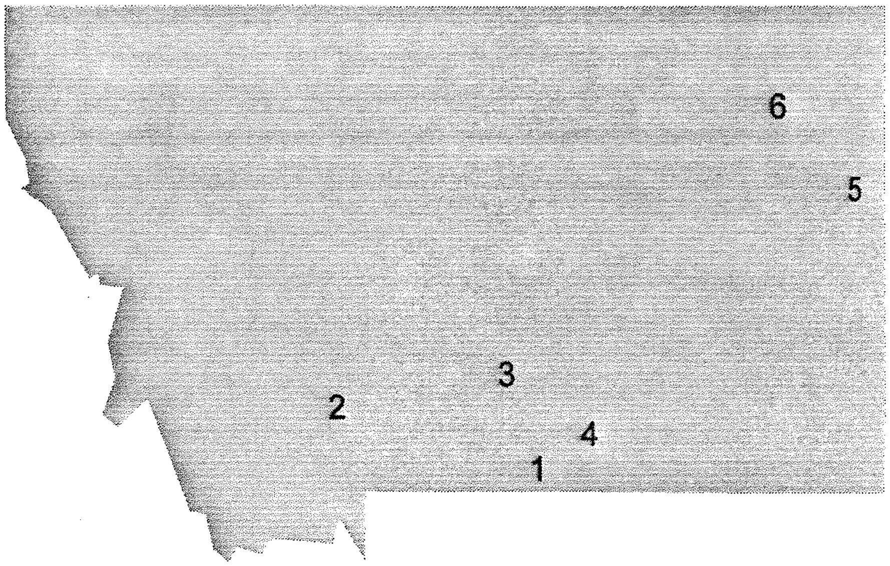

**Figure 1**. Location of winter wheat (Sites 1 &2) and spring wheat (Sites 3-6) fertilizer trials.

### Site description, cultural practices, and field methods

Site location, soil-type, background soil Cl, and growing season precipitation are reported in Table 1. Soil Cl analyses were based on samples collected prior to seeding or shortly after emergence from unfertilized border strips. Soil Cl analyses were performed by mixing 25 g soil in 50 ml 0.01 M $Ca(NO_3)_2 \cdot 4H_2O$. Following 30 min of shaking, samples were allowed to settle and a 20-ml aliquot was removed. Sample and blank aliquot were spiked with 0.02 mg Cl and analyzed for Cl by potentiometric titration using 0.005 N $AgNO_3$ and an Orion 96-17 combination specific ion electrode

| Site | Location | Soil series | Rainfall † | Soil Cl level and depth distribution (cm) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 0-30 | 30-60 | 60-90 | 90-120 |
| | | | mm | ppm | | | |
| 1 | Bighorn Mtn. | Shaak clay loam | 60 | 0.36 | 0.58 | 0.53 | 0.43 |
| 2 | Bozeman | Amsterdam silt loam | 197 | 0.84 | 0.69 | 0.69 | 0.89 |
| 3 | Huntley | Lohmiller silty clay loam | 160 | 1.43 | 0.63 | 0.54 | 0.54 |
| 4 | Lodgegrass | Richfield silty clay loam | 77 | 0.36 | 0.54 | 0.54 | 0.54 |
| 5 | Sidney | Williams loam | 228 | 0.93 | 1.48 | - | - |
| 6 | Poplar | Williams silt loam | 182 | 0.84 | 0.63 | 0.63 | - |

† Growing season rainfall - 1 April or emergence to harvest for winter (sites 1-2) and spring wheat (sites 3-6), respectively.

Winter wheat was seeded in 30-cm rows at a rate of 195 pure-live seeds/$m^2$. Seeding occurred on 22 September and 18 September at sites 1 and 2, respectively. Spring wheat was seeded in 15-cm rows at a rate of 250 pure-live seeds/$m^2$. Seeding occurred on 1 April, 11 April, 13 April, 13 April, and 18 April at site 3 - 'Experiment I', site 3 - 'Experiment ii', site 5, site 6, and site 4, respectively.

Fertilizer KCl was used as the Cl source in all studies. Treatments receiving KCl are hereafter referred to as Cl+. Fertilizer $K_2SO_4$ was applied to maintain a constant K level across the study sites or in the appropriate control treatments. Control plots receiving only $K_2SO_4$ are hereafter referred to as Cl-. Both KCl and $K_2SO_4$ were applied at seeding in a band located approximately 5 cm below and 7 cm to the side of the seed row. At all sites the sulfur variable resulting from using $K_2SO_4$ was not deemed important due to high indigenous soil $SO_4$ levels. Sufficient fertilizer N and P were applied to ensure adequate nutrition of these nutrients according to soil test recommendations. Weeds were controlled by hand-hoeing and applying broadleaf herbicides at appropriate rates and growth stages

Effect of Cl on kernel growth in spring wheat was determined by harvesting immature spikes at approximately 1 wk intervals beginning 10 to 14 d following anthesis initiation. Approximately 0.18 $m^2$ were harvested at each sampling event. The harvested spikes were dried at 65°C, counted to determine spike density, and then threshed. The grain remaining was weighed and 1000 kernel weights were determined. From this data kernel number per spike was determined.

Whole above ground plant samples (60-cm row) were collected at Feekes (Large, 1954) growth stage 10 to 10.1 from all plots. In 'Experiment ii' - site 3 whole plant samples were collected at Feekes growth stages 4 (27 May), 6 (3 June), 10 (13 June), 10.3 (20 June), 10.5.4 (27 June), 11.1 (5 July), and 11.3 (25 July). All plant samples were dried (65 °C), ground, and analyzed for Cl by potentiometric titration (LaCroix et al., 1970). Grain yield was determined by harvesting with a small-plot combine approximately 4 $m^2$ from the center rows of each plot. Mature kernel weights were based on counts of 500 from subsamples collected at this harvest.

Physiological leaf spot severity was evaluated by visually rating the percentage of flag and/or flag-1 leaf area affected by chlorotic or necrotic lesions. Leaf blades from 20 to 30 culms were rated per plot. Severity ratings were measured at growth stage 10.5.4 or early during grain-fill. Leaf samples with lesions were tested for the presence of *Pyrenophora tritici* f. sp. *repentis* (*PTR*) or tanspot disease by a procedure modified from Raymond et al. (1985). Disease tissue was surface sterilized in a sodium hypochlorite solution (0.1 g/g) for 1 to 2 min and placed on potato dextrose plates. Colonies suspected of being *PTR* were transferred to V-8 agar plates which were placed at room temperature under a 24-hr florescent light cycle for 3 to 4 d. Thereafter, the light cycle was modified to a 12-hr on-off cycle to induce sporulation.

## Results and discussion

### Winter wheat

Winter wheat yield was increased by Cl at site 1, but not at site 2 (Table 2 and 3). Tilt applications did not affect yield at site 1. Growing season precipitation at this site (Table 1) was extremely low in 1994 and foliar disease pressure was light, with the exception of Cephalosporium stripe in Stephens. Tilt applications generally had little effect on yield response to applied Cl. Whole plant Cl concentrations in the Cl- were .054 and .100% at sites 1 and 2, respectively. Hence, plant Cl status was lower at site1 though both sites were below the 0.15% and 0.30% critical plant Cl levels reported by Fixen et. al (1986) and Engel et al. (1994), respectively. Mature 1000 kernel weights were increased by Cl at sites 1 and 2 (Table 1 and 2). The lack of a grain yield response to applied Cl at site 2, inspite of higher kernels, indicates another yield component was affected. Although other yield components were not measured at site

Table 2. Winter wheat yield and mature kernel weight in several cultivars as affected

by Cl fertilization. Site 1, 1994. Bighorn Mountain foothills. Mean of Tilt- and Tilt+ treatments.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | ---------- bu/a --------- | | | ---------- g-- -------- | | |
| Kestrel | 58.1 | 61.4 | * | 29.7 | 31.2 | *** |
| Manning | 64.3 | 70.6 | *** | 32.9 | 33.7 | * |
| Redwin | 50.9 | 55.3 | ** | 30.9 | 33.4 | *** |
| Stephens | 57.7 | 59.8 | + | 38.0 | 40.5 | *** |
| Tiber | 57.2 | 60.2 | * | 31.3 | 33.7 | *** |
| Mean | 57.6 | 61.5 | *** | 32.6 | 34.5 | *** |

Error mean square = 6.257 and 0.537 for yield and tkw, respectively, 30 df
+,*, **, *** significant at or below .10, .05, .01, and .001 level.

Table 3 Winter wheat yield and mature kernel weight in several cultivars as affected by Cl fertilization. Site 2. Bozeman.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | ---------- bu/a --------- | | | ------------ g ----------- | | |
| Kestrel | 89.9 | 93.1 | NS | 31.9 | 33.5 | *** |
| Manning | 95.9 | 97.7 | NS | 37.3 | 38.9 | *** |
| Redwin | 81.8 | 82.8 | NS | 35.5 | 36.6 | ** |
| Stephens | 95.4 | 96.1 | NS | 45.7 | 48.4 | *** |
| Tiber | 88.5 | 89.6 | NS | 35.4 | 36.6 | ** |
| Mean | 90.3 | 91.9 | NS | 37.2 | 38.8 | *** |

Error mean square = 6.02 and 0.295 for yield and tkw, respectively, 20 df
*, **, *** significant at or below .05, .01, and .001 level.

2, we believed the larger kernels that resulted from applied Cl were a compensation for fewer kernels per spike, an effect that would precede kernel size. This phenomena has been observed in previous years.

Physiological leaf spot was present in four cultivars (Kestrel, Redwin, Manning, and Stephens) at site 1 and in Kestrel at site 2. Overall, winter wheat leaf spot severity was considerable lighter in 1994 than observed in previous years. This is probably associated with the low rainfall conditions. Results from previous investigations indicate that leaf spotting is enhanced by high rainfall and soil moisture conditions. Applied Cl greatly suppressed leaf spotting in all affected cultivars (Table 4, site 2 data not presented). Tilt applications had no affect on leaf spot severity and tests for *PTR* presence on affected portions of leaf blade samples were negative. These results are consistent with observations from previous years, and indicate the cause of the leaf spot phenomena is physiogical in nature and not microbial.

Table 4. Effect of Cl and Tilt on physiological leaf spot severity (% chlorosis + necrotic tissue on leaf blades) in several winter wheat cultivars. Site 1. Bighorn Mtn.

| Leaf | Cultivar | Tilt- | | | Tilt+ | | |
|---|---|---|---|---|---|---|---|
| | | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | | ---------- % --------- | | | --------- % --------- | | |
| Flag | Kestrel | 13.0 | 0.1 | *** | 14.5 | 0.3 | *** |
| | Manning | 3.5 | 0.0 | *** | 3.2 | 0.0 | ** |
| | Redwin | 2.3 | 0.0 | ** | 2.6 | 0.0 | ** |
| | Stephens | 2.0 | 0.3 | + | 2.1 | 0.1 | * |
| | Tiber | 0.0 | 0.0 | NS | 0.0 | 0.0 | NS |
| Flag-1 | Kestrel | 27.5 | 0.5 | *** | 22.9 | 0.0 | *** |
| | Manning | 7.0 | 0.3 | *** | 4.9 | 0.0 | ** |
| | Redwin | 3.8 | 0.3 | * | 2.6 | 0.0 | + |
| | Stephens | 4.5 | 1.2 | * | 4.4 | 0.2 | ** |
| | Tiber | 0.0 | 0.0 | NS | 0.0 | 0.0 | NS |

Error mean square = 6.02 and 0.295 for yield and tkw, respectively, 20 df
+, *, **, *** significant at or below .10, .05, .01, and .001 level.

Spring wheat

Spring wheat yield was increased by Cl at sites 4 and 6, but not at sites 3 and 5 (Tables 5-8). Whole plant Cl concentrations in the Cl- were .067, .039, .137, and .142 at these respective sites. Hence, the lowest plant Cl testing sites were the sites where significant yield responses were observed. Mature kernel weights were increased by Cl at sites 4 and 6, and in two cultivars at site 3. Increases in kernel weight at site 4 averaged 17%. This level of kernel weight response to Cl is among the highest we have ever observed. Yield did not increase in same proportion to kernel weight at this site. Similar to the results at site 2, this suggests other yield components were negatively affected by Cl, i.e. kernels per spike.

A leaf spot in 'WB881' durum was observed at sites 4 and 6. The origin of this leaf spot is believe to be physiological in nature. Leaf spot severity in the Cl- was particuarly great at site 6 (Table 9). Plant Cl levels were extremely low in the Cl- and early season moisture was particularly high at this site (123 mm in June). These conditions have all favored physiological leaf spot in winter wheat and suggest the same processeses may be occurring in this durum cultivar. Applied Cl greatly suppressed leaf spot severity at sites 4 and 6. The leaf spot response to applied Cl at site 6 was the largest response we have ever found.

Table 5. Spring wheat yield and mature kernel weight in several cultivars as affected by Cl fertilization. Site 3. Huntley.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | --------- bu/a -------- | | | ---------- g --------- | | |
| Amidon | 68.9 | 68.6 | NS | 29.4 | 28.8 | NS |
| Marshall | 88.7 | 89.6 | NS | 31.6 | 32.9 | NS |
| Newana | 85.7 | 86.7 | NS | 32.8 | 34.5 | + |
| Pondera | 79.7 | 81.7 | NS | 31.3 | 30.3 | NS |
| Rambo | 85.6 | 88.0 | NS | 34.8 | 36.3 | NS |
| WB926 | 81.5 | 78.1 | NS | 39.0 | 43.3 | *** |
| Mean | 81.7 | 82.1 | NS | 33.2 | 34.4 | ** |

Error mean square = 12.40 and 2.84 for yield and tkw, respectively, 30 df
+,*, **, *** significant at or below .10, .05, .01, and .001 level.

Table 6. Spring wheat yield and mature kernel weight in several cultivars as affected by Cl fertilization. Site 4. Lodgegrass.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | ---------- bu/a --------- | | | ------------ g ----------- | | |
| Amidon | 37.3 | 39.7 | ** | 24.6 | 27.7 | *** |
| Marshall | 36.7 | 37.9 | NS | 21.8 | 25.0 | *** |
| Newana | 36.7 | 36.8 | NS | 23.2 | 26.7 | *** |
| Pondera | 34.6 | 39.5 | *** | 22.7 | 27.2 | *** |
| Rambo | 37.1 | 40.0 | *** | 23.6 | 28.1 | *** |
| Lew | 34.4 | 35.8 | + | 26.6 | 28.8 | *** |
| Mean | 36.1 | 38.3 | *** | 23.8 | 27.3 | *** |

Error mean square = 1.278 and 0.643 for yield and tkw, respectively, 24 df
+,*, **, *** significant at or below .10, .05, .01, and .001 level.

Table 7. Spring wheat yield and mature kernel weight in several cultivars as affected by Cl fertilization. Site 5. Sidney.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | ---------- bu/a --------- | | | ------------ g ----------- | | |
| Amidon | 61.1 | 62.7 | NS | 27.7 | 26.9 | NS |
| Marshall | 67.5 | 69.0 | NS | 24.7 | 25.0 | NS |
| Newana | 67.5 | 66.1 | NS | 27.3 | 27.3 | NS |
| Pondera | 66.5 | 66.4 | NS | 26.7 | 26.9 | NS |
| Rambo | 67.0 | 66.0 | NS | 26.9 | 27.5 | NS |
| Lew | 57.8 | 62.1 | NS | 29.6 | 30.3 | NS |
| Mean | 64.6 | 65.4 | NS | 27.2 | 27.3 | NS |

Error mean square = 4.958 and 1.008 for yield and tkw, respectively, 24 df
*, **, *** significant at or below .05, .01, and .001 level.

Table 8. Spring wheat yield and mature kernel weight in several cultivars as affected by Cl fertilization. Site 6. Poplar.

| Cultivar | Yield | | | 1000 Kernel weight | | |
|---|---|---|---|---|---|---|
| | Cl- | Cl+ | Prob > F | Cl- | Cl+ | Prob > F |
| | ---------- bu/a -------- | | | ---------- g ---------- | | |
| Amidon | 52.3 | 57.9 | + | 30.4 | 31.9 | * |
| Marshall | 66.6 | 71.9 | + | 28.0 | 29.3 | * |
| Newana | 57.7 | 68.2 | *** | 31.7 | 34.2 | *** |
| Pondera | 54.9 | 61.1 | + | 28.8 | 30.5 | ** |
| Rambo | 55.7 | 60.4 | + | 29.6 | 30.9 | * |
| Lew | 49.3 | 60.0 | *** | 29.3 | 33.9 | *** |
| Mean | 56.1 | 63.3 | *** | 29.6 | 31.8 | *** |

Error mean square = 18.90 and 0.877 for yield and tkw, respectively, 24 df
+,*,**,*** significant at or below .10, .05, .01, and .001 level.

Table 9. Effect of chloride fertilization on physiological leaf spot severity, yield, mature kernel weight, and plant Cl at head emergence in WB881 durum. Site 4 and 6 Poplar.

| Site | Cl rate | Leaf spot severity | | Yield | 1000 kernel wt | Plant Cl |
|---|---|---|---|---|---|---|
| | | Flag | Flag-1 | | | |
| | lbs/a | --------- % | --------- | bu/a | g | % |
| 4 | 0 | 8.5 | 11.0 | 34.5 | 43.8 | 0.078 |
| | 45 | 0.6 | 1.9 | 36.6 | 47.3 | 0.464 |
| | Prob > F | * | ** | + | ** | *** |
| 6 | 0 | 86.8 | 95.8 | 49.2 | 38.2 | 0.034 |
| | 45 | 6.1 | 35.8 | 60.3 | 40.4 | 0.552 |
| | Prob > F | *** | *** | *** | * | *** |

+,*,**,*** significant at or below .10, .05, .01, and .001 level.

## Future plans

No large changes are planned for the 1995 growing season. Winter wheat studies were seeded at four sites this past fall. Three are located in Bighorn County and one is located on the Post Farm. The study at the Post Farm will focus on applied Cl levels required to suppress leaf spotting in eight susceptible winter wheat cultivars ('MacVir', 'Kestrel', 'Kmor', 'Sierra', 'Redwin', 'Hoff', and 'Promontory'). The three studies in Bighorn County will include eight winter wheat cultivars ('Redwin', 'Neeley', 'Rocky', 'Tiber', 'Weston', 'Manning', 'Sierra', and 'Kestrel'). Responsiveness to applied among these cultivars will be compared. Spring wheat studies similar to the 1994 studies are planned at up to 6 new locations. Dryland field sites testing < 12 kg/ha (0-60 cm depth) will be found in south central and northeast Montana for this portion of the investigation. At least one site will include a separate study of several durum wheat cultivars, including 'WB881'. It is hoped by the end of the 1995 season a sufficient data-base will be established for defining a soil Cl test and fertilizer recommendation program (objective 2).

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## Addendum I:

Proceedings to be presented at Western Nutrient Management Conference, Salt Lake City, Utah. March 9-10, 1995.

# Chloride nutrition of western wheat

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## Abstract

Research from several Western states has demonstrated that wheat yields can be improved by Cl fertilization. Soil and plant analyses may provide diagnostic tools for Cl response prediction. This study was undertaken to define soil and plant Cl levels over which yield responses occur; develop a fertilizer Cl recommendation; determine yield components most affected by Cl; and determine the effect of Cl on foliar diseases and/or disease-like symptoms. Whole plant Cl - relative yield response data from 143 cultivar x site episodes in Montana indicated adequate Cl nutrition occurred when Cl concentrations were >0.40% at head emergence. Response frequency to applied Cl increased as the nutrient concentration dropped below this level. At Cl concentrations <0.10% significant yield responses to applied Cl occurred in 30 of 45 (67%) cultivar x site episodes. Overall, yield increased an average 5.1 bu/a at the 58 episodes where significant responses were observed. Soil Cl - plant Cl relationships indicated 32 lbs/a available Cl in the soil were required to achieve a 0.40% whole plant concentration. Kernel weight was the yield component most frequently affected by Cl. At plant Cl concentrations <0.10% significant kernel weight responses to applied Cl were observed at 41 of 45 cultivar x site episodes. Plant Cl nutrition had a profound effect on physiological leaf spot in selected winter wheat cultivars. Results from seven locations indicated that when physiological leaf spotting occurred in susceptible winter wheat cultivars ('Kestrel', 'Redwin', 'Manning'), there was a high probability plant and soil (0-24" depth) Cl concentrations were < 0.10% and 10 lbs/a, respectively.

## Introduction

Chloride has been recognized as an essential plant nutrient since 1954 (Broyer et al., 1954). Initially, it was classified as a micronutrient with plants requiring only trace amounts for their physiological functions. For more than 20 years it was generally believed that field crops would not benefit from Cl applications because of its ubiquitous presence in soils. The importance of Cl as a fertilizer nutrient in the West was not given serious consideration until studies in Oregon demonstrated significant yield increases from Cl in take-all root rot (incited by *Gaeumannomyces graminis* var. *tritici)* infected winter wheat (Taylor et al., 1981; Christensen et al., 1981). Since this time wheat research from several Western and Great Plains states has demonstrated numerous examples of economic yield responses from Cl applications (Christensen et al., 1981; Petrie and Brown, 1983; Fixen et al., 1986a; Engel et al., 1992; Engel et al., 1994). Factors including and beyond Cl's role in biochemical functions, osmotic regulation, plant development, and disease suppression may be involved.

Soil and plant analyses may be useful tools in predicting yield responses by wheat to Cl applications. This is provided that critical levels and/or ranges can be established. Critical soil and/or plant Cl levels (Fixen et. al, 1986, Engel et al., 1994) have been published, but the information has been derived from comparatively small data-bases. In Montana, an ongoing research program is being conducted to broaden our current wheat Cl fertility data-base. The objectives of this program are to I) better define soil and plant Cl level over which yield responses occur, ii) develop a fertilizer Cl recommendation, iii) determine yield components most affected by Cl, and iv) determine the effect of Cl on foliar diseases and/or disease-like symptoms.

## Methods

### Experimental design and fertilizer application

Dryland and irrigated field experiments were established at 21 sites in south central and northeast Montana between 1988 and 1994. In most cases the field sites included two experiments. In 'experiment I' several cultivar selections (5 or 6) were grown under two Cl levels, 0 Cl (Cl-) and a treatment receiving 40 or 60 lbs/a Cl (Cl+). Experiments were designed as a split-plot with cultivar main-plots and Cl level sub-plots. In 'experiment ii' a single wheat cultivar was grown at 4 to 5 Cl levels (i.e 0, 10, 20, 40, and 80 lbs/a for winter wheat; 0, 10, 20, 40, and 60 lbs/a for spring wheat). Treatments were replicated 5 to 6 times and plot dimensions were ~32' x 6 '. Propiconazole (Tilt+) and control (Tilt-) treatment comparisons were included in several winter wheat studies. Propiconazole was applied on 2-3 dates during the vegetative growth stages at 4 oz/a per application event to control foliar diseases.

Fertilizer KCl was used as the Cl source in all studies, except one site where $CaCl_2$ was used. Fertilizer $K_2SO_4$ was applied to all Cl- plots in experiment I and to all plots in experiment ii, except the highest Cl rate. An appropriate rate was used to maintain a constant K level across each experiment. Fertilizer KCl and $K_2SO_4$ were applied in a band located to the side of the seed row, or as a fall-post emergence broadcast application. At all sites the sulfur variable resulting from using $K_2SO_4$ was not deemed important due to high indigenous soil $SO_4$ levels. Sufficient fertilizer N and P were applied to ensure adequate nutrition of these nutrients according to soil test recommendations.

### Field and laboratory methods

Sites were characterized for soil Cl content based on samples collected prior to seeding, or shortly after emergence from unfertilized areas. Soil Cl analyses were performed by potentiometric titration using 0.005 N $AgNO_3$ and an Orion 96-17 combination specific ion electrode. Whole above ground plant samples were collected at Feekes (Large, 1954) growth stage 10-10.1 from all plots. All plant samples were dried (65 °C), ground, and analyzed for Cl by potentiometric titration (LaCroix et al., 1970). Grain yield was determined by harvesting with a small-plot combine the center rows of each plot. Mature kernel weights were based on counts of 500 from subsamples collected at this harvest.

Physiological leaf spot severity was evaluated by visually rating the percentage of flag and/or flag-1 leaf area affected by chlorotic or necrotic lesions. Leaf blades from 20 to 30 culms were rated per plot. Severity ratings were measured at growth stage 10.5.4 or early during grain-fill. Leaf samples with lesions were tested for the presence of *Pyrenophora tritici* f. sp. *repentis* (*PTR*) or tanspot disease by a procedure modified from Raymond et al. (1985).

## Results and discussion

### Plant Cl - yield relationships

Field research results from 143 cultivar x site episodes were used to generate wheat whole plant Cl concentration - yield (expressed as a percentage of the maximum yielding Cl treatment) relationships (Figure 1). Data-points for individual cultivars were plotted because the cultivar x Cl level (Cl- vs Cl+) interaction was significant (P<.10 level) at a few locations. Also, the cultivar main effect was significant at all sites in experiment I. This was found to influence relative yield ([yield Cl-/ yield Cl+] x100). Generally, the relationship expressed in figure 1 are similar to classical nutrient responses curves described by Bates (1971), Ulrich and Hill (1967), and others. The only difference is that yield deficits that result from inadequate Cl are frequently small relative to other essential nutrients. The results indicate whole plant Cl concentrations at head emergence can be used to segregate yield responsive from non-responsive sites. In this study Cl concentrations <0.10% produced significant yield responses to applied Cl in 30 of 45 (67%) cultivar x site episodes. At 0.10-.20%, 0.20-.30%, and 0.30-.40% plant Cl significant wheat yield responses to applied Cl were observed at 43%, 38%, and 33% of the episodes, respectively. Few significant yield responses to applied Cl were observed at >0.40% Cl. Therefore, field sites can be assumed to be adequately supplied with Cl, or unresponsive, where plant Cl at head emergence exceeds this level.

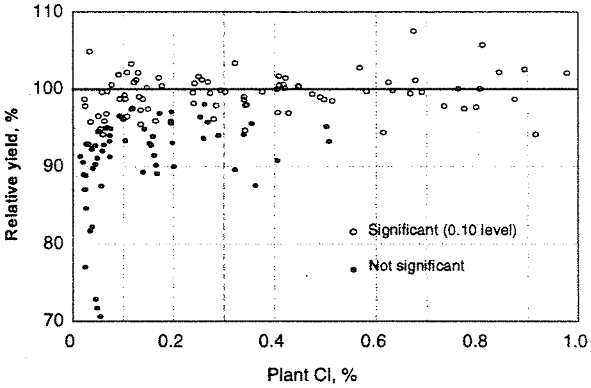

Figure 1. Relationship between plant Cl and relative yield (% maximum). Montana. 1988-1994.

Yield response size averaged 5.1 bu/a over the 58 episodes where significant responses were observed. The largest yield responses occurred at plant Cl levels < .10%, and there was a tendency for yield deficits to decrease as plant Cl status improved. As with other nutrients, environmental, soil, and/or plant factors beyond plant nutrient status strongly affected the magnitude of Cl response at a specific location. Therefore, a low plant Cl concentration (i.e. < 0.10%) was not a guarantee that a large yield response to Cl fertilizer would result. In several instances the responses were modest in size even at this low nutrient concentration.

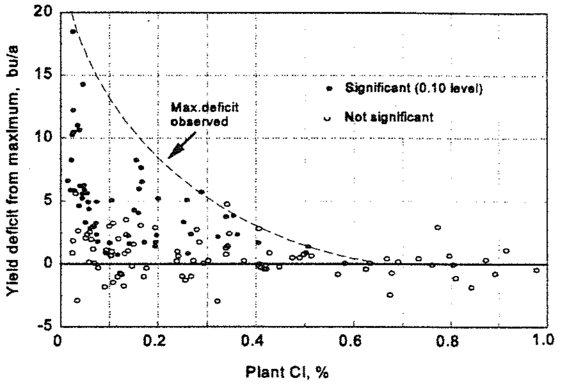

Figure 2. Relationship between plant Cl and yield deficit from the maximum. Montana. 1988-1994.

<u>Soil Cl - plant Cl relationships and Cl fertilizer recommendation</u>

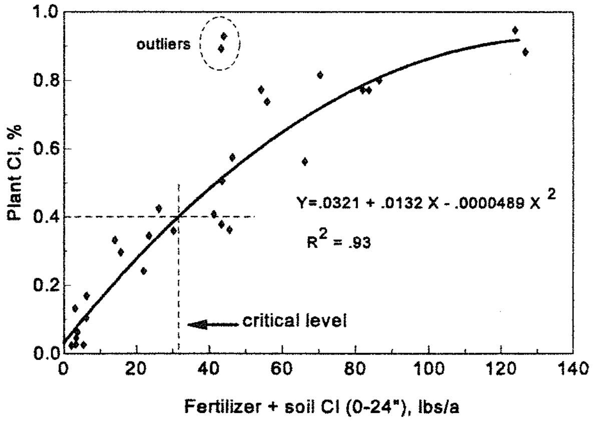

Figure 3. Relationship between fertilizer + soil Cl and plant Cl. Montana. 1988 - 1993.

Most of the field sites selected in this investigation contained uniformly low, < 1.0 ppm Cl, at all soil depths (0-48"). The 0 Cl treatment typically had plant Cl concentrations < 0.10%. Hence, it was not possible from these treatments alone to develop a meaningful regression relationship between soil Cl and plant Cl, or to determine the relative importance of soil Cl positioned at different depths in the profile. The relationship between fertilizer + soil Cl (0-24") and plant Cl may provide some insight into the quantity of Cl necessary to ensure adequate nutrition. In our study plant Cl concentrations increased with fertilizer + soil Cl (0-24" depth) according to a quadratic relationship (Figure 3). Two data-points were considered outliers in this analysis. Also, cultivar means were used in this analysis as this factor had little effect on plant Cl. Assuming a plant Cl > 0.40% ensures adequate nutrition, a 32 lbs/a critical soil level can be defined from the curve.

The proposed fertilizer guideline for Western wheat is to add sufficient Cl to achieve > 0.40% plant Cl at head emergence, or to bring plant available Cl (fertilizer + soil Cl) to 32 lbs/a. Soil Cl situated in the upper 2' of the profile should be readily available to the plant and is consider in this analyses. Whether soil Cl situated below 2' is absorbed by the plant early enough in the season to produce the maximum response is not known. Fixen et al. (1986b) found soil Cl below 24" to be considerable less available to spring wheat than Cl in the upper 24". However, many soil testing labs in the West consider $NO_3$-N to 48" in their N recommendation programs and soil Cl should be at least as available to the plant as $NO_3$-N.

Chloride fertilizer, sold as 0-0-62, is currently priced at $.16 - $.17/lb. Hence, the material cost of application using the above guidelines is comparatively small. In addition, a large percentage of applied fertilizer Cl may be available to succeeding wheat crops under dryland conditions. Only small amounts of Cl are removed in the grain (<3 lbs/a) even under high yield potentials (+70 bu/a). Chloride in the wheat straw should be recycled and released to the soil as the residue decomposes. Also, as rainfall is comparatively low in many wheat growing areas in the West, leaching events are infrequent even though Cl is mobile in soils.

Plant Cl and mature kernel weights

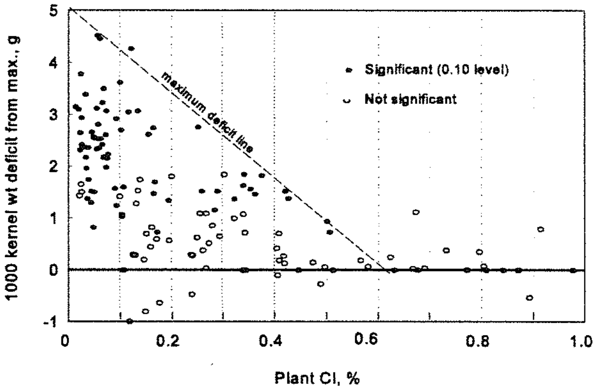

Figure 4. Relationship between plant Cl and mature kernel weight deficit from the maximum. Montana. 1998-1994.

Kernel size was the yield component most frequently affected by Cl fertilization. Thousand kernel weight response to Cl averaged 2.3 g at the 69 cultivar x site episodes where significant responses were observed. In many cases the kernel size increases were sufficient to explain all or most of the yield response (data not presented). Larger mature kernels can be attributed to: i) a prolonged grain-fill period, i.e. flower initiation to physiological maturity or date when maximum kernel weight achieved, or ii) an accelerated kernel growth rate. Research results to date suggests that effect 'ii' may be more important (Engel et al., 1994). Mature kernel weight deficits from inadequate Cl were observed to increase in frequency and magnitude as plant Cl dropped < 0.40% (Figure 4). Above this level mature kernel was generally not affected by applied Cl. At plant Cl concentrations <0.10% significant kernel weight deficits occurred in 41 of 45 episodes (91%). Significant yield increases did not always accompany kernel weight responses. In several instances the increase in kernel weights appeared to be a compensation for fewer kernels per spike, an effect that would precede kernel size (data not presented).

Physiological leaf spot and Cl nutrition.

A leaf spot of unknown origin which occurred in selected winter wheat cultivars was profoundly affected by plant Cl nutrition. Our first experience with this phenomena occurred in 1991 at a field site with only 4 lbs/a soil Cl (0-24" depth). At this site Cl had a dramatic and visually obvious effect on leaf spot severity in 'Redwin' and 'Manning' winter wheat. These results came as a great surprise to us. Initially, it was believed the lesions were tanspot disease ( incited by *PTR*) because of the similarity in symptom appearance. Also, Cl had been shown to suppress this disease in South Dakota (Fixen et al., 1986b). However, more recent investigations now suggest the leaf spot phenomena was probably not disease related, but a physiological disorder similar to that described by Smiley et al. (1993). There were several reasons for this conclusion: i) propiconazole or Tilt, a foliar fungicide, had no effect on leaf spot severity, ii) *PTR* could not be isolated from symptomatic tissue using the Raymond et al. (1985) method, and iii) 'Tiber' winter wheat a cultivar genetically very similar to 'Redwin' produced no lesion symptoms (Table 1).

Physiological leaf spot severity - available Cl relationships at a site south of Lodgegrass, Montana (Bighorn Mountain foothills) indicated only small amounts of fertilizer Cl were required to dramatically reduce leaf spot severity (Figure 5). Coincident with a reduction in leaf spot severity was a near linear increase in whole plant Cl concentration . The results from this site and six other locations suggests that when physiological leaf spots occur in 'Redwin' and other susceptible winter wheat cultivars ('Kestrel', 'Manning'), there is a high probability the Cl concentration in the plant (<.10%) and/or soil (<10 lbs/a in 0-24" depth) is extremely low.

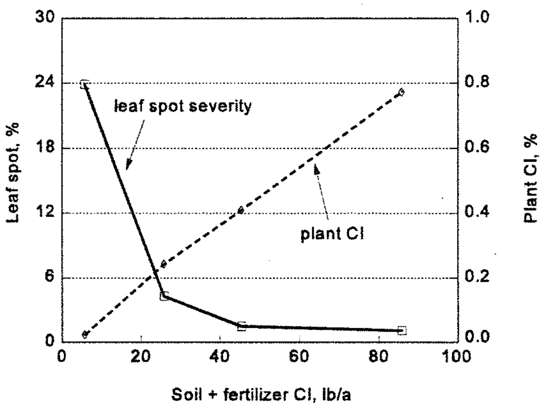

Figure 5. Effect of soil + fertilizer Cl on physiological leaf spot in flag leaves of 'Redwin' winter wheat. Lodgegrass, Montana. 1993.

Low soil or plant Cl status was not a guarantee that physiologic leaf spot would occur in susceptible varieties. Only minor symptoms were observed at several sites even though soil and plant Cl levels were very low. Other factors appear to play a role in the severity and development of these lesions. To date, our experience indicates that in susceptible varieties leaf spotting was favored by a combination of low soil Cl, plus prolonged wet and cool weather particularly during vegetative growth stages.

## References

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