The Effect of Chloride Fertilizer on Wheat and Barley*

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Introduction:

In 1954, Cl^- was established as an essential plant nutrient (Broyer et al., 1954). Until the early 1980's, however, Cl^- fertilization of cereals was not a concern since yield increases specifically due to the nutritional effect of Cl^- were highly unlikely under field conditions. Interest in Cl^- as a fertilizer has increased in the past decade partly as a result of unexpected yield responses of cereals to KCl applications on soils testing high in potassium (Blair, 1984; Skogley and Haby, 1981). Recent studies in the Northern Great Plains confirm that the Cl^- component of fertilizers can, in some instances, increase the yield of wheat and barley (Engel and Grey, 1991; Fixen et al., 1986a,b; Goos et al., 1987; Goos et al., 1989; Wang, 1987). These responses to Cl^- are best regarded as yield increases to the addition of an insufficient, not a deficient nutrient (Fixen, 1987). That is, yield responses are not due to the direct and unique role of Cl^- in metabolic processes but rather to indirect effects of Cl^- on plant growth. Cl^- concentrations are not sufficiently low to severely limit yield or to produce deficiency symptoms; rather, Cl^- concentrations are not sufficiently high to attain optimum yields (Fixen, 1987). Cl^- fertilizers have also been shown to reduce disease severity, improve grain quality and advance crop maturity.

The mechanism through which Cl^- operates to produce these "non-nutritional" yield increases has not been firmly established. Although yield responses to Cl^- have often been linked to the suppression of foliar and root diseases, the suppression of disease by Cl^- has not consistently produced an increase in grain yield (Buchenau et al., 1990, personal communication; Christensen and Brett, 1985; Shefelbine et al., 1986; Timm et al., 1986). Yield responses to Cl^- which were not attributable to disease suppression have also been observed (Bonczkowski et al., 1988; Engel and Grey, 1991; Fixen et al., 1986b; Goos et al., 1989).

In spite of a lack of knowledge about the mechanism by which Cl^- increases grain yield, several factors which affect the probability of a yield response to Cl^- have been identified. Research in South Dakota indicates that a yield response is likely in soils containing less than 66 kg Cl^- ha^{-1} to 60 cm. Researchers in other regions have found this guideline to be somewhat unreliable in the prediction of a profitable yield response to chloride fertilizers (Engel and Grey, 1991; Lamb and Windels, 1989; Lamb et al., 1986; Lamb et al., 1987). Several factors in addition to soil Cl^- concentrations have been identified. Crop species and cultivar also influence the likelihood of a response (Fixen et al., 1986b; Fixen, 1988; Gelderman et al., 1988). In circumstances where disease is suppressed by Cl^-, other factors including the type of disease, the amount of disease pressure and the species and variety of crop are also important (Fixen, 1987).

Field studies were conducted in 1989, 1990 and 1991 to determine the profitability of Cl^- fertilization in Manitoba. At all field sites, soil Cl^- content measured <66 kg Cl^- ha^{-1} to 60 cm (Table 1); the application of Cl^- would be recommended according to current South Dakota soil test guidelines. The effect of Cl^- fertilization on yield, disease severity, plant nutrient concentrations and grain quality of Katepwa wheat and Bedford barley was studied at five field sites in each of 1989 and 1990. The low frequency of response to Cl^- in these trials may have been due to the cultivars of wheat and barley grown. South Dakota researchers have observed that American cereal cultivars differ in their responsiveness to Cl^- (Fixen, 1988; Gelderman et al., 1988). To characterize the Cl^- responsiveness of several cultivars of wheat and barley commonly grown in Manitoba, cultivar trials were conducted at one site in 1990 and at three sites in 1991. The effect of Cl^- on yield, plant nutrition and grain quality of these cultivars was determined.

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Table 1: Soil Chloride Content at Experimental Sites (1989-1991)

Site	Soil Chloride Content (kg Cl^- ha^{-1} to 60 cm)*		
	1989	1990	1991
Anola	22	22	40
Carman	28	9	—
Darlingford	31	24	—
Portage	17	45	12
University	19	12	18

* determined by mercury(II) thiocyanate method (Fixen et al., 1988)

Methods and Materials:

a) 1989/90 Chloride Fertilizer Trials - Bedford Barley and Katepwa Wheat

Sixteen field experiments (8 with Bedford barley and 8 with Katepwa wheat) were conducted at five sites in each of 1989 and 1990.

A complete factorial experiment consisting of Cl^- at rates of 0, 25 or 50 kg Cl^- ha^{-1} and two sources of broadcast Cl^- (KCl or NaCl) was used. An additional treatment of 25 kg Cl^- ha^{-1} as KCl placed in the seedrow was included. In each year, the effect of Cl^- on common root rot was studied at three of the barley sites and two of the wheat sites. In addition, the effect of Cl^- on spot blotch was studied at one of the barley sites. For the common root rot experiments, the Cl^- treatments listed previously were applied, with or without disease inoculum. The spot blotch experiment was similar to the common root rot experiment, except the former did not include seedrow placed KCl. A randomized complete block design using five or six replications was employed at all sites. Subplots consisted of 8 drill rows (18 cm spacing) 6 m in length.

Cl^- fertilizer was hand broadcast within several days of seeding. Commercial grade KCl and reagent grade NaCl were used. For the common root rot studies, common root rot inoculum was applied in the seedrow to the two to four innermost rows of each subplot at time of seeding. For the spot blotch studies, inoculum was evenly applied to the soil immediately adjacent to the base of the two innermost rows of each subplot approximately one month after seeding after the canopy had closed.

Basal applications of N,P and S were made to meet or exceed soil test recommendations. Herbicides were applied at recommended rates to control weeds. Alleys and border areas directly adjacent to the plots were seeded to wheat or barley to reduce edge effects.

Plant tissue samples were taken from the inner rows of each subplot at the boot to heading stage. The aboveground portion of the plant was dried at 68°C and ground to pass a 2 mm sieve using a Wiley mill. Plant tissue concentrations of Cl^-, NO_3^-, NH_4^+, K, Cu, Mn and Zn were determined. Cl^- concentration was determined by $AgNO_3$ titration (LaCroix et al., 1970), NO_3^- and NH_4^+ by steam distillation (Keeney and Nelson, 1982) and K, Cu, Mn, and Zn by atomic absorption of a nitric perchloric digest (Isaac and Kerber, 1971).

In the common root rot studies, at approximately the soft dough stage, a random sample of 25 plants with subcrown internodes was dug from each subplot. Subcrown internodes were rated for common root rot (Ledingham et al., 1973) using a blind rating system.

In the spot blotch studies, a cursory spot blotch rating was conducted at approximately the soft dough stage. Rating was based on a combination of disease severity and height of disease in the canopy.

Final harvest consisted of the shoot portion of plants from 3 m of the two innermost drill rows of each subplot. Samples were cut by hand approximately 1 inch from the soil surface, air dried, then threshed with a stationary thresher. Measures taken included grain yield, straw yield, thousand kernel weight, hectolitre weight and barley kernel plumpness. Thousand kernel weight was based on a subsample of 200 kernels per subplot. Hectolitre weight and barley kernel plumpness were determined using procedures outlined by the Canadian Grain Commission (1984).

b) 1990/91 Chloride Fertilizer Trials - Barley and Wheat Cultivars

A factorial experiment consisting of four cultivars of wheat or barley and three fertilizer treatments was conducted at one site in 1990 and at three sites in 1991. In 1990, fertilizer treatments consisted of a control, 50 kg Cl^- ha^{-1} as broadcast KCl and 50 kg Cl^- ha^{-1} as broadcast NaCl. In 1991, $CaCl_2$ was used in place of NaCl. 'Bedford', 'Brier', 'Heartland' and 'Argyle' barley (*Hordeum vulgare* L.), and 'Katepwa', 'Roblin', 'Biggar' and 'Marshall' wheat (*Triticum aestivum* L.) were the cultivars grown. Bedford, Brier and Heartland are 6-row feed cultivars. Argyle is a 6-row barley suitable for malting or feed purposes. All barley cultivars grown were recommended cultivars in Manitoba in 1991. Katepwa, Roblin and Biggar were recommended cultivars in Manitoba in 1991. Katepwa and Roblin are high quality Canadian Western Red Spring wheats while Biggar is a red, medium quality Canadian Prairie Spring wheat. Marshall, which is not recommended for Manitoba, is an American semi-dwarf hard red spring wheat. Marshall was included because studies conducted in the Northern United States have demonstrated Marshall to be responsive to Cl^- fertilizer applications.

All cultivars were sown to achieve a stand density of 250 germinated seeds per m^2 based on thousand kernel weight and germination percentage of each seedlot. Cl^- fertilizers were handbroadcast within several days of planting. Commercial grade KCl, reagent grade NaCl and commercial grade $CaCl_2$ were the fertilizer sources used.

Basal applications of N and P were made to meet or exceed soil test recommendations. Alleys and border areas were seeded to wheat or barley in order to reduce edge effects. Herbicides were applied at recommended rates for the control of weeds.

Sites were sampled at midseason and at maturity. Midseason harvest was conducted at the boot to heading stage. Dry matter yield and plant tissue concentrations of Cl^-, NO_3^-, NH_4^+, K, Cu, Mn and Zn were determined at midseason. Crop advancement was also determined. Cl^- concentration was determined by $AgNO_3$ titration (LaCroix et al., 1970), NO_3^- and NH_4^+ by steam distillation (Keeney and Nelson, 1982) and K, Cu, Mn, and Zn by atomic absorption of a nitric perchloric digest (Isaac and Kerber, 1971).

After heading, cursory foliar disease ratings based on the height of disease lesions in the crop canopy and the severity of disease were conducted for selected treatments and sites. This rating system was purely descriptive, not quantitative. Foliar diseases present were neither identified nor differentiated from one another.

Final harvest consisted of the shoot portion of plants from 3 m of two inside drill rows from each subplot. Samples were air dried, then threshed with a stationary thresher. Grain yield, straw yield, thousand kernel weight, hectolitre weight and barley kernel plumpness were determined. Thousand kernel weight was based on a subsample of 200 kernels per subplot. Hectolitre weight and barley kernel plumpness were determined according to the procedures outlined by the Canadian Grain Commission (1984).

Results and Discussion:

a) 1989/90 Chloride Fertilizer Trials - Bedford Barley and Katepwa Wheat

Bedford Barley

Cl^- applications significantly increased midseason plant tissue Cl^- concentration for Bedford barley at all sites. Neither fertilizer source (Figure 1) nor placement had a significant effect on plant tissue Cl^- concentration. Cl^- applications significantly decreased plant tissue NO_3^- concentration for Bedford barley in 1 of 8 field experiments and tended to decrease plant tissue NO_3^- concentration in an additional 4 field experiments. These reductions in plant tissue NO_3^- concentrations were not consistently associated with a suppression of disease. Cl^- did not have a consistent effect on plant tissue concentrations of K, Cu, Mn, Zn or NH_4^+.

The addition of Cl^- significantly reduced the severity of common root rot in 2 of 6 common root rot experiments (Table 2). However a resultant significant increase in grain yield did not occur in any case where a significant reduction in root rot was observed. Cl^- applications did not visibly reduce spot blotch in either of the two field experiments conducted.

Table 2: The Effect of Chloride Fertilizer on Common Root Rot Severity of Bedford Barley and Katepwa Wheat in Manitoba (1989-1990)*

Crop	Number of Plots in which Cl^- Significantly Reduced Common Root Rot Severity**	Average Reduction in Common Root Rot†:	
		Responsive Sites Only	Across All Sites
Bedford barley	2 of 6	0.22	0.12
Katepwa wheat	1 of 4	0.22	0.10

* application rate was 50 kg Cl^- ha^{-1}
** $P \leq 0.05$
† Disease rating based on severity of lesions on subcrown internode: 1=clean 2=slight 3=moderate 4=severe

Cl^- applications significantly increased the grain yield of Bedford barley in 2 of the 8 field experiments conducted (Table 3). Neither soil Cl^- concentration nor plant tissue Cl^- concentration reliably predicted yield responses to Cl^- (Figures 2 and 3). The two yield responses observed occurred at the University of Manitoba site, one in 1989 and one in 1990. In the spot blotch study at the University of Manitoba in 1989, the addition of 50 kg Cl^- ha^{-1} as either KCl or NaCl increased grain yield by ~300 kg ha^{-1} - the mean grain yield for this plot was ~4400 kg ha^{-1}. In the common root rot study at the University of Manitoba in 1990, the application of 50 kg Cl^- ha^{-1} as either KCl or NaCl increased grain yield by ~490 kg ha^{-1} -the mean grain yield for this plot was ~5650 kg ha^{-1}. Although the spot blotch and common root rot experiments at the University of Manitoba were conducted in adjacent plots, in each year a significant yield response was observed in only one of the two plots. Soil Cl^- concentrations were the same in both plots, well below the 66 kg Cl^- ha^{-1} to 60 cm recommended in current South Dakota soil test guidelines. Equivalent rates of Cl^- had been applied to both plots. In neither case were yield responses associated with a significant reduction in plant disease.

Table 3: The Effect of Chloride Fertilizer on Yield Response of Bedford Barley and Katepwa Wheat in Manitoba (1989-1990)*

Crop	Number of Plots in which Cl^- Significantly Increased Yield**	Average Yield Response (kg ha^{-1}) at:	
		Responsive Sites Only	Across All Sites
Bedford barley	2 of 8	393	187
Katepwa wheat	0 of 8	---	-1

* application rate was 50 kg Cl^- ha^{-1}
** $P \leq 0.05$

Overall, the effect of Cl^- on thousand kernel weight, hectolitre weight and barley kernel plumpness was small and inconsistent.

Katepwa Wheat

The addition of Cl^- significantly increased plant tissue Cl^- concentration for Katepwa wheat in 6 of 6 field experiments in which plant tissue Cl^- concentration was determined. Neither fertilizer source (Figure 1) nor placement had a significant effect on plant tissue Cl^- concentration. Cl^- applications significantly decreased plant tissue NO_3^- concentration in all of the 4 experiments in which plant tissue NO_3^- concentration was determined. The effect of Cl^- applications on plant tissue concentrations of K, Cu, Mn, Zn and NH_4^+ was small or nonexistent.

Cl^- significantly reduced common root rot in 1 of 4 common root rot studies (Table 2). However, a consequent significant increase in grain yield did not result at the site where the reduction in root rot was observed.

Cl^- applications did not significantly increase grain yield in any of the 8 field experiments conducted (Table 3). Neither soil Cl^- concentration nor plant tissue Cl^- concentration reliably predicted yield responses to Cl^- (Figures 2 and 3). The lack of a yield response may be due to the cultivar of wheat grown. In the cultivar trials conducted in 1990 and 1991, Katepwa responded less frequently than Biggar, Marshall and Roblin (Table 4).

Cl^- was found to slightly, but significantly increase thousand kernel weight for Katepwa wheat in 3 of 8 field experiments. The effect of Cl^- on hectolitre weight was inconsistent.

b) 1990/91 Chloride Fertilizer Trials - Barley and Wheat Cultivars

Barley Cultivars

The application of 50 kg Cl^- ha^{-1} as KCl or either NaCl or $CaCl_2$ consistently and significantly increased midseason plant tissue Cl^- concentration for all cultivars at all sites. Cl^- applications significantly reduced plant tissue NO_3^- concentrations in 1991 only. Significant reductions in plant tissue NO_3^- concentration were observed for Bedford and Brier in three of four field experiments and for Argyle and Heartland in one of four field experiments. Cl^- applications did not have a consistent and significant effect on midseason plant tissue concentrations of K, Mn, Cu, Zn or NH_4^+.

Cl^- applications did not appear to affect crop advancement for any of the barley cultivars tested.

A low frequency of yield response to Cl^- was observed in the barley cultivars tested (Table 4). The application of 50 kg Cl^- ha^{-1} as either KCl or NaCl significantly increased grain yield for Heartland by approximately 900 kg ha^{-1} (from 4970 to 5870 kg ha^{-1}) in one of four field experiments. The addition of Cl^- did not significantly increase the grain yield for any of the other barley cultivars tested in any of the four field experiments conducted.

Table 4: The Effect of Crop Cultivar on Yield Response of Wheat and Barley to the Application of Chloride Fertilizers in Manitoba (1990-1991)*

Crop	Cultivar	Number of Sites in which Cl^- Significantly Increased Yield**	Average Yield Response ($kg\ ha^{-1}$) at:	
			Responsive Sites Only	Across All Sites
Barley	Bedford	0 of 4 †	---	-321
	Brier	0 of 4	---	145
	Argyle	0 of 4	---	266
	Heartland	1 of 4	905	197
Wheat	Katepwa	0 of 4	---	-16
	Roblin	1 of 4	492	137
	Biggar	2 of 4	333	150
	Marshall	2 of 4 ‡	363	116

* application rate was 50 kg Cl^- ha^{-1}

** $P \leq 0.05$

† At 1 of 4 sites, a significant decrease in yield (~ 1200 kg ha^{-1}) was observed.

‡ At 1 of 4 sites, a significant decrease in yield (~ 390 kg ha^{-1}) was observed.

In general, effects of Cl^- on grain quality of barley were nonexistent or deleterious. Decreases in hectolitre weight and in the percentage of plump kernels with the application of Cl^- were observed most frequently in the cultivars Brier and Heartland. Cl^- did not have a consistent and significant effect on total N of grain.

Wheat Cultivars

The application of 50 kg Cl^- ha^{-1} as KCl or either NaCl or $CaCl_2$ consistently and significantly increased midseason plant tissue Cl^- concentration for all cultivars of wheat at all sites. Cl^- significantly reduced plant tissue NO_3^- concentration for Katepwa, Roblin and Marshall in two of four field experiments and for Biggar in one of four field experiments. Cl^- applications did not have a consistent and significant effect on midseason plant tissue concentrations of K, Mn, Cu, Zn or NH_4^+.

In several instances the application of Cl^- appeared to advance maturity for the cultivars Marshall and Biggar.

After heading, cursory foliar disease ratings were conducted for selected treatments and sites. The addition of 50 kg Cl^- ha^{-1} visibly reduced foliar disease for Marshall wheat in both 1990 and 1991 and for Roblin wheat in 1991. However, a similar reduction in foliar disease was not observed for Katepwa wheat in either case. The visible reductions in foliar disease did not always result in a significant increase in grain yield. However, increases in thousand kernel weight occurred in all cases where a reduction in foliar disease had been observed.

The wheat cultivars tested responded more frequently than the barley cultivars to the application of Cl^- (Table 4). Of the wheat cultivars tested, Cl^- significantly increased grain yield of Biggar and of Marshall in two of four field experiments. The yield of Roblin was significantly increased by Cl^- in one of four field experiments. Cl^- did not significantly increase the grain yield of Katepwa.

In the wheat trials, significant increases in thousand kernel weight and hectolitre weight most often occurred in conjunction with a significant increase in grain yield. Significant increases in thousand kernel weight did occur without an associated significant increase in grain yield, however. Slight reductions in total N of grain by Cl^- tended to occur when Cl^- both significantly decreased midseason plant tissue NO_3^- concentration and significantly increased grain yield.

Summary and Conclusions:

The application of Cl^- consistently and significantly increased midseason plant tissue Cl^- concentration for wheat and barley. Overall, neither fertilizer source nor placement were found to affect plant availability of Cl^-. Significant reductions in plant tissue NO_3^- concentrations by Cl^- were observed for both wheat and barley. Cl^- applications had little or no effect on plant tissue concentrations of K, Cu, Mn, Zn and NH_4^+ for either wheat or barley.

Reductions in common root rot by Cl^- were observed in 2 of 6 experiments with Bedford barley and in 1 of 4 experiments with Katepwa wheat. In several instances, visible reductions in foliar disease were observed for certain of the cultivars. Significant increases in grain yield were not generally associated with these reductions in disease, however increases in thousand kernel weight were occasionally observed.

Cl^- applications were found to significantly increase grain yield for Bedford barley in 2 of 8 experiments and for Katepwa wheat in 0 of 8 experiments. Profitable responses to Cl^- were inconsistent and difficult to predict. Neither soil Cl^- concentration nor plant tissue Cl^- concentration reliably predicted yield responses to Cl^-. Overall, the wheat cultivars tested responded more frequently to the application of Cl^- than did the barley cultivars tested. Of the wheat cultivars tested, Marshall, Biggar and Roblin were found to respond more frequently to Cl^- than Katepwa. The observed yield responses did not appear to be dependent upon a suppression of disease by Cl^-. The high degree of variability evident in the responses observed among sites and among years suggests that environmental conditions may have had a strong influence on crop response to Cl^-.

In conclusion, Cl^- can, on occasion, provide a modest increase in the grain yield of wheat and barley. However, the reliable prediction of profitable responses to Cl^- remains difficult. Producers should ensure that crop needs for N,P,K and S are provided for before experimenting with chloride fertilizers.

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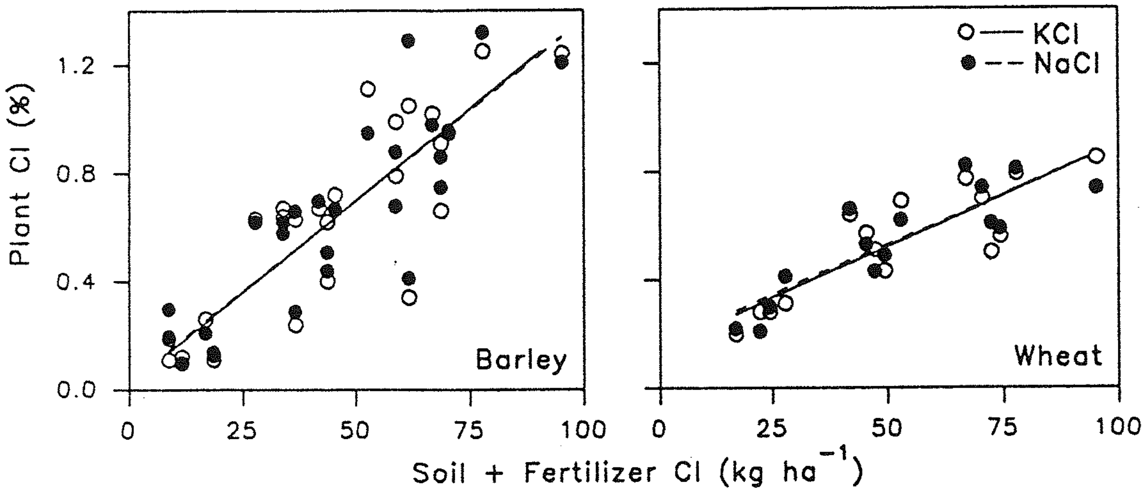

Fig. 1. Effect of Soil Cl and Two Sources of Fertilizer Cl on Plant Cl Concentration in Non-inoculated Bedford Barley and Katepwa Wheat

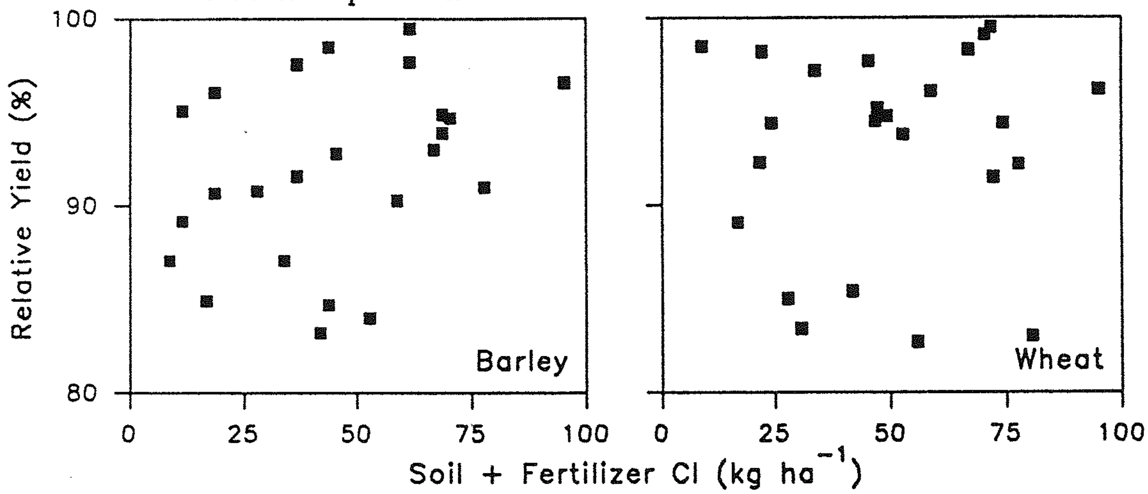

Fig. 2. Relationship between Soil + Fertilizer Cl and Relative Yield for Non-inoculated Katepwa Wheat and Bedford Barley

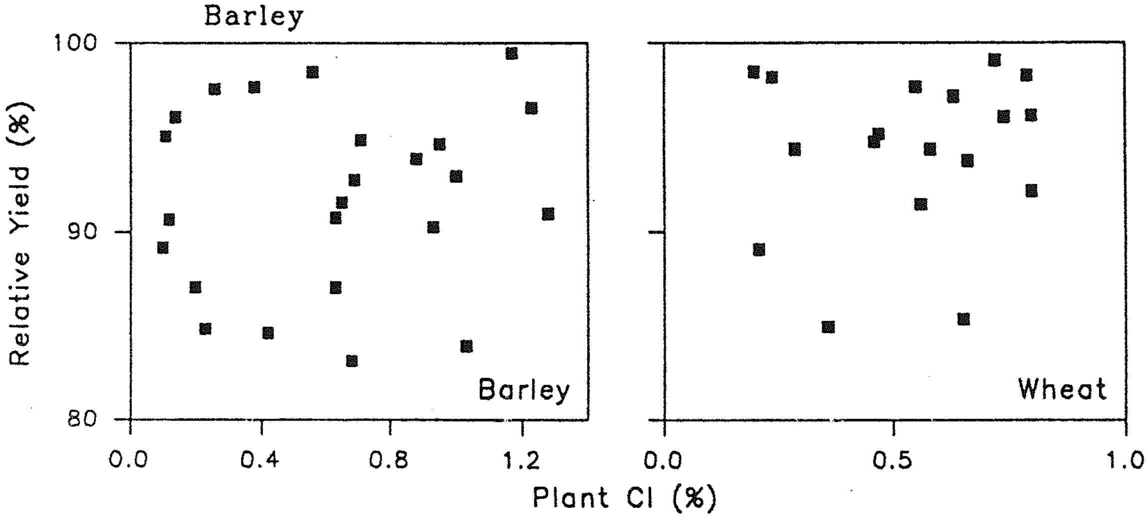

Fig. 3. Relationship between Plant Tissue Cl and Relative Yield for Non-inoculated Katepwa Wheat and Bedford Barley