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Paul E. Gaspar

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RESPONSE OF OAT TO CHLORIDE FERTILIZATION

BY

PAUL E. GASPAR

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RESPONSE OF OAT TO CHLORIDE FERTILIZATION

This dissertation is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this dissertation does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Dale L. Reeves Major Advisor	Date
Dr. Paul E. Fixen Thesis Advisor	Date
Dr. Tom E. Schumacher Thesis Advisor	Date
Dr. Maurice L. Horton Head, Plant Science Department	Date

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RESPONSE OF OAT TO CHLORIDE FERTILIZATION

ABSTRACT

PAUL E. GASPAR

Several studies conducted in South Dakota have shown significant yield increases in wheat and barley due to chloride (Cl) fertilization. The effects of Cl on oat were evaluated in the greenhouse and two field experiments. Five cultivars and 3 KCl fertilizer levels (0, 58, and 117 Kg ha^{-1}) were tested in a factorial arrangement. In a second experiment, five N fertilizer levels (0, 34, 68, 102, 136 kg ha^{-1}) and 2 KCl fertilizer levels (0 and 135 kg ha^{-1}) on oat (Benson) were tested in a factorial arrangement. The greenhouse study had 4 levels of Cl (0, 10, 20, and 40 mg l^{-1}) and two watering schedules (non-restricted and restricted). The objectives were: (a) determine if oat cultivars respond to Cl fertilization, (b) examine the effect of Cl on plant water relations (c) examine the relationship between Cl fertilization and crown rust infection, (d) evaluate the effected of N and Cl fertilization on grain yield and lodging, and (e) evaluate the antagonism between NO_3^- and Cl^- uptake.

Chloride addition significantly increased oat grain yield at some sites. The addition of 32 kg Cl ha^{1-} gave near maximum oat grain yield. At the Cl responsive sites,

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I. INTRODUCTION

The chloride (Cl) anion was first recognized as an essential micronutrient in 1954 (Broyer, 1954). Broyer was able to show Cl deficiency symptoms on tomato (Lycopersicon esculentum) grown in a hydroponic solution lacking Cl. The Cl deficiency symptoms found on the tomato plant were wilting leaf tips, chlorosis, necrosis, and bronzing. Broyer believed the critical Cl^- solution concentration needed for normal growth was 0.26 g kg^{-1}. In 1957, Johnson et al. reported a the critical Cl^- concentration in plant tissue was 0.1 g kg^{-1}. Recently, Fixen et al. (1987) found the optimum plant Cl^- concentration needed for maximizing grain yield was approximately 1.5 g kg^{-1} in spring wheat (Triticum aestivum L.) at heading stage. Significant grain yield increases due to Cl have occurred in spring wheat, (T. aestivum L.) winter wheat (T. aestivum L.), barley (Hordeum vulgare L.), sugarbeet (Beta vulgaris L.), and potato (Solanum tuberosum).

The reason for the response to Cl is not clear. Some of the reasons proposed are; cofactor for photosynthesis, plant water relations, and/or disease suppression. A number of researchers have suggested Cl is an essential cofactor for photosynthesis (Bove et al., 1963, Heath and Hind, 1969,and Izawa, Heath, and Hind, 1969). However, Terry (1977) suggested Cl reduced leaf area but did not decrease the rate of photosynthesis per unit area. Currently many researchers are undecided on the biochemical role Cl plays in enzyme activation and photosynthesis.

The effect of Cl on plant water relation is currently being evaluated by a number of researchers. Fixen et al.,(1986) and Christensen et al., (1981) have demonstrated positive affects on plant water relations due to Cl fertilization. If Cl reduces the osmotic potential and increases relative water content in plants, the addition of Cl may allow the plant to continue growth and development under stressful conditions.

An interaction between Cl^- and NO_3^- anions for uptake has been found by Beaten, 1984, Fixen et al. 1987, and Goos et al. 1987. Chloride fertilization can reduce NO_3^- uptake and NO_3^- can compete with Cl^- uptake. In oat (Avena sativa L.) production there is a positive relationship between nitrogen fertilization and lodging. Brinkman (1985) and Ohm (1976) showed significant increases in lodging due to increases in nitrogen fertilization. A reduction in nitrogen uptake caused by the antagonism between the NO_3^- and Cl^- anion may result in a decrease in lodging.

Chloride research has primarily been conducted on wheat, barley, sugarbeet, and potato. Little research has been conducted on oat. Therefore, three experiments were proposed to evaluate the response of oat to chloride fertilization. The principal objectives of these studies were to: (a) determine if different oat cultivars respond the same to Cl fertilization, (b) examine the effect of Cl has on relative water content, osmotic potential, osmotic potential adjusted for full turgor, water potential, and stomatal conductance, (c) examine the relationship between Cl fertilization and crown rust (Puccinia coronata) infection, (d) evaluate the relationship between grain yield, lodging and levels of N and Cl.

II. The Response of Oat Cultivars to Chloride

INTRODUCTION:

Chloride (Cl) additions at moderate levels can result in an increase in small grain yield (Christensen, et al. 1982; Fixen, et al. 1986a; Goos et al. 1987; Timm et al. 1986; Zubriski et al. 1970). Yield response has been primarily demonstrated for wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) cultivars. Soil Cl levels > 43.5 kg ha^{-1} (0-60 cm) were adequate for near-maximum wheat yield (Fixen et al. 1986b). Fixen et al. (1987) found wheat varieties responded differently to the addition of potassium chloride (KCl) fertilizer. Preliminary research conducted at South Dakota State University in 1985 indicated that some oat (Avena sativa L.) varieties responded positively where others did not.

Chloride addition has an affect on plant solute concentration (Christensen et al. 1981). Christensen, et al. (1981) found osmotic potentials for NH_4Cl treated winter wheat plants were significantly lower than for $(NH_4)_2SO_4$ treatments. The osmotic potential at full turgor was also lower in the Cl treated plants. This would indicate that osmoregulation occurred and that plant turgor was increased (Hsiao, et al. 1976; Meyer, and Boyer, 1972; Turner and Jones, 1980). This could result in continued growth under stressful conditions. When turgor pressure was maintained under stressful conditions, plants had greater growth rates than plant which did not maintain turgor (Morgan, 1988). Turgor maintenance may also have an affect on leaf extension, leaf senescence, leaf rolling, leaf angle, leaf waxiness, and the rate of development. Morgan, (1983) showed that plants with the ability to osmotically adjust (osmoregulation in response to water stress) had a higher number of initiated tillers and greater seed set per tiller. Since grain yield is the product of inflorescences per unit area, seeds per inflorescence, and seed weight, one could assume a plant with the ability to osmotically adjust would have higher yields. The understanding of water relationships and how Cl effects them, could help in explaining the role of Cl in oat productivity.

Many investigators have concluded that Cl has a role in disease control in small grains (Christensen, et al., 1982; Fixen, et al., 1986b; Goos, et al., 1987; Powelson and Jackson, 1978; Russell, 1978; Timm et al., 1986). Timm et al. (1986) found a significant reduction of common root rot (<u>Cochiolobolus</u> <u>sativus</u>) in barley with the addition of KCl. Barley yields tended to increase with KCl additions. Christensen et al., (1982) found Cl^-

containing fertilizer significantly reduced take-all root rot (*Gaeumannomyces graminis* var. *tritici* Walker) and stripe rust (*Puccinia striiformis* West) resulting in increased wheat yields. Chloride caused the suppression of stripe rust by either lengthening the latent period or by reducing the amount of effective inoculum. Russell, (1978) also found a reduction of stripe rust on several winter wheat cultivars as the result of the addition of sodium chloride or KCl. Fixen et al. (1986b) found that Cl additions significantly reduced tanspot (*Pyrenophora trichostoma* (Fr.) Fckl.) and leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici*) in spring wheat. Crown rust (*Puccinia coronata*) is a major disease of oat. However, the relationship of Cl to the expression of crown rust on oat is unknown.

The objectives of this investigation were to: (a) determine if selected oat cultivars respond to KCl addition on high K-testing soils; (b) evaluate the effect Cl addition has on plant water relations under field conditions; and (c) examine the relationship between Cl additions and crown rust infection in oat.

MATERIALS AND METHODS:

During 1986 and 1987, experiments were conducted on Pachic Udic Haploborolls and Udic Haplustolls in eastern South Dakota. The sites were very high in ammonium acetate extractable K ($K > 391$ kg ha^{-1}). Properties of the soils, previous crop, and tillage practices at each site are presented in Tables 1 and 2. A glass electrode using 1:1(w/w) soil to water ratio on a stirred sample was used to determine pH. The organic matter content was determined by the modified Walkley Black method. Nitrate was determined by using an Orion[3] specific ion electrode, phosphorus by the Bray and Kurtz no.1 method with 1:10(w/v) soil to solution ratio, potassium by extraction with ammonium acetate, and Cl^- by potentiometric titration with $AgNO_3$. All soil analysis except Cl^- determination were done by the South Dakota State University Soil Testing Laboratory (Carson and Gelderman, 1980).

The experiment was conducted in a split plot randomized complete block design with six replications. The main plot treatments were oat cultivars and the sub-plot treatments were 0, 58, and 117 Kg KCl ha^{-1}. The KCl was broadcast and incorporated with a field cultivator. Four of the five sites were located on fields of farmer-cooperators while the other site was located on the South

Table 1. Site characteristics, 1986-1987.

Site	County	Soil type and classification	Previous Crop	Tillage System
86H	Hamline	Estelline sil, Pachic Udic Haploboroll	wheat	chisel-disk
86L	Lake	Dempster sil, Udic Haplustoll	soybean	double disk
87H	Hamline	Estelline sil, Pachic Udic Haploboroll	fallow	plow-disk
87L	Lake	Dempster sil, Udic Haplustoll	soybean	double disk
87B	Brookings	Lismoure sil, Pachic Udic Haploboroll	corn	plow-disk

Table 2. Site Characteristics, 1986-1987

	0 to 60 cm		61 to 120 cm		0 to 15 cm			
Site	NO_3-N	Cl	NO_3-N	Cl	P	K	pH	Organic Matter
	kg ha^{-1}							g kg^{-1}
86H	55	25	73	35	20	594	7.4	38
86L	34	28	19	38	94	448	6.6	35
87H	100	10	71	12	121	706	7.3	23
87L	48	39	32	34	28	470	6.2	30
87B	57	25	41	26	173	560	6.9	35

Dakota State University Agronomy Farm in Brookings, SD. Sites were seeded in the last two weeks of April. The oat cultivars seeded at each site were Benson, Froker, Lancer, Moore, and Ogle. Plot size was 1.2 m by 7.6 m at all sites. The herbicides used for weed control were Propachlor and Bromoxynil + MCPA. Nitrogen fertilizer was applied based on a 3.59 Mg ha^{-1} grain yield goal and accounting for nitrate-nitrogen to a 60 cm depth. All sites received 20 kg P ha^{-1} as concentrated super phosphate applied with the drill and delivered with the seed. A 12.5 kg ha^{-1} seeding rate was used at all sites.

Plots were harvested with a small plot combine. The test weight was determined by weighing 473 cm^3 of seed for each plot. Plant samples were collected from 1 m of row for determining yield components. Effective tillers in a randomly selected 1-m row segment were counted at maturity. Kernels from the 1-m section were weighed and counted. To determine kernels $tiller^{-1}$, the total number of kernels were divided by the number of tillers. The 1000-kernel weight was calculated by dividing the kernel weight by the kernel number and multiplying by 1000. Plant development determinations were taken at heading stage using the Haun scale (Haun, 1973). The Haun scale is more precise than the Feeks scale. Protein and oil content of the oat groat were determined by grinding approximately 5 g of oat groat with a Udy mill into flour and analyzing with a modified Technicon Infranalyzer 300. Crown rust was recorded two weeks after heading (Feekes stage 10.3) from each plot using the Cobb scale. Plant height was recorded two weeks before maturity as the distance from the soil to the top of the panicle. The Belgium index was used for rating lodging. This index is calculated by multiplying the area lodged (1-9) by the intensity of lodging (1-5) by a constant (0.2). The final value ranges from 0.2 (no lodging) to 9.0 (plot completely flat).

Relative water content, solute potential, solute potential corrected for full turgor, water potential, and stomatal conductance measurements were obtained at three stages of growth (boot (Feekes stage 10) , heading, and grain filling (Feekes stage 11.1) between 10 A.M. and 3 P.M.. All measurements were taken on the flag leaf. The measurements were taken at four sites (86H, 86L, 87H,and 86L). Water potential was measured only on the cultivars Moore and Ogle, relative water content and osmotic potential, osmotic potential at full turgor, and stomatal conductance were determined on all cultivars. Relative water content was determined by removing the flag leaf blade from 5 plants in each plot, placing the leaves in an aluminized pouch, and immediately measuring the fresh weight at the edge of the field. The leaves were then placed into a humidified bag and equilibrated in the dark for 4 hours at a temperature of 5°C. The leaves were then blotted dry, reweighed to determine the turgid weight, dried at 70°C for 48 hours, and weighed to determine dry weight. Relative water content was calculated by dividing the calculated water content at sampling (fresh weight - dry weight) by the water content of turgid leaves (turgid weight - dry weight) and multiplying by 100 (Slavik, 1974).

Solute potential measurements were made on the same leaves used in the relative water content measurement. Before the fresh weight was taken, a 5 cm segment of each leaf was cut from the base of the leaf blade, placed in a section of tygon tubing, and sealed with stoppers. The sample was immediately frozen in dry ice (-29° C) and stored in a freezer at -5°C until processing. Osmotic potential was measured on sap expressed by placing the sample in a bench vise to express the cellular sap on a filter paper disc (6 mm diameter). The psychrometer was calibrated with standard sodium chloride solutions (Turner, 1981). The saturated filter paper disc was placed in the center of the sample holder of Model C-52

Wescor sample chamber connected to a Wescor HR - 33T Dew Point Microvoltmeter using the technique described by Turner (1981). Solute potential at full turgor was calculated by multiplying the relative water content by the osmotic potential and dividing by 100. Leaf water potential was measured with a pressure chamber (Slavik, 1974). A flag leaf was selected randomly from each plot. The leaf was inserted into an aluminized mylar sheath (5 by 15 cm.) for 10 seconds before excision. This allowed the leaf to reach equilibrium and to minimize water loss as suggested by Turner, (1981). To prepare the leaf for the pressure chamber, a fresh cut was made at the base of the leaf. The leaf was inserted into a rubber washer and then placed in the chamber with the freshly cut end visible. The chamber was sealed and pressure was applied at a rate of 1 bar every 5 seconds. When cell sap appeared at the cut surface, the control valve was turned off and the pressure indicated on the gauge was recorded. Stomatal conductance measurements were taken on the flag leaf with a steady state porometer (Li-Cor 1600). Three measurements were taken per plot and averaged, resulting in 18 measurements per treatment.

Plant Cl^- content measurements were taken during two stages (boot and heading) at four locations (86H, 86L, 87H, and 87B). A sample consisted of 10 to 15 whole plants (above ground) from each plot. Plant Cl^- concentration was measured by shaking 0.5 g dried ground plant material in 50 ml of .1M HNO_3 for 15 minutes on a reciprocating shaker (LaCroix et al., 1970). Chloride was titrated directly with .0282 M $AgNo_3$ using a Brinkman digital burette (Brinkman Instr., Westbury, NY). The end point was detected with an Orion 96-17b (Arion, Cambridge, MA) combination chloride electrode and Fisher acid extraction method.

Plant potassium (K) concentration was determined for samples taken at heading at sites 86H and 86L by extracting 0.20 g of dried ground plant material with 20 ml of 0.35 M acetic acid. Flame emission spectrophotometry was used to determine the K concentration in the extract.

RESULTS AND DISCUSSION:

The site overall interactions for grain yield were not significant ($P > 0.10$). The Cl effect on grain yield averaged over all sites was significant ($P < 0.05$). The 32 kg Cl ha^{-1} and 64 kg Cl ha^{-1} treatments resulted in a 3% increase in grain yield compared to the control (Table 3). The Cl by cultivar interaction was significant at the 0.11 probality level suggesting that some cultivars tended to respond to chloride more consistently than others. Lancer and Froker grain yield response to 32 kg Cl ha^{-1} averaged across all sites was -0.01 Mg ha^{-1}, while Benson, Moore, and Ogle averaged 0.01 Mg ha^{-1} in response.

Even though the site interactions were not significant, individual analysis of specific sites suggest a greater effect of Cl at some locations and years than at others. The grain yield response of oat cultivars to Cl was significant at both of the 1986 sites. The grain yield responses to 32 and 64 kg Cl ha^{-1} were similar at the 86 sites.

A cultivar by Cl interaction occurred at the 87B site. At this site, Ogle was the only cultivar that significantly responded to Cl. Ogle had a 0.35 Mg ha^{-1} grain yield response to 32 kg Cl ha^{-1}. These studies indicate that 60 kg ha^{-1} of soil plus fertilizer Cl (0 to

Table 3. Effect of Cl addition on grain yield of five oat cultivars at five sites and averaged over sites.

Cultivar	Cl	Site 86H	 86L	 87H	 87L	 87B	Ave.
	kg ha^{-1}	mg ha^{-1}					
Benson	0	2.50	2.37	1.84	2.21	3.27	2.44
	32	2.68	2.51	1.85	2.41	3.16	2.52
	64	2.65	2.36	1.96	2.54	3.39	2.58
Froker	0	2.37	2.07	1.97	2.54	2.62	2.31
	32	2.52	2.09	1.84	2.40	2.56	2.28
	64	2.44	2.10	1.90	2.50	2.43	2.27
Lancer	0	3.19	2.26	2.16	2.41	2.90	2.58
	32	3.19	2.43	2.08	2.33	2.92	2.59
	64	3.24	2.25	2.10	2.54	2.83	2.59
Moore	0	2.96	2.46	2.09	2.76	3.27	2.71
	32	3.19	2.76	2.25	2.77	3.38	2.87
	64	3.23	2.84	2.22	2.75	3.31	2.87
Ogle	0	2.69	2.00	2.37	2.58	3.53	2.63
	32	2.69	1.98	2.38	2.52	3.88	2.69
	64	2.74	2.09	2.52	2.47	3.89	2.74
Ave.	0	2.74	2.23	2.09	2.50	3.12	2.54
	32	2.85	2.36	2.08	2.49	3.18	2.59
	64	2.86	2.33	2.14	2.56	3.17	2.61
Cl LSD(0.05)		0.08	0.08	NS	NS	NS	0.04
Cult. x Cl LSD(0.05)		NS	NS	NS	NS	0.25	0.06
<u>Significance</u> of <u>F</u>							
Cult.		**	**	**	*	**	**
Cl		**	**	0.28	NS	NS	*
Cult. x Cl		NS	NS	NS	NS	*	0.11

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

60 cm) was sufficient to maximize grain yield.

The effect of the addition of Cl on test weight and yield components (tillers meter^{-1}, kernels tiller^{-1}, and 1000 kernel weight) were evaluated to determine whether grain yield response of oat cultivars could be explained by changes in these components. Test weight was significantly ($P < 0.10$) increased by the addition of Cl at 87H and there was a cultivar by Cl interaction at 87L (Table 4). Test weight increased 8 kg m^{-3} when 32 kg Cl ha^{-1} was applied at 87H. At site 87L Froker was the only cultivar that responded to Cl addition. Since the two sites where Cl effected test weight were sites in which there was no grain yield response, it was concluded that Cl induced changes in test weight were not related to Cl effects on grain yield.

Chloride addition did not significantly affect tillers meter^{-1} (range 41 to 100) or kernels tiller^{-1} (range 22 to 48). A significant ($P < 0.10$) increase in 1000 kernel weight due to Cl addition was found at both of the 1986 sites (Table 5). However, there was no difference between the 32 and 64 kg Cl ha^{-1} rates. A significant increase in grain yield and 1000 kernel weight due to Cl addition occurred at both of the 1986 sites. At least part of the grain yield response may be

Table 4. Effect of Cl addition on test weight of five oat cultivars at five sites.

		Site				
Cultivar	Cl	86H	86L	87H	87L	87B
	kg ha^{-1}	kg m^{-3}				
Benson	0	333	401	263	357	337
	32	343	395	265	368	324
	64	337	413	275	360	342
Froker	0	323	380	275	341	316
	32	324	397	280	346	330
	64	326	384	281	373	328
Lancer	0	379	433	285	365	320
	32	378	420	293	347	326
	64	384	420	280	359	328
Moore	0	346	396	294	370	332
	32	348	417	297	365	338
	64	348	390	302	368	344
Ogle	0	306	350	301	352	329
	32	302	351	325	359	335
	64	302	352	323	350	335
Ave.	0	337	392	284	357	327
	32	339	396	292	357	331
	64	339	392	292	362	335
Cl LSD(0.05)		NS	NS	9	NS	NS
Cult. x Cl LSD(0.05)		NS	NS	NS	20	NS
<u>Significance</u> <u>of</u> <u>F</u>						
Cult.		**	**	**	*	0.25
Cl		NS	NS	0.08	0.17	0.24
Cult. x Cl		NS	0.22	NS	0.09	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

explained by the increase in 1000 kernel weight. The Cl plots appeared to be greener later in the season than the control plots. This suggests a possible lengthening of the grain fill period which could result in an increase in 1000 kernel weight.

Crown rust readings were taken at four sites (Table 6). Moderate levels of crown rust was observed in 1986 and 1987. Chloride addition had a significant [illegible] effect on crown rust infection only at [illegible]. A [illegible] percent increase in crown rust was observed at the higher rate of Cl addition (64 kg Cl ha^{-1}). This level of infection should not greatly affect grain yield. Since this occurred on a site which did respond to chloride in terms of grain yield, the effect of Cl on crown rust infection does not appear to be related to grain yield.

Table 5. Influence of Cl addition on 1000 kernel weight of five oat cultivars at two sites.

		Cultivar						Sign. of F		
Site	Cl	Bensen	Froker	Lancer	Moore	Ogle	Ave	Cl	Cult x Cl	LSD(0.05)
	kg ha^{-1}	g								
86H	0	22.9	19.3	18.6	16.8	19.4	19.4	**	NS	0.9
	32	23.3	19.8	20.2	19.7	20.5	20.7			
	64	23.3	19.9	20.1	19.5	20.8	20.7			
86L	0	23.8	18.8	22.1	22.1	21.7	21.7	**	NS	0.5
	32	24.4	20.7	22.6	22.9	22.4	22.6			
	64	25.2	20.2	23.3	21.5	22.5	22.5			

*,** = Significant at 0.05, 0.01 level, respectively.

NS = Not significant.

The lodging index was determined during grain fill at five locations. No effect of Cl on lodging was observed in 1987. At [illegible] a severe wind storm caused substantial lodging of the entire site after heading, thus masking any possible treatment effect. The effects of Cl addition on lodging in 1986 depended on location (Table 7). Chloride addition significantly reduced lodging at 86H while a significant increase in lodging was observed at 86L. The effects of Cl on lodging found in this study would not likely have an effect on grain explained by the increase in 1000 kernel weight. The Cl plots appeared to be greener later in the season than the control plots. This suggests a possible lengthening of the grain fill period which could result in an increase in 1000 kernel weight.

Crown rust readings were taken at four sites (Table 6). Moderate levels of crown rust was observed in 1986 and 1987. Chloride addition had a significant ($P < 0.10$) effect on crown rust infection only at 87L. A 2.7 percent increase in crown rust was observed at the higher rate of Cl addition (64 kg Cl ha^{-1}). This level of infection should not greatly affect grain yield. Since this occurred on a site which did respond to chloride in terms of grain yield, the effect of Cl on crown rust infection does not appear to be related to grain yield.

The lodging index was determined during grain fill at five locations. No effect of Cl on lodging was observed in 1987. At 87B a severe wind storm caused substantial lodging of the entire site after heading, thus masking any possible treatment affect. The effects of Cl addition on lodging in 1986 depended on location (Table 7). Chloride addition significantly reduced lodging at 86H while a significant increase in lodging was observed at 86L. The effects of Cl on lodging found in this study would not likely have an effect on grain

Table 6. Effect of KCl addition on crown rust of five oat cultivars at four sites.

Cultivar	Cl	Site 86H	 86L	 87L	 87B
	kg ha^{-1}	Cobb Scale			
Benson	0	13.3	6.8	6.5	10.0
	32	9.7	8.5	7.2	8.3
	64	17.5	6.0	6.5	8.3
Froker	0	27.5	21.3	11.5	12.5
	32	25.5	23.0	16.2	15.5
	64	24.2	18.8	20.0	7.2
Lancer	0	31.3	20.0	15.0	20.0
	32	32.2	19.2	15.0	22.0
	64	27.5	16.2	17.5	25.8
Moore	0	12.5	10.2	4.0	8.7
	32	14.2	12.7	3.5	8.0
	64	14.5	13.7	6.3	11.3
Ogle	0	23.8	21.5	16.7	23.0
	32	29.2	23.3	20.8	23.0
	64	27.5	21.6	16.7	21.7
Ave.	0	21.7	16.0	10.7	14.8
	32	22.2	17.3	12.5	15.4
	64	22.2	15.3	13.4	14.9
Cl LSD(0.05)		NS	NS	2.5	NS
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	**	**	**
Cl		NS	NS	0.10	NS
Cult. x Cl		NS	NS	NS	0.21

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Table 7. Influence of Cl addition on lodging of five oat cultivars at three sites.

		Cultivar							Sign. of F	
Site	Cl	Benson	Froker	Lancer	Moore	Ogle	Avg.	LSD(0.05)	Cl	Cult x Cl
	kg ha^{-1}	Belgium Index/1								
86H	0	3.0	0.5	0.2	3.5	0.3	1.5	0.4	*	0.29
	32	2.0	0.4	0.2	2.3	0.2	1.0			
	64	2.1	0.3	0.2	2.8	0.3	1.1			
86L	0	3.9	4.3	2.8	2.2	6.8	4.0	0.5	**	NS
	32	4.6	3.2	4.7	1.8	7.5	4.4			
	64	5.0	4.1	4.8	3.2	7.6	4.9			
87H	0	6.2	3.9	5.0	4.9	6.7	5.4	NS	NS	NS
	32	5.8	4.3	4.6	5.1	7.7	5.5			
	64	5.5	4.5	3.6	6.2	6.6	5.3			

/1 Belgium index: 0.2 = no lodging, 9.0 = plot 100% lodged.

*,** = Significant at 0.05, 0.01 level, respectively.

NS = Not significant.

yield (personal communication, Dr Dale Reeves). A following chapter will address the effects of Cl on lodging at different rates of nitrogen.

Plant height was measured during grain fill in 1986 (Table 8). Chloride addition significantly ($P < 0.01$) reduced plant height 2 cm at 86H. This reduction in plant height did not likely impact grain yield. A significant difference in the stage of development was observed in both years at the Hamlin county site (Table 9). The Cl treated plots were at a more advanced stage of development than the checks. Site 86H was the only site where Cl addition increased both development, 1000 kernel weight, and grain yield. The groat protein and oil content were not affected by the additions of chloride (data not shown).

Relative water content was not significantly ($P < 0.10$) affected by addition of Cl but relative water content tended to increase with the addition of Cl (Data not shown). The osmotic potential adjusted for full turgor was significantly ($P < 0.10$) lower than the check at 86L and 87H during the boot stage and at 87H and 87B during grain fill (Tables 10 and 11). The 64 kg Cl ha^{-1} rate was required to get a significant reduction in solute potential adjusted for full turgor. Similar

Table 8. Influence of Cl addition on oat plant height of five oat cultivars at two sites.

		Cultivar							Sign. of F.	
Site	Cl	Benson	Froker	Lancer	Moore	Ogle	Avg.	LSD(0.05)	Cl	Cult x Cl
	kg ha^{-1}	cm								
86H	0	113.8	111.7	102.5	120.7	103.7	110.5	1.1	**	0.29
	32	111.5	110.2	101.0	117.7	99.2	107.9			
	64	111.7	109.5	100.7	118.2	102.8	108.6			
86L	0	100.2	100.5	91.3	103.5	92.0	97.5	NS	0.22	0.23
	32	101.8	100.0	90.8	101.3	95.2	97.8			
	64	101.0	100.8	93.2	105.7	94.0	98.9			

*,** = Significant at 0.05, 0.01 level, respectively.

NS = Not significant.

Table 9. Effect of Cl addition on development of five oat cultivars at four sites.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	Haun Scale			
Moore	0	6.4	6.3	2.4	2.3
	32	6.3	6.3	2.5	2.3
	64	6.4	6.4	2.6	2.4
Ogle	0	7.0	7.1	2.8	2.7
	32	7.1	7.1	3.0	2.7
	64	7.2	6.9	2.9	2.7
Benson	0	6.8	6.7	2.4	2.3
	32	7.0	6.6	2.7	2.3
	64	7.0	6.5	2.7	2.5
Froker	0	6.6	6.4	2.1	2.0
	32	6.8	6.3	2.3	2.0
	64	6.8	6.2	2.3	2.0
Lancer	0	7.4	6.7	2.9	2.9
	32	7.5	6.8	2.9	2.9
	64	7.5	6.8	3.0	2.9
Ave.	0	6.8	6.6	2.5	2.4
	32	6.9	6.6	2.7	2.4
	64	7.0	6.6	2.7	2.5
Cl LSD(0.05)		0.1	NS	0.1	NS
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	**	**	**
Cl		0.08	0.23	**	0.27
Cult. x Cl		NS	NS	0.19	0.14

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Table 10. Influence of Cl on osmotic potential and osmotic potential adjusted for full turgor at boot stage.

		Osmotic Potential		Osmotic Potential at Full Turgor	
		Site			
Cultivar	Cl	86L	87H	86L	87H
	kg ha^{-1}	-MPa			
Benson	0	1.84	1.11	1.67	1.03
	32	1.87	1.25	1.71	1.14
	64	1.93	1.32	1.75	1.20
Froker	0	1.82	1.23	1.63	1.11
	32	1.76	1.12	1.59	1.03
	64	1.86	1.19	1.66	1.07
Lancer	0	1.92	1.25	1.66	1.14
	32	2.01	1.37	1.76	1.22
	64	2.27	1.39	1.82	1.25
Moore	0	1.84	1.10	1.65	1.00
	32	1.85	1.33	1.69	1.21
	64	1.95	1.29	1.77	1.13
Ogle	0	1.83	1.22	1.68	1.09
	32	1.89	1.20	1.74	1.08
	64	1.84	1.24	1.69	1.11
Avg.	0	1.85	1.18	1.68	1.07
	32	1.88	1.25	1.71	1.14
	64	1.97	1.29	1.78	1.15
Cl LSD(0.05)		0.08	0.07	0.07	0.07
<u>Sign.</u> <u>of</u> <u>F</u>					
Cult.		*	0.18	*	0.29
Cl		*	*	*	0.09
Cult. x Cl		NS	NS	NS	NS

*,** = Significance is less than 0.01, 0.05, respectively.
NS = Significance is greater than 0.30.

Table 11. Influence of Cl on osmotic potential and osmotic potential adjusted for full turgor at grain fill.

		Osmotic Potential	Osmotic Potential at Full Turgor	
		Site		
Cultivar	Cl	87H	87H	87B
	kg ha^{-1}	-MPa		
Bensen	0	1.85	1.67	1.50
	32	1.85	1.63	1.41
	64	2.19	1.95	1.50
Froker	0	1.77	1.53	1.43
	32	1.83	1.59	1.37
	64	1.86	1.62	1.45
Lancer	0	1.85	1.64	1.51
	32	1.86	1.63	1.38
	64	1.77	1.58	1.50
Moore	0	1.70	1.51	1.36
	32	1.64	1.43	1.32
	64	1.79	1.57	1.34
Ogle	0	1.68	1.48	1.26
	32	1.66	1.44	1.31
	64	1.83	1.61	1.39
Avg.	0	1.77	1.57	1.41
	32	1.77	1.54	1.36
	64	1.89	1.67	1.44
Cl LSD(0.05)		0.11	0.09	0.07
Cult. x Cl LSD(0.05)		0.19	0.17	NS
<u>Significance</u> <u>of</u> <u>F.</u>				
Cult.		*	**	.07
Cl		0.06	*	.09
Cult. x Cl		0.08	.08	NS

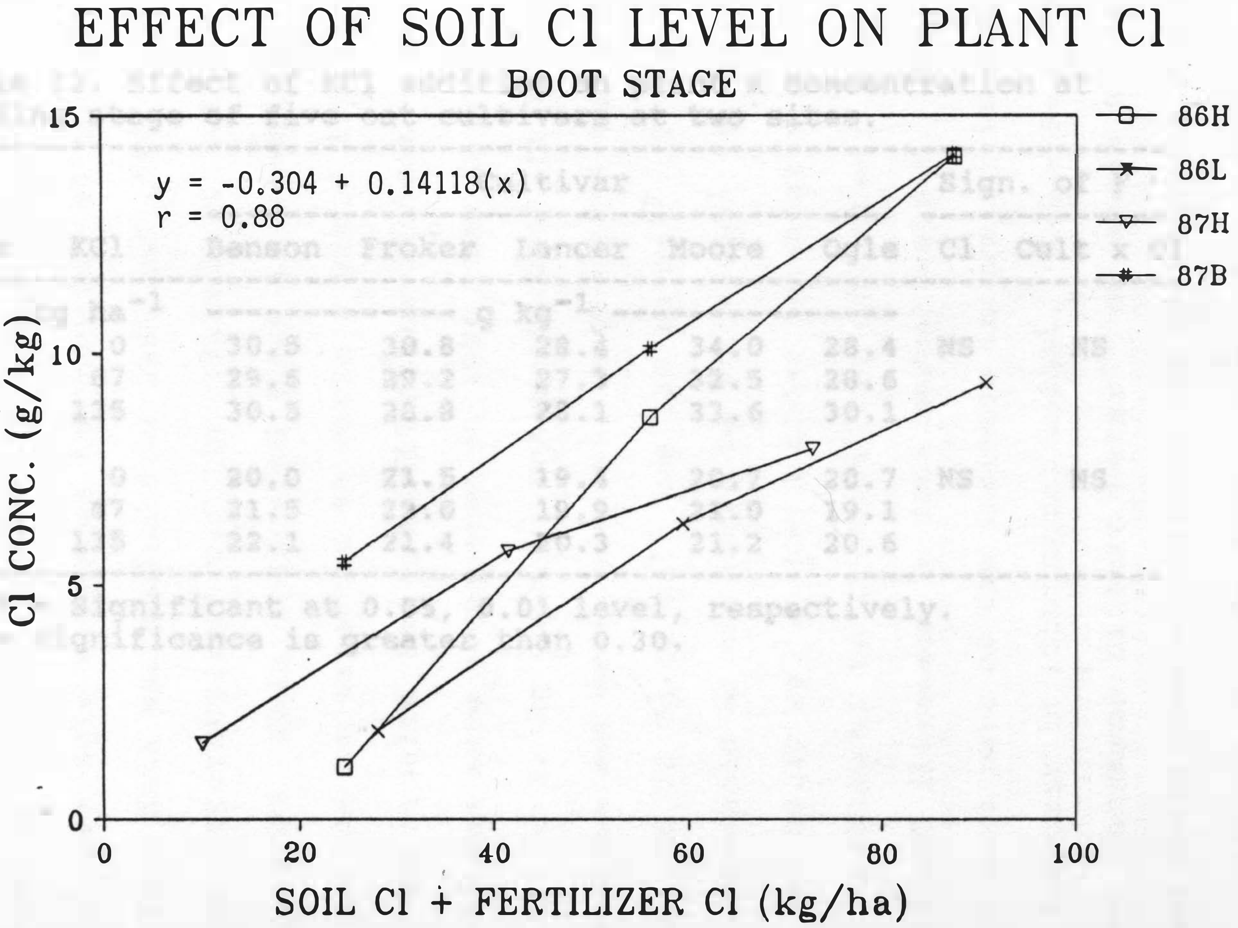
*,** = Significance is less than 0.01, 0.05, respectively.
NS = Significance is greater than 0.30.

results were found for uncorrected solute potential (Tables 10 and 11). The relationship between decreases in osmotic potential or osmotic potential adjusted for full turgor and increases in grain yield is inconclusive since a decrease in osmotic potential did not always result in an increase in grain yield. It appears that Cl can affect osmotic potential and osmotic potential adjusted for full turgor. However, the decrease in osmotic potential and osmotic potential adjusted for full turgor generally did not result in an increase in grain yield.

Leaf water potential was taken on two cultivars (Moore and Ogle). Chloride addition did not significantly ($P < 0.10$) affect leaf water potential (data not shown). However, leaf water potential generally decreased with the addition of Cl. Stomatal conductance was not significantly affected by the additions of Cl, but the cultivars Moore and Ogle tended to show greater stomatal conductance response from Cl addition (data not shown).

The addition of Cl significantly affected the plant Cl^- concentrations at the 0.01 probability level at all sites and growth stages. The linear regression equation relating soil Cl (0-60 cm) plus fertilizer Cl to plant Cl^- concentration sampled at heading had a correlation coefficient of 0.86 (figure 1). When plants were sampled at boot a correlation coefficient of 0.88 was obtained (figure 2). Yield responses occurred in 1986 when the check plant Cl concentrations were less than 1.5 g kg^{-1}. The relationship of plant Cl^- concentration to yield response is not as easily interpreted for the 1987 data. No tissue samples were analyzed at the 87L site and even though plant Cl^- concentrations were relatively low on the check plots at the 87H site there was very little or no effect on grain yield. The 87B chloride tissue level was 4.8 g kg^{-1} for Ogle which was the only yield responsive cultivar at this site. More studies are needed to verify the critical plant Cl^- concentration for oat. It appears a plant Cl^- concentration test may be used as a tool for estimating soil Cl levels and determining possible responsive situations in oat.

Plant K^+ concentration was measured at heading on yield responsive sites (Table 12). There was no significant difference between the KCl treated plots and the checks. Thus, the yield increase was very likely Cl related not K^+ related.



EFFECT OF SOIL Cl LEVEL ON PLANT Cl

BOOT STAGE

Figure 2

Table 12. Effect of KCl addition on plant K concentration at heading stage of five oat cultivars at two sites.

		Cultivar					Sign. of F	
Site	KCl	Benson	Froker	Lancer	Moore	Ogle	Cl	Cult x Cl
	kg ha^{-1}			g kg^{-1}				
86H	0	30.5	30.8	28.4	34.0	28.4	NS	NS
	67	29.6	29.2	27.3	32.5	28.6		
	135	30.5	28.8	28.1	33.6	30.1		
86L	0	20.0	21.5	19.4	20.7	20.7	NS	NS
	67	21.5	22.0	19.9	21.0	19.1		
	135	22.1	21.4	20.3	21.2	20.6		

*,** = Significant at 0.05, 0.01 level, respectively.
NS = Significance is greater than 0.30.

SUMMARY:

The results of the field study conducted at 5 sites over a 2 year period indicated Cl addition significantly increased oat grain yields at all locations in 1986. Only the cultivar Ogle responded to chloride at one site in 1987. When data was pooled over 1986 and 1987 there was no site interactions and the overall Cl effect was significant. This indicated that in some cases Cl addition can be expected to cause a yield increase in oat. The results for specific sites indicate that the response was more pronounced in 1986 than in 1987. The addition of 32 kg Cl ha^{-1} was sufficient in obtaining near maximum oat grain yields. During 1986 the average response to 32 kg Cl ha^{-1} was 120 kg ha^{-1} of oat. The price threshold of oat would be \$0.24 kg^{-1} if the price of Cl was \$0.37 kg^{-1}. The 2 sites in which significant yield responses to Cl addition occurred, also had significant increases in 1000 kernel weight. Thus, it appears that part of the increase in grain yield is due to an increase in 1000 kernel weight. Chloride addition did not increase tillers $meter^{-1}$ or seeds $tiller^{-1}$. Although there were significant oat grain yield responses to Cl addition at some sites, they were generally too small to be profitable for the year of application under current economic conditions.

Moderate levels of crown rust infection was observed in 1986 and 1987. Crown rust infection was not affected by the addition of Cl. Thus, the grain yield response can not be attributed to a decrease in crown rust infection.

Addition of KCl significantly increased the plant Cl^- concentration but had no effect on the plant K^+ concentration. Therefore, the grain yield response was likely due to Cl. The soil + fertilizer Cl concentration in the top 60 cm of the soil profile was highly correlated (0.86) with the plant Cl^- concentration at heading stage. Soil plus fertilizer Cl levels greater than 60 kg Cl ha^{-1} (0-60cm) were sufficient for near maximum yields at responsive sites.

Chloride addition did not significantly affect relative water content, leaf water potential, or stomatal conductance in oat. However, Cl additions significantly decreased solute potential and solute potential adjusted for full turgor during boot stage and/or grain fill at three sites. Data illustrating the relationship between the decrease in osmotic potential or osmotic potential adjusted for full turgor and an increase in grain yield was inconclusive. Sites in which osmotic potential or osmotic potential adjusted for full turgor were affected by Cl did not always result in increases in grain yield. Secondly, the level of Cl addition needed to decrease osmotic potential or osmotic potential adjusted for full turgor was 64 kg ha^{-1} while only 32 kg ha^{-1} were needed for a significant increase in grain yield. The effect of chloride on plant senescence needs further confirmation. An increase in grain fill period could explain the changes in 1000 kernel weight and grain yield. Further research should examine possible relationships between Cl addition and grain fill duration.

III. Effect of Nitrogen and Chloride on Yield and Lodging in Oat

INTRODUCTION:

Losses from lodging can be as much as 30% of the total grain yield in small grains (Pinthus, 1973). The effects of lodging are especially prevalent in high yield environments where water and nutrients are non-limiting. High rates of nitrogen (N) fertilization predispose small grain to lodging. There is a positive relationship between N fertilization and lodging in oat (Brinkman, 1985; Pinthus, 1973; Ohm, 1976; Mulder, 1954). The effects of high rates of N apparently can not be attributed entirely to N effects on plant height. High N levels increase lodging in semi-dwarf cultivars as well as in tall cultivars, however, the lodging is less severe (Pinthus, 1973).

The uptake of N during stem elongation is most critical in relationship to lodging. A high availability of N during this stage will promote basal culm internode elongation and therefore lodging (Pinthus 1973). Nitrogen effects the basal culm internodes by increasing their length (Mulder, 1954).

Chloride ions in the soil solution may reduce nitrogen uptake by the plant through Cl competition with nitrate ions. The uptake of N is related to the soil chloride (Cl) level. Murarka et al. (1973) studied the effects of rates of N, potassium (K), and Cl fertilizers and the N by K by Cl interaction on the total N, NO_3^-, and protein in potato (Solanum tuberosum L.) plants. They concluded that Cl^- competes with NO_3^- uptake and accumulation but that Cl^- does not affect the conversion of N to protein. Cram (1973) and Smith (1973) found that NO_3^- accumulation was reduced by prior NO_3^- or Cl^- accumulation. The system behaved as a Cl^- homeostat under a system where nitrates were unavailable. Glass and Siddiqi (1985) found that Cl^- flux was not determined solely by an internal feedback signal (vacuolar NO-3 and Cl^- concentration) but by the interaction between the external inhibition of Cl^- influx by external NO_3^- concentration and internal vacuolar Cl^- and $NO3^-$ concentration.

Chloride may also affect the nitrification process in the soil. Christensen and Brett 1985) showed that Cl slowed the disappearance of NH_4-N and appearance of NO_3-N in the soil by inhibiting nitrification.

Timm et al. (1986) observed that NO_3-N levels in barley (Hordeum vulgare L.) culms were lowered by the addition of KCl. Reduction in shoot NO_3^- concentration of spring wheat (Triticum aestivum L.) by Cl additions was also reported by Fixen et al. (1987a) and Fixen

(1987b). These reductions were likely either caused by direct ion competition or Cl inhibition of nitrification (Christensen and Brett, 1985 and Golden et al., 1979).

The objectives of this study were to: (a) examine the effect of levels of N and KCl on oat lodging and plant height, (b) evaluate the effect of varying rates of applied N and Cl^- on oat (Avena sativa L.) yield, yield components, groat protein and oil, and crown rust (Puccinia coronata), and (c) evaluate the relationship between nitrate and chloride uptake in oat.

MATERIALS AND METHODS:

Oat response to N and Cl was evaluated at 5 sites in eastern South Dakota during 1986 and 1987. Soils at the sites were Pachic Udic Haploborolls and Udic Haplustolls. Soil properties and previous crop are reported in Tables 1 and 2. The pH was measured with a glass electrode using 1:1(w/w) soil to water ratio on a stirred sample, organic matter by the modified Walkley Black method, nitrate using an Orion specific ion electrode, phosphorus by the Bray and Kurtz no.1 method with 1:10(w/v) soil to solution ratio, potassium by extraction with ammonium acetate, and chloride by potentiometric titration with $AgNO_3$ (Adriano and Doner 1982). All soil analysis except Cl^- determination was done by the South Dakota State university Soil Testing Laboratory (Carson and Gelderman, 1980).

All sites were planted between April 15 and May 1. The oat cultivar (Benson) was planted with a double disk drill opener at 126 kg ha^{-1}. Concentrated super phosphate was applied with the seed to all plots at 20 kg ha^{-1}. Plots were sprayed with Propachlor and Bromoxynil + MCPA to control weeds.

Experimental variables were two KCl levels (0 and 135 Kg ha^{-1}) in a factorial combination with 5 levels of N (0, 34, 68, 102, and 136 kg ha^{-1}) applied as urea. For

Table 1. Site characteristics, 1986-1987.

Site	County	Soil type and classification	Previous Crop	Tillage System
86H	Hamline	Estelline sil, Pachic Udic Haploboroll	wheat	chisel-disk
86L	Lake	Dempster sil, Udic Haplustoll	soybean	double disk
87H	Hamline	Estelline sil, Pachic Udic Haploboroll	fallow	plow-disk
87L	Lake	Dempster sil, Udic Haplustoll	soybean	double disk
87B	Brookings	Lismoure sil, Pachic Udic Haploboroll	corn	plow-disk

Table 2. Site Characteristics, 1986-1987

	0 to 60 cm		61 to 120 cm		0 to 15 cm			
Site	NO_3-N	Cl	NO_3-N	Cl	P	K	pH	Organic Matter
	kg ha^{-1}							g kg^{-1}
86H	55	25	73	35	20	594	7.4	38
86L	34	28	19	38	94	448	6.6	35
87H	100	10	71	12	121	706	7.3	23
87L	48	39	32	34	28	470	6.2	30
87B	57	25	41	26	173	560	6.9	35

N (0, 34, 68, 102, and 136 kg ha^{-1}) applied as urea. For an oat yield goal of 3.59 Mg ha^{-1} South Dakota State University soil testing laboratory recommends 146 kg ha^{-1} soil plus fertilizer NO_3-N. The soil Cl level required for oat has not been determined. However, the Cl recommendation for wheat from the South Dakota State University soil testing laboratory is fertilizer Cl=60-soil Cl (0 to 60 cm).

Fertilizer was broadcast and incorporated with a field cultivator before seeding. Treatments were arranged in a randomized complete block split-plot design with N levels as main plots and Cl levels as sub-plots. Sub-plot size was 1.2 m by 7.6 m with 15 cm row spacing and 6 replications. When testing across the 5 sites in the analysis of variance, site was tested with (replication)site, N by site x N, Cl by site x Cl, site x N by (replication)site x N, site x Cl by (replication) site x Cl, N x Cl by site x N x Cl, and site x N x Cl by residual. When testing within a site in the analysis of variance, N was tested with replication x N, Cl by replication x Cl , and N x Cl by residual.

Plots were harvested with a small plot combine. The test weight was determined by weighing 473 cm^3 of seed for each plot. Plant samples were collected from 1 m of row for determining yield components. Effective tillers in a randomly selected 1 m row segment were counted at maturity. Plants from the 1 m section were removed from the plot, thrashed, and seed was weighed and counted. To determine seeds tiller^{-1}, the total number of seeds were divided by the number of tillers. The 1000-kernel weight was calculated by dividing the weight of the seeds by the number of seeds and multiplying by 1000. Protein and oil concentrations of the oat groat were determined by a Modified Technicon Infranalyzer 300. For each plot, approximately 5 g of groats were ground with a Udy mill into flour for analysis.

Crown rust was recorded two weeks after heading (Feekes stage 10.3) from each plot using the Cobb Scale. Plant height was recorded two weeks before maturity as the distance from the soil level to the top of the panicle. The Belguim index was used for rating lodging. Lodging index was calculated by multiplying 0.2 times the area lodged (1-9) and by the intensity of lodging (1-5). The final range is from 0.2 (no lodging) to 9.0 (plot completely flat).

Plant NO_3-N samples were collected at boot (Feekes stage 10) and heading (Feekes 10.3) stages at four locations (86H, 86L, 87H, and 87B). A sample consisted of 10 to 15 whole plants (above ground) from each plot.

Plant NO_3-N concentration was determined by shaking 0.5 g of dried ground plant material in 50 ml of 0.025 M $Al_2(SO_4)_3$ for 5 minutes on a reciprocating shaker (Millham et al. 1970). Nitrate-N concentration was determined with an Orion model 92-07 (Orion, Cambridge, MA) and Sargent-Welch LSX pH meter with an expanded scale. Plant Cl^- concentration was measured by shaking 0.5 g dried ground plant material in 50 ml of .1M HNO_3 for 15 minutes on a reciprocating shaker (LaCroix et al., 1970). Chloride was titrated directly with .0282 M $AgNO_3$ using a Brinkman digital burette (Brinkman Instr., Westbury, NY). The end point was detected with an Orion 96-17b (Orion, Cambridge, MA) combination Cl^- electrode and Fisher 825 MP meter (Fisher Science Company, Pittsburgh, PA).

RESULTS AND DISCUSSION:

Lodging and Plant Height:

There was a significant ($P < 0.01$) site by N by Cl interaction for lodging. Lodging after heading occurred at three sites (86H, 86L, and 87B). Lodging was increased by the addition of N at all three sites and in most cases Cl addition reduced lodging (Figure 1). The amount of lodging was considerably higher at 87B at all levels of N due to a severe wind and rain storm that occurred after heading. The greatest reduction in lodging due to Cl addition occurred at the high rate of N during 1986 at both sites.

Plant height was significantly ($P < 0.01$) increased by N addition at the 2 sites tested (Table 3). The largest increase in plant height occurred when 34 kg N ha^{-1} was applied. Increases in N addition above 68 kg N ha^{-1} did not increase plant height. Chloride addition did not effect plant height.

Grain Yield:

The effects of N and Cl on grain yield are shown in table 4. When Cl addition was evaluated over the 5 sites, Cl effects were not significant ($P < 0.10$). However, the location by Cl interaction was nearly significant ($P < 0.12$) suggesting that some site differences in response may have occurred. An evaluation

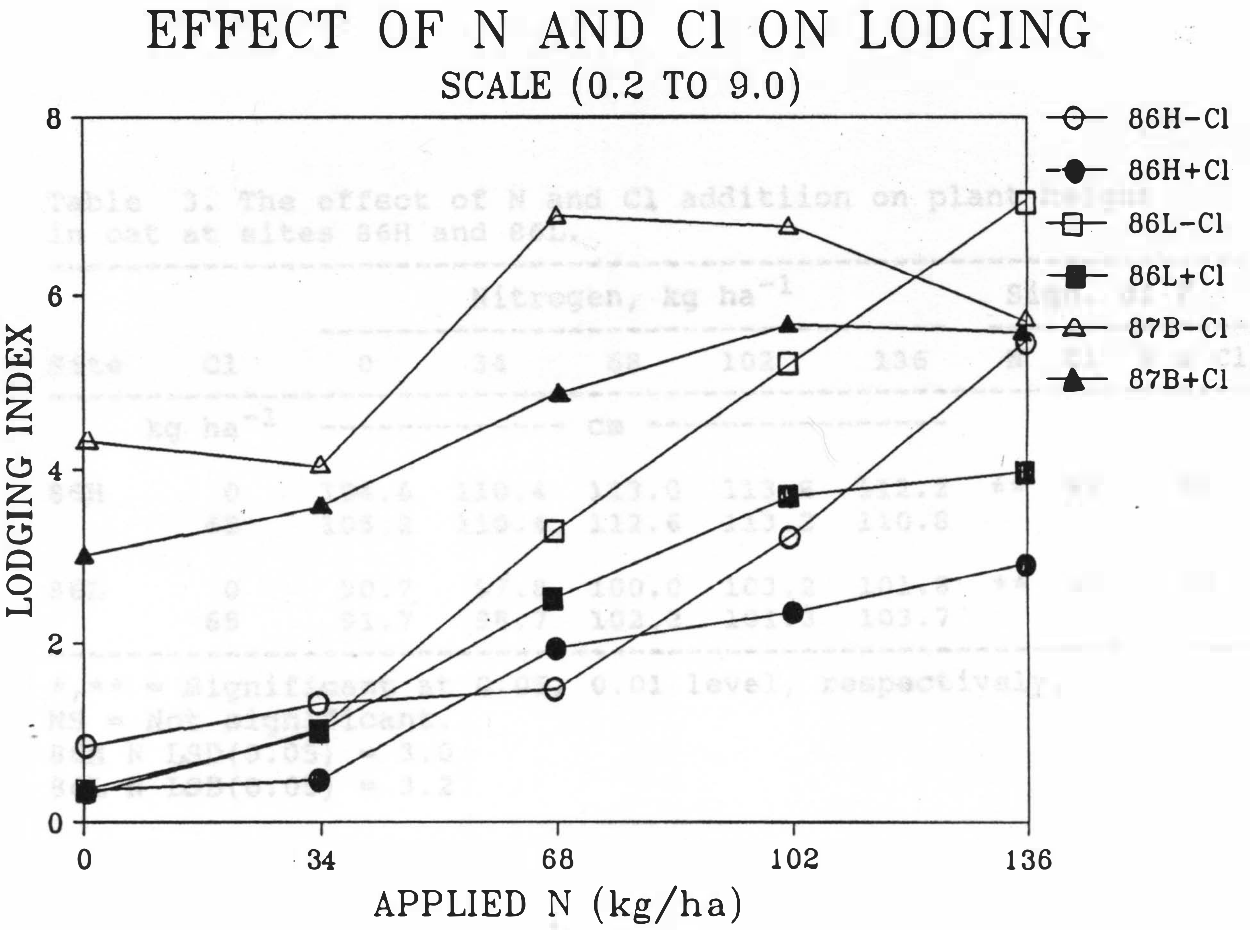

EFFECT OF N AND Cl ON LODGING
SCALE (0.2 TO 9.0)
LODGING INDEX
0
2
4
6
8
APPLIED N (kg/ha)
0
34
68
102
136
86H-Cl
86H+Cl
86L-Cl
86L+Cl
87B-Cl
87B+Cl

Figure 1

Table 3. The effect of N and Cl additiion on plant height in oat at sites 86H and 86L.

		Nitrogen, kg ha^{-1}					Sign. of F		
Site	Cl	0	34	68	102	136	N	Cl	N x Cl
	kg ha^{-1}			cm					
86H	0	104.6	110.4	113.0	113.8	112.2	**	NS	NS
	65	105.2	110.4	112.6	113.2	110.8			
86L	0	90.7	97.8	100.0	103.2	101.8	**	NS	NS
	65	91.7	98.7	102.2	101.3	103.7			

*,** = Significant at 0.05, 0.01 level, respectively.
NS = Not significant.
86H N LSD(0.05) = 3.0
86L N LSD(0.05) = 3.2

Table 4. Influence of N and Cl addition on oat grain yield at 5 sites.

		Site				
N	Cl	86H	86L	87H	87L	87B
kg ha^{-1}		Mg ha^{-1}				
0	Ave.	2.29	1.72	2.47	2.15	3.86
34		2.64	2.15	2.40	2.36	3.54
68		2.58	2.44	2.27	2.67	3.47
102		2.57	2.43	2.44	2.58	3.50
136		2.46	2.55	2.30	2.61	3.43
Ave.	0	2.45	2.27	2.33	2.51	3.52
	65	2.57	2.24	2.42	2.45	3.61
N LSD(0.05)		0.24	0.20	NS	0.19	0.30
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		*	**	NS	**	*
Cl rate		*	NS	.07	.23	.29
N x Cl		NS	.22	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability levels, respectively. NS = probability is greater than 0.30.

differences in response may have occurred. An evaluation of the individual sites indicate that Cl addition significantly ($P < 0.10$) increased grain yield at 86H and 87H. At the Cl responsive sites, Cl addition increased grain yield 0.12 and 0.09 Mg ha^{-1}.

A significant ($P < 0.01$) site by N interaction occurred indicating site differences. Nitrogen fertilizer significantly increased yields at 3 of the 5 sites while a decrease in yield was measured at one site with high yield potential and severe lodging. The main effect of N on yield for sites of similar yield potential was regressed using the continuous linear response and plateau model discussed by Jauregui and Paris (1985). The slope of the linear response region was 0.00869 Mg kg^{-1} with an optimum N level of 88.48 kg ha^{-1} and resulting in a yield of 2.49 Mg ha^{-1} (Figure 2).

<u>Test weight and yield components:</u>

Test weight was significantly lowered by the addition of N at sites 86H, 86L, and 87L (Table 5). Nitrogen significantly increased lodging and decreased test weight at both sites in 1986. The decrease in test weight in 1986 may have been due to an increase in lodging caused by N addition. Lodging frequently results in a reduction in test weight (Pinthus, 1973 and Brinkman et al., 1985). Severe lodging occurred at 87B after heading on all

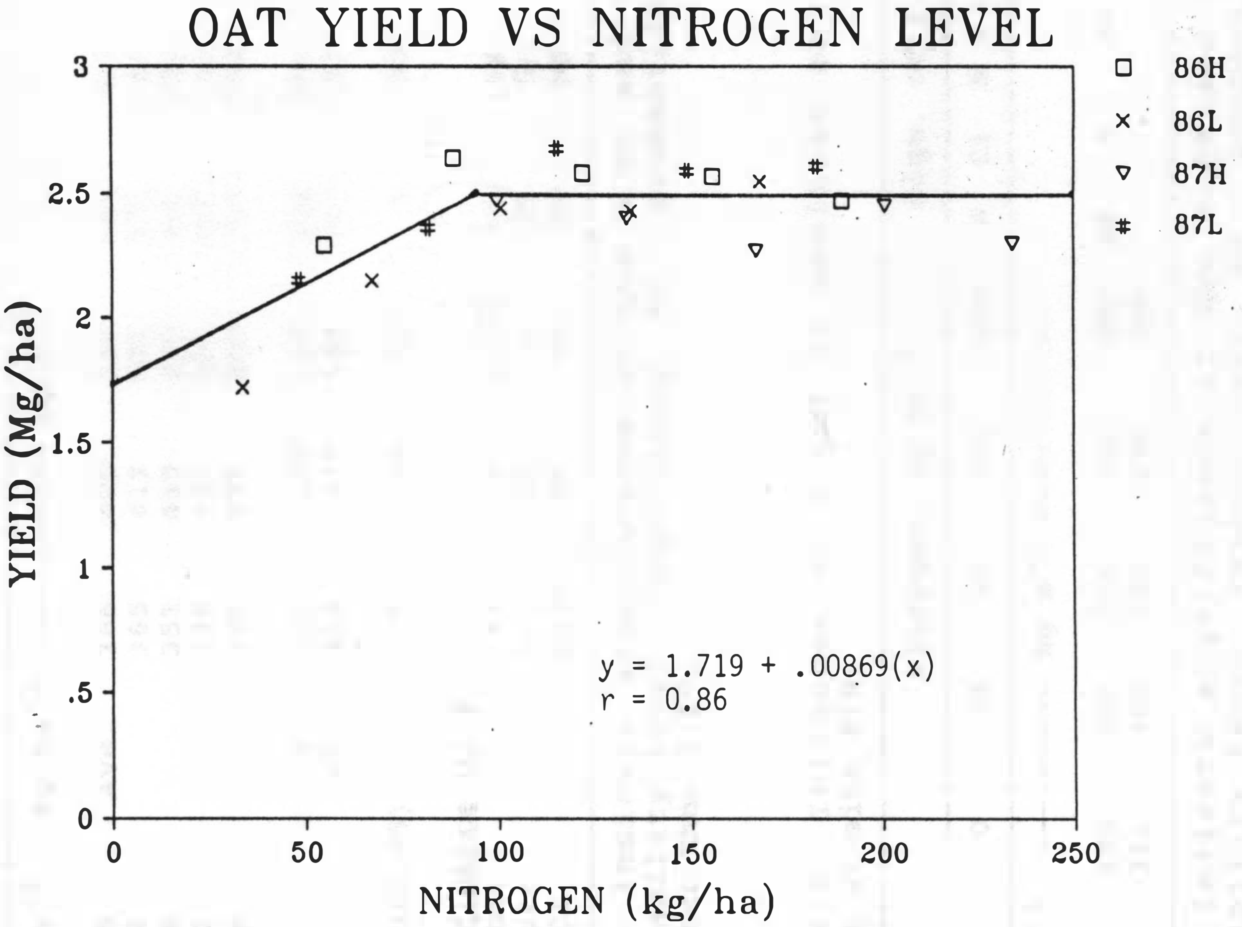

OAT YIELD VS NITROGEN LEVEL
YIELD (Mg/ha)
3
2.5
2
1.5
1
.5
0
NITROGEN (kg/ha)
0
50
100
150
200
250
□ 86H
× 86L
▽ 87H
# 87L
y = 1.719 + .00869(x)
r = 0.86

Figure 2

Table 5. Main effects N and Cl addition on test weight in oat at 5 sites.

		Site					
N	Cl	86H	86L	87H	87L	87B	Ave.
kg ha^{-1}	kg ha^{-1}			kg m^{-3}			
0	Ave.	366	409	317	372	375	368
34		365	419	304	370	363	364
68		351	419	299	361	356	357
102		339	407	300	370	362	356
136		329	397	299	357	363	349
Ave.	0	347	409	300	366	366	358
	65	354	412	308	367	363	361
N LSD(0.05)		15	16	NS	9	NS	
<u>Significance</u> <u>of</u> <u>F</u>							
N rate		**	*	0.27	**	NS	
Cl rate		0.16	NS	*	NS	NS	
N x Cl		0.30	NS	**	NS	NS	

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

Table 6. Influence of N and Cl addition on test weight at site 87H.

	Nitrogen, kg ha^{-1}					Sign. of F.		
Cl	0	34	68	102	136	N	Cl	N x Cl
kg ha^{-1}			kg m^{-3}					
0	323	305	279	302	293	NS	*	**
65	311	303	320	299	306			

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.
N by Cl LSD(0.05) = 19.

plots. A significant ($P < 0.01$) N by Cl interaction occurred at 87H (Table 6). Chloride significantly increased test weight only at the 68 kg ha^{-1} N rate. This was also the N rate which had the greatest amount of lodging at 87B. The addition of Cl resulted in a substantial decline in lodging at the 68 kg N ha^{-1} rate. No trends for test weight were apparent at the other N rates. Chloride may indirectly affect test weight through an effect on lodging.

Nitrogen additions significantly ($P < 0.05$) increased tillers m^{-1} averaged across all sites (Table 7). The largest increase in tillers m^{-1} occurred when 102 kg N ha^{-1} was applied. Brinkman and Rho (1984) also found that N addition increased tiller m^{-1}, but that the increase in tillers was not positively associated with the grain yield response. Chloride had no effect on the number of tillers m^{-1}.

Seeds $tiller^{-1}$ were significantly ($P < 0.10$) affected by the addition of N and Cl at 87L (Table 8). Seeds $tiller^{-1}$ were decreased by the additions of Cl, but the reduction did not have an effect on grain yield at 87L. The changes in seed $tiller^{-1}$ as N levels increased was inconsistent and were not related to the change in grain yields at 87L. Chloride or N addition did not

Table 7. Influence of N and Cl addition on tillers m^{-1} averaged across 5 sites.

	Nitrogen, kg ha^{-1}					Sign. of F		
Cl	0	34	68	102	136	N	Cl	N x Cl
kg ha^{-1}	tillers m^{-1}							
0	52	55	57	59	58	*	NS	NS
65	53	52	56	59	59			

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.
N LSD(0.05) = 4.

Table 8. The effect of N and Cl addition on seeds $tiller^{-1}$ in oat at site 87L.

	Nitrogen, kg ha^{-1}						Sign. of F		
Cl	0	34	68	102	136	Ave.	N	Cl	N x Cl
kg ha^{-1}	seeds $tillers^{-1}$								
0	33	34	33	32	38	34	**	0.06	NS
65	31	35	29	30	34	32			
Ave.	32	35	31	31	36				

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.
N LSD(0.05) = 3.

significantly affect seeds tiller^{-1} at the other 4 sites. Nitrogen and Cl additions appeared to have minor effects on seeds tiller^{-1}.

A significant ($P < 0.01$) Site by N by Cl interaction occurred for 1000 kernel weight. Chloride addition increased 1000 kernel weight at sites 86H, 86L, 87H, and 87B (Table 9). Sites 86H and 87H had a significant yield response to Cl, thus a portion of the grain yield response was likely due to an increase in 1000 kernel weight. Nitrogen addition decreased 1000 kernel weight and increased lodging at both sites in 1986. Mulder (1954) found a similar relationship between N addition and lodging. Mulder (1954) believed that the increase in lodging would reduce carbohydrate assimilation which could affect carbohydrate accumulation in the grain and result in a decrease in 1000 kernel weight. At site 87B a significant ($P < 0.10$) N by Cl interaction occurred (Table 10). The Cl addition significantly increased 1000 kernel weight when 68 kg N ha^{-1} was applied. The largest reduction in lodging due to Cl addition at 87B also occurred at 68 kg N ha^{-1}. Chloride additions reduced lodging and increased 1000 kernel weight at the height N addition rates during 1986. This suggests that the increase in 1000 kernel weight caused by Cl addition was the result of decreased lodging when Cl was applied.

Table 9. The effect of N and Cl addition on 1000 kernel weight in oat.

		Site				
N	Cl	86H	86L	87H	87L	87B
kg ha^{-1}				g		
0	0	25.2	27.1	31.1	30.7	27.1
34	0	23.5	27.5	28.0	31.0	27.0
68	0	22.5	26.5	28.6	30.6	24.4
102	0	22.1	25.9	28.6	30.0	26.9
136	0	21.6	25.5	28.2	30.4	26.9
Ave.	0	22.7	25.7	28.0	30.3	26.4
	65	23.4	27.2	29.8	30.8	27.2
N LSD(0.05)		0.9	1.3	NS	NS	NS
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		**	*	NS	NS	NS
Cl rate		0.08	**	0.07	0.13	0.14
N x Cl		NS	0.15	0.11	0.30	0.08

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

Table 10. Influence of N and Cl addition on 1000 kernel weight at 87B.

	Nitrogen, kg ha^{-1}					Sign. of F		
Cl	0	34	68	102	136	N	Cl	N x Cl
kg ha^{-1}			g					
0	27.4	27.4	24.1	26.8	26.3	NS	0.14	0.08
65	26.9	26.6	27.9	27.0	27.5			

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.
N x Cl LSD(0.05) = 2.5.

Groat Protein and Oil content:

Groat protein and oil content were evaluated at all five sites. Protein concentrations in the groat were significantly increased by N addition at 86H, 86L, 87H and 87L (Table 11). Pinthus (1973) indicated that lodging increased protein concentration but that absolute amounts of protein were not affected. This did not occur at the 1986 sites. Protein ha^{-1} and protein kernel^{-1} were significantly increased at the 1986 sites (data not shown). An N rate of at least 68 kg N ha^{-1} was needed to significantly increase protein content at all sites except 87H. Soil N level at site 87H was high and would decrease the expected N fertilizer effect on protein content.

Chloride addition caused a slight reduction in groat protein concentrations at three sites (86H, 87L, and 87B). At the Cl responsive sites, Cl reduced protein content 5 g kg^{-1}. However, protein ha^{-1} and protein kernel^{-1} were increased at the 86H site and not affected at the remaining sites. This indicates that the reduction of groat protein concentrations are not likely a result of reduced N availability. Increased grain carbohydrate assimilation may have resulted in a dilution of protein in the kernel.

Table 11. The effect N and Cl addition on groat protein concentration in oat at 5 sites.

		Site					
N	Cl	86H	86L	87H	87L	87B	Ave.
kg ha^{-1}		g kg^{-1}					
0	0	178	162	222	172	187	184
34	0	178	166	233	178	194	190
68	0	185	174	234	202	197	199
102	0	190	185	229	211	195	202
136	0	199	194	233	203	197	205
Ave.	0	188	176	233	197	194	198
	65	185	177	227	191	195	195
N LSD(0.05)		9	5	9	8	NS	
<u>Significance</u> <u>of</u> <u>F</u>							
N rate		**	**	*	**	NS	
Cl rate		*	NS	*	*	NS	
N x Cl		NS	NS	NS	NS	NS	

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

A significant ($P < 0.05$) site by N by Cl interaction existed for groat oil content. Chloride addition significantly ($P < 0.10$) decreased oil content at 3 of the 5 sites, while N applications significantly decreased groat oil content at 2 sites (Table 12). A N by Cl interaction for groat oil content occurred at 86H (Table 13). Chloride decreased oil content at all N rates except at the 34 kg ha^{-1} rate. The maximum reduction due to the application of N or Cl^- was 3 g kg^{-1}. Although significant, both protein and oil reductions were minimal.

<u>Crown</u> <u>rust:</u>

Crown rust (<u>Puccinia</u> <u>coronata</u>) was based on a visual determination of the percent leaf area infected. A significant ($P < 0.01$) site by N interaction occurred. Crown rust was significantly ($P < 0.10$) increased by N additions at 3 of the 4 sites evaluated (Table 14). Chloride addition significantly ($P < 0.01$) decreased crown rust when evaluated across all 5 sites. However, the level of reduction averaged less than 1 percent of the leaf area and would not cause an economic grain yield loss.

<u>Plant</u> <u>Chloride</u> <u>and</u> <u>Nitrate-N</u> <u>concentrations</u>:

Plant NO_3-N and Cl^- tissue concentrations were determined at the boot and heading stages at 4 sites.

Table 12. The effect N and Cl addition on groat oil content in oat at 5 sites.

N	Cl	Site 86H	86L	87H	87L	87B
kg ha^{-1}	kg ha^{-1}	g kg^{-1}				
0	Ave.	74.0	69.0	57.0	65.0	66.0
34		75.0	70.0	59.0	63.0	66.0
68		76.0	68.0	56.0	62.0	66.0
102		75.0	67.0	58.0	61.0	67.0
136		75.0	68.0	56.0	61.0	66.0
Ave.	0	76.0	69.0	57.0	62.0	66.0
	65	75.0	68.0	58.0	63.0	66.0
N LSD(0.05)		NS	2.0	NS	1.8	NS
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		NS	*	NS	**	NS
Cl rate		0.07	*	*	0.16	NS
N x Cl		**	NS	NS	NS	NS

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

Table 13. The effect N and Cl addition on groat oil content in oat at site 86H.

Cl	Nitrogen, kg ha^{-1} 0	34	68	102	136	Sign. of F. N	Cl	N x Cl
kg ha^{-1}	kg m^{-3}							
0	76.0	73.0	78.0	77.0	76.0	NS	0.07	**
65	73.0	78.0	74.0	74.0	74.0			

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.
N by Cl LSD(0.05) = 3.5.

Table 14. The effect of N and Cl addition on crown rust in oat at 4 sites.

		Site				
NITROGEN	Cl	86H	86L	87L	87B	Ave.
kg ha^{-1}	kg ha^{-1}	%				
0	Ave.	15.8	4.5	5.1	5.9	7.8
34		23.3	9.7	5.1	5.5	10.9
68		23.5	12.4	5.5	6.7	12.0
102		32.2	18.6	7.4	7.0	16.3
136		27.8	16.4	8.4	6.0	14.6
Ave.	0	24.8	13.1	6.8	6.9	12.9
	65	24.2	11.6	5.9	5.6	11.8
N LSD(0.05)		6.0	4.8	2.8	NS	
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		**	**	0.08	0.21	
Cl rate		NS	NS	0.15	*	
N x Cl		NS	0.18	NS	0.12	

*,** Indicate significance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl addition on plant NO_3-N at boot stage is shown in figure 3. A significant ($P < 0.01$) site by N by Cl interaction occurred. When the plant NO_3-N concentration was low, as in 86L, chloride did not reduce the NO_3-N concentration. However, when the plant NO_3-N concentration was high, Cl additions significantly reduced the plant NO_3-N concentration. Even though NO_3-N levels in the plant were reduced by Cl addition, grain yields were the same or increased over the no Cl treatment. A significant ($P < 0.05$) N by Cl interaction occurred at 86H. Chloride addition had a greater effect on plant NO_3-N concentration at high N rates than at the lower rates of N addition. The effects of chloride on nitrate concentrations paralleled the reduction in lodging at the 86H site. However, at the 86L site Cl significantly reduced lodging at the high N addition rates with no effect on plant nitrate concentration's. This suggests that a depression in plant nitrate concentrations from the Cl addition was not responsible for the reduction in lodging at the 86L site.

There was also a significant N by Cl interaction at boot stage for plant Cl^- concentration at both sites in 1986 (Figure 4). When the plants were treated with Cl, plant Cl^- concentration decreased as N addition

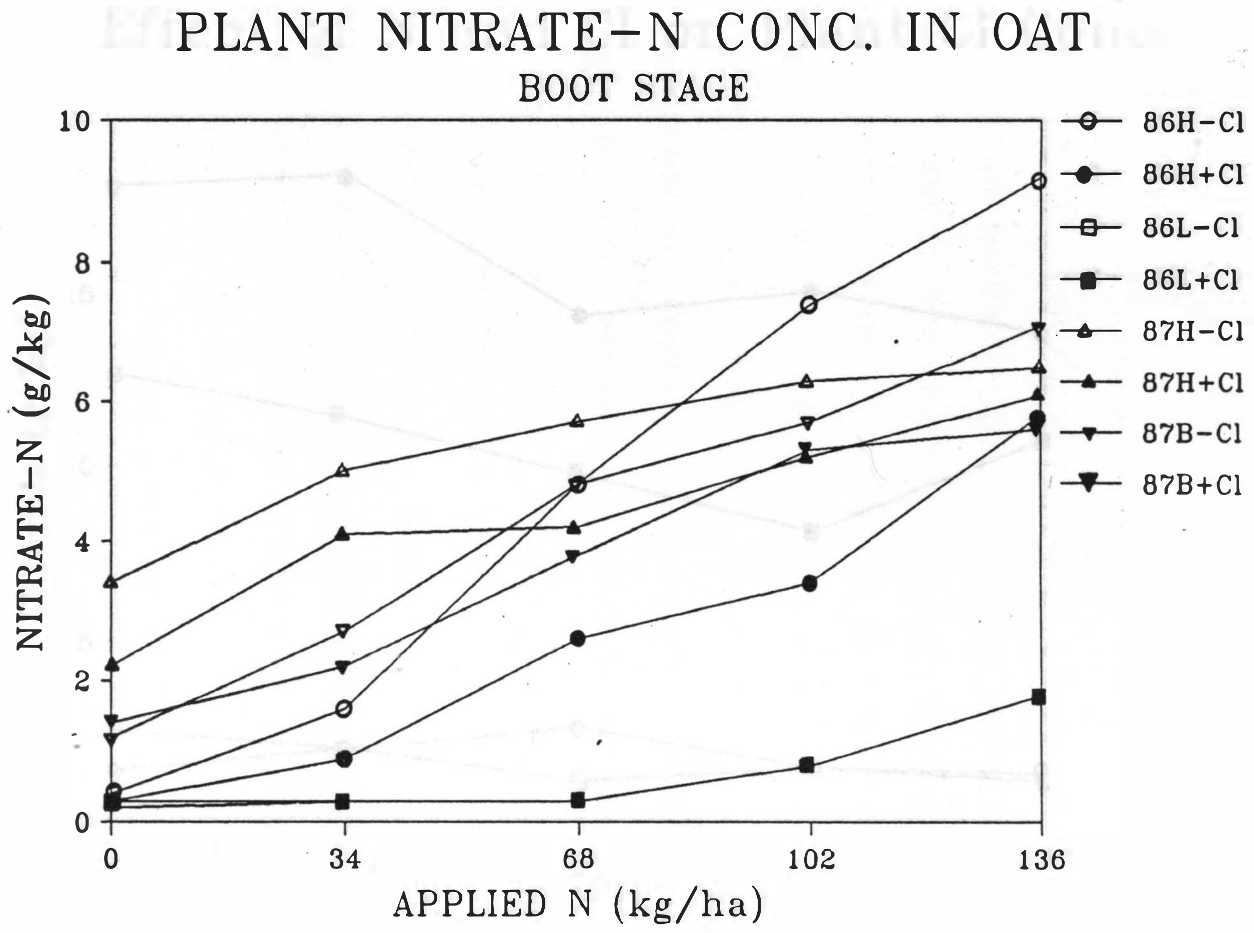

PLANT NITRATE-N CONC. IN OAT
BOOT STAGE
NITRATE-N (g/kg)
10
8
6
4
2
0
0
34
68
102
136
APPLIED N (kg/ha)
86H-Cl
86H+Cl
86L-Cl
86L+Cl
87H-Cl
87H+Cl
87B-Cl
87B+Cl

Figure 3

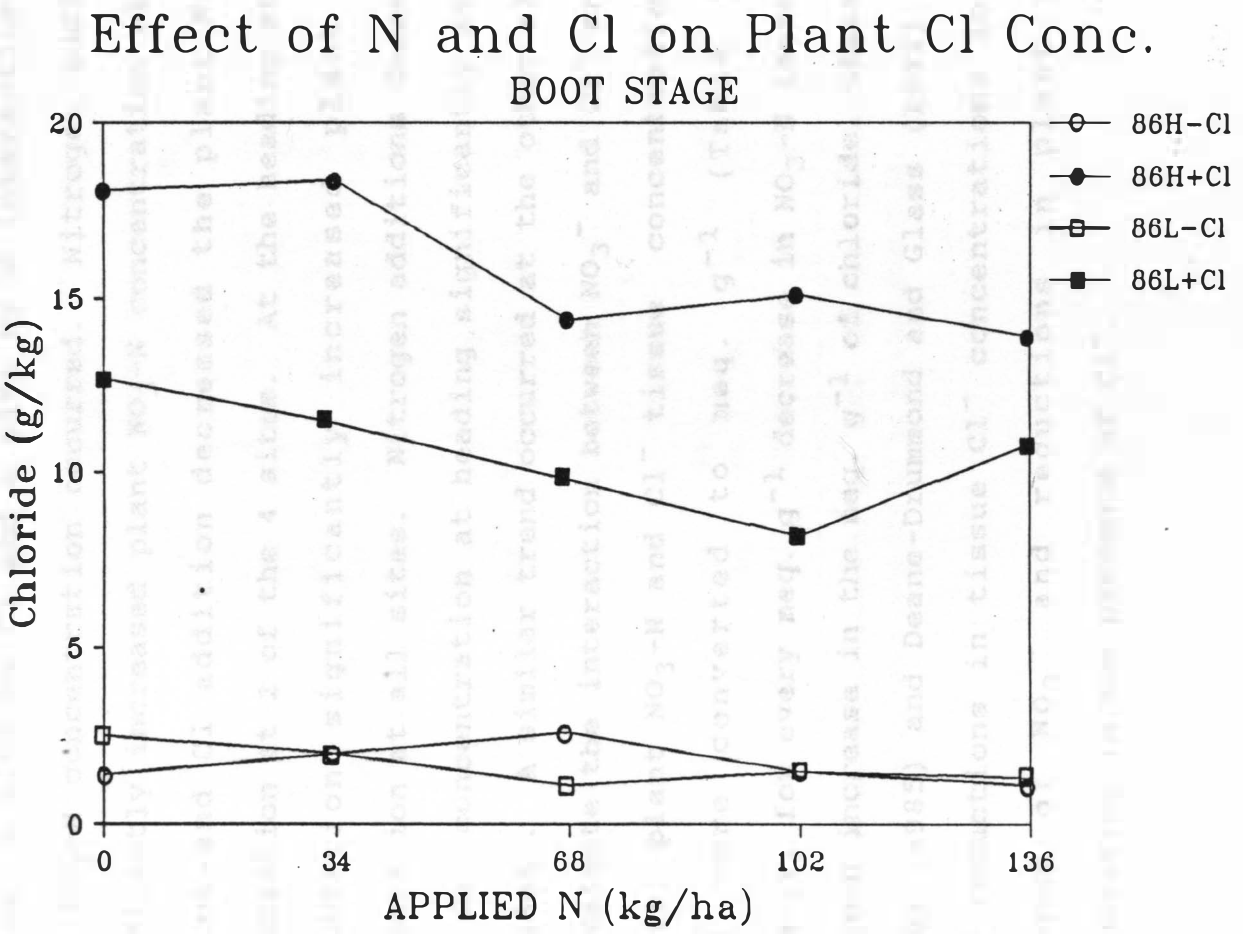

Effect of N and Cl on Plant Cl Conc.
BOOT STAGE
Chloride (g/kg)
20
15
10
5
0
0
34
68
102
136
APPLIED N (kg/ha)
86H-Cl
86H+Cl
86L-Cl
86L+Cl

Figure 4

increased.

The effect of N and Cl addition on plant NO_3-N and Cl^- concentration at heading are shown in table 15. At heading, a site by Cl and a site by N interaction for plant NO_3-N concentration occurred. Nitrogen addition significantly increased plant NO_3-N concentration at all 4 sites and Cl addition decreased the plant NO_3-N concentration at 2 of the 4 sites. At the heading stage, Cl addition significantly increased plant Cl^- concentration at all sites. Nitrogen additions decreased plant Cl^- concentration at heading significantly at one site (86L). A similar trend occurred at the other sites. To evaluate the interaction between NO_3^- and Cl^- anions further, plant NO_3-N and Cl^- tissue concentration (g kg^{-1}) were converted to meq. g^{-1} (Table 16). Generally, for every meq. g^{-1} decrease in NO_3-N there was a 10 fold increase in the meq. g^{-1} of chloride. Glass and Siddiqi (1985) and Deane-Drummond and Glass (1982) also found reductions in tissue Cl^- concentrations in the presence of NO_3^- and reductions in plant NO_3^- concentration in the presence of Cl^-.

Table 15. Effect of nitrogen and chloride addition on the concentration of NO_3-N and Cl^- in oat plant tissue at heading stage.

		Site							
N level	Cl level	86H		86L		87H		87B	
		g kg^{-1}							
--(kg ha^{-1})--		NO_3-N	Cl^-	NO_3-N	CL^-	NO_3-N	Cl^-	NO_3-N	Cl^-
0	Ave.	0.3	5.4	0.1	5.0	2.0	6.1	1.1	7.9
34		0.6	5.6	0.2	4.7	3.3	5.0	2.2	8.9
68		1.2	5.8	0.2	3.8	3.4	5.2	3.2	8.2
102		1.9	4.5	0.4	5.7	4.3	4.9	4.5	8.3
136		3.0	5.3	0.8	4.4	4.7	4.3	5.3	8.6
Ave.	0	1.5	1.4	0.3	1.8	4.0	2.0	3.4	5.6
	65	1.3	9.3	0.3	7.6	3.1	8.2	3.1	11.2
N LSD(0.05)		0.4	NS	0.3	0.9	0.7	1.1	0.7	NS
<u>Sign.</u> <u>of</u> <u>F</u>									
N rate		**	NS	**	**	*	*	**	NS
Cl rate		**	**	NS	**	*	**	.14	**
N x Cl		NS	NS	NS	NS	N	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability levels, respectively. NS = probability is greater than 0.30.

Table 16. Effect of nitrogen and chloride addition on the meq. mg^{-1} of nitrates and chloride in oat plant tissue averaged across 4 sites.

Growth Stage	Cl level (kg/ha)	Nitrogen (kg ha^{-1})									
		0		32		68		102		136	
		-meq. g^{-1}-									
		NO_3-N	Cl^-	NO^3-N	Cl^-	NO^3-N	Cl^-	NO^3-N	Cl^-	NO^3-N	Cl^-
Boot	0	21	101	38	97	63	91	82	94	100	80
	65	17	408	29	406	44	356	60	336	80	353
Heading	0	17	82	26	79	36	79	49	84	58	64
	65	13	269	24	267	29	267	42	253	53	259

SUMMARY:

Nitrogen addition increased grain yields at 3 of 5 sites. The maximum yield was 2.49 Mg ha^{-1}. Chloride significantly increased grain yield at 86H and 87H. At site 86H, the grain yield response could be explained by the decrease in lodging and an increase in 1000 kernel weight caused by Cl addition. At site 87H, Cl addition increased grain yield and 1000 kernel weight in the absence of lodging and N response. In a companion study conducted in 1986 similar results were found. The response may have been caused by a lengthening of the grain fill period which was observed on the Cl treated plots.

Test weight was significantly lowered by the addition of N at 86H, 86L, and 87L. The reduction in test weight generally occurred when soil (0-60cm) + fertilizer N exceeded 120 kg ha^{-1} and when lodging occurred. Chloride may indirectly affect test weight through an effect on lodging. Nitrogen additions decreased 1000 kernel weight during 1986. Chloride addition increased 1000 kernel weight 1.3 g kg at both sites in 1986 and at site 87H. Lodging was significantly increased by the addition of N while Cl addition significantly decreased lodging at both 1986 sites and at

87H. The effect chloride had on lodging was greater at the high N rates than at the low rates. It appears that the decrease in test weight and 1000 kernel weight may be due to an increase in lodging caused by N addition while the decrease in lodging caused by Cl additions may have increased 1000 kernel weight. Thus, Cl addition may be a feasible management practice to help reduce lodging.

Plant NO_3-N concentrations were significantly decreased by Cl^- addition at both sampling periods at sites 86H, 87H, and 87B. Chloride addition reduced plant NO_3-N concentration 24 percent. Nitrogen addition significantly decreased plant Cl^- concentration at the boot stage. When 136 kg ha^{-1} of N was applied, plant Cl^- concentration was reduced 15 percent. These results indicate NO_3^- - Cl^- antagonism was greatest early in the growing season. When comparing meq. g^{-1} NO_3^- to Cl^-, Cl anions were increased 10 times for each meq. g^{-1} of NO_3^-. The lack of antagonism found later in the growing season may be due to the over-all reduction of Cl^- and NO_3-N concentrations in the soil and plant tissue.

IV. A Greenhouse Study Eevaluation the Effect of Chloride on Plant Waer Relations in Oat

INTRODUCTION:

Most higher plants are subjected to a number of environmental stresses during the growing season. One stress that is difficult to predict or control is water stress. Plants endure water deficits by drought avoidance or by drought tolerance (Kramer, 1983). Osmotic adjustment aids drought tolerance mechanisms by using solute concentration to maintain plant turgor potential and thus allow continued plant growth (Morgon, 1983). Morgan, (1988) found when turgor pressure was maintained under stressful conditions, plants had greater growth rates than plant which did not maintain turgor. Morgan suggested turgor maintenance may have an affect on the rate of development, leaf extension, leaf senescence, leaf rolling, leaf angle, and leaf waxiness. Chloride may contribute to osmotic adjustment and turgor maintenance. Christensen et al. (1981) found Cl applications reduced cellular solute potential and thus may contribute to osmotic adjustment. Fixen et al. (1986) found Cl additions increased relative water content. This increase in relative water content could maintain a number of physiological processes, such as, cell growth, stomatal opening, and photosynthesis.

The objectives of this experiment were to evaluate the effect of Cl on relative water content, leaf water potential, osmotic potential, osmotic potential at full turgor, and stomatal conductance, in oat (Avena sativa L.) and to determine the ability of an oat cultivar to osmotically adjust in response to water stress and examine the relationship of chloride accumulation with osmotic adjustment.

MATERIALS AND METHODS:

Oat (Moore) was grown in the greenhouse at 22°C to 24°C during the day and 18° C during the night. Photoperiod was extended to 12 hours by illumination with metal halide lamps. Seeds (10) were planted January 27 in plastic pots filled with washed silica sand. The oat plants were watered with distilled water and modified Hoaglands solution (Hoagland and Arnon, 1950). The experimental design was a randomized complete block with 8 treatments and 6 replicates. The treatments consisted of 4 concentrations of Cl^- in the Hoaglands solution (0, 10, 20, and 40 mg l^{-1}) and 2 watering schedules (non-restricted and restricted). The Cl treatments were equivalent to 0, 2.5, 5, and 10 mg Cl kg^{-1} soil. The Cl^- concentrations would be considered very low, low, medium, and high (Fixen et al., 1986). The composition of the Hoagland solution (exclusive of chloride) was 0.5 mM $NH_4H_2PO_4$, 2.0 mM KNO_3, 2.5 mM $Ca(NO_3)_2$, 1.0 mM $MgSO_4$, 2.86 mg L^{-1} H_3BO_3, 1.5 mg L^{-1} $MnSo_4*H_2O$, 0.22 mg L^{-1} $ZnSO_4*7H_2O$, 0.08 mg L^{-1} $CuSO_4*5H_2O$, 0.02 mg L^{-1} $H_2MoO_4*H_2O$, and 2.08 mg L^{-1} FeEDDHA. Chloride was added as $CaCl_2$. Plants were watered every-other day with Hoaglands or distilled water. Hoaglands solution was applied every fourth day. Plants were harvested at heading. Total leaf area, Flag leaf area and dry matter freezer until processing. Osmotic potential was measured for sap expressed by placing the sample in a bench vise to express the cellular sap on a filter paper disc (6 mm diameter). A psychrometer was calibrated with standard sodium chloride solutions (Turner, 1981). The saturated filter paper disc was placed in the center of the sample holder of a Model C-52 Wescor sample chamber connected to a Wescor HR - 33T Dew Point Microvoltmeter using the technique described by Turner (1981). Solute potential at full turgor was calculated by multiplying the relative water content by the osmotic potential and dividing by 100. A randomly selected flag leaf from each pot was measured for leaf water potential with a pressure chamber (Scholander et at. 1965). The leaf was inserted into an aluminized mylar sheath (5 by 15 cm.) for 10 seconds before excision. This allowed the leaf to reach equilibrium and to minimize water loss as suggested by Turner (1981). To prepare the leaf for the pressure chamber, the leaf was excised at the blade base and was inserted into a rubber washer. The rubber washer and the leaf were placed in the chamber with the excised end visible. Once the chamber was sealed, pressure was applied at a rate of 1 bar every 5 seconds. When cell sap appeared at the cut surface, the control valve was turned off and the pressure indicated on the gauge was recorded (bars). Stomatal conductance measurements were taken on the flag leaf with a steady state porometer. Three measurements were taken per pot and averaged.

Plant Cl concentration was measured at the heading stage. A sample consisted of above ground dry mater from six plants from each pot. Samples were extracted for Cl^- measurement by shaking 0.5 g dried ground plant material in 50 ml of 0.1M HNO_3 for 15 min. on a reciprocating shaker (LaCroix et al., 1976). Chloride was titrated directly with .0282 M $AgNo_3$. The end point was detected with an Orion 96-17b (Orion, Cambridge, MA) combination Cl^- electrode and Fisher 825 MP meter (Fisher Science Company, Pittsburgh, PA).

RESULTS:

Hoagland solution chloride vs. plant chloride conc.

The Cl treatments significantly ($P(F) < 0.001$) affected plant Cl concentration (Table 1). These tissue concentrations are similar to field plant tissue concentrations. Plant Cl^- concentration was also significantly ($P < 0.001$) affected by water treatments. The water-restricted pots had 7.15 g of Cl per kg of dry matter, while the non-restricted pots contained 6.47 g Cl per kg of dry matter. A Cl by water interaction ($P(F) < 0.10$) occurred (Figure 1). Plant Cl^- concentrations were increased 13% more in the water restricted treatment relative to the control between 0 and 2.5 mg Cl^- kg^{-1}, 12% between 2.5 and 5.0 mg Cl^- kg^{-1}, but only by 2% between 5 and 10 mg Cl^- kg^{-1}.

Yield:

Dry matter production, flag leaf area, and total leaf area were measured to evaluate how Cl levels and different watering schedules affected oat tissue production (Table 1). Chloride additions did not significantly affect dry matter production, flag leaf area or total leaf area; however, the two water treatments significantly affected dry matter production and total leaf area. The restricted pots produced 14 percent less dry matter than the non-restricted pots.

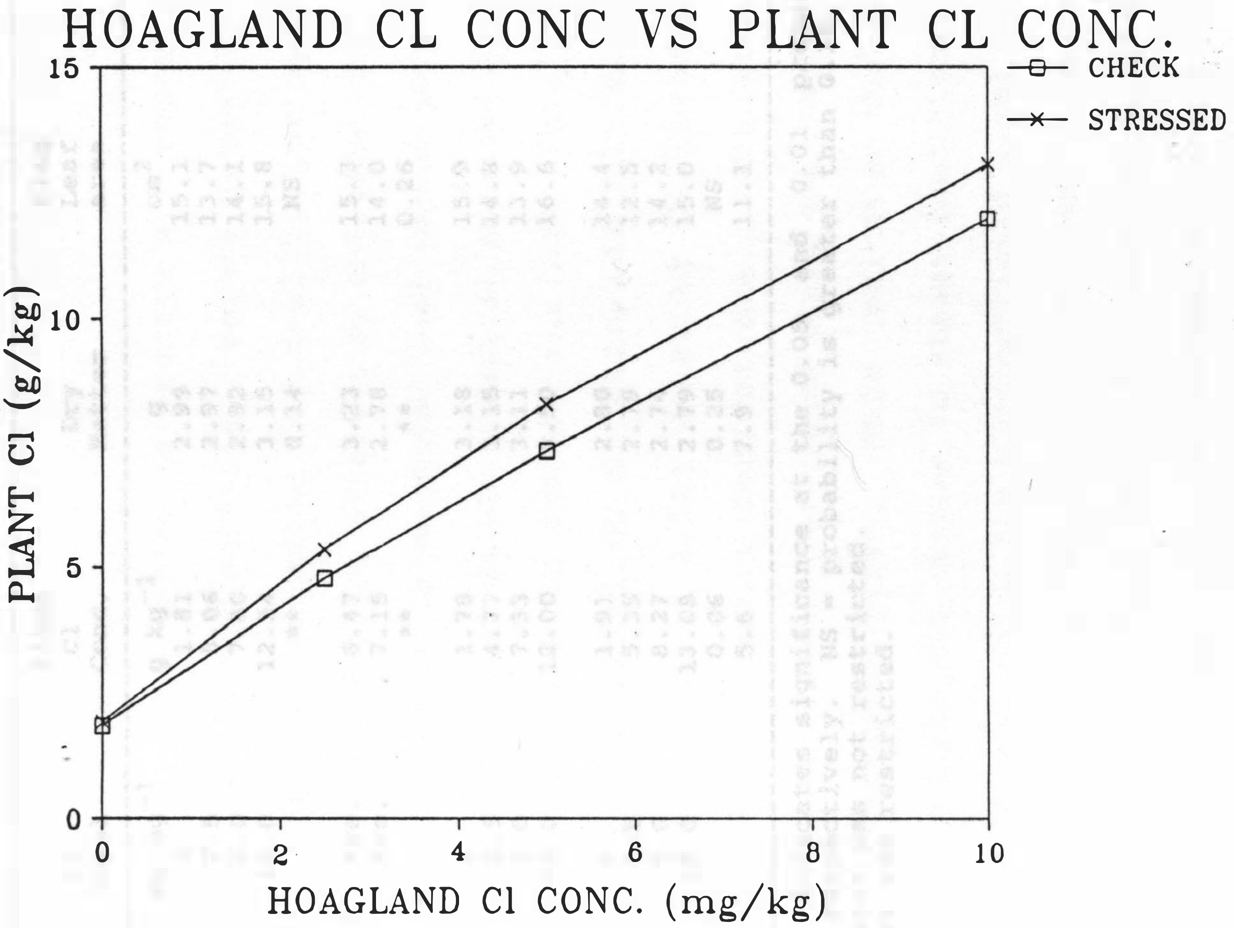

HOAGLAND CL CONC VS PLANT CL CONC.
CHECK
STRESSED
PLANT Cl (g/kg)
15
10
5
0
0
2
4
6
8
10
HOAGLAND Cl CONC. (mg/kg)

Figure 1

Table 1. The effect of chloride and water stress on plant Cl concentration, dry matter production, flag leaf area, and total leaf area.

Water Level	Cl Level	Plant Cl Conc.	Dry Matter	Flag Leaf area	Total Leaf area
	kg mg^{-1}	g kg^{-1}	g	cm^2	cm^2
Ave.	0	1.81	2.99	15.1	44.2
Ave.	2.5	5.06	2.97	13.7	39.5
Ave.	5.0	7.80	2.92	14.1	40.9
Ave.	10.0	12.54	3.15	15.8	40.9
Sign.		**	0.14	NS	0.21
N-R	Ave.	6.47	3.23	15.3	45.0
R	Ave.	7.15	2.78	14.0	37.8
Sign.		**	**	0.26	**
N-R	0	1.78	3.18	15.9	45.9
	2.5	4.77	3.15	14.8	43.9
	5.0	7.33	3.11	13.9	44.1
	10.0	12.00	3.50	16.6	46.3
R	0	1.91	2.80	14.4	42.5
	2.5	5.35	2.79	12.5	35.2
	5.0	8.27	2.74	14.2	37.8
	10.0	13.08	2.79	15.0	35.5
Sign.		0.06	0.25	NS	NS
CV		5.6	7.9	11.1	25.8

*,** = Indicates significance at the 0.05 and 0.01 probability levels, respectively. NS = probability is greater than 0.30.
N-R = water was not restricted.
R = water was restricted.

The restricted pot's leaf area was 16 percent less than the non-restricted pots. There was no significant interaction between water and Cl treatments for total leaf area, flag leaf area, or dry matter production.

Plant water relations:

Plant water relation parameters are reported in table 2. Leaf water potential, solute potential, and solute potential adjusted for full turgor were not significantly (P < 0.10) affected by chloride additions. However, Cl tended to decrease leaf water potential, solute potential, and solute potential adjusted for full turgor. Relative water content was not significantly (P(F) < 0.10) affected by chloride additions. A significant (P(F) < 0.10) water by Cl interaction occurred for stomatal conductance. The stomatal conductance for a water-restricted plant was greater than the non-restricted plant. This indicates the water-restricted plants had adapted to stress conditions, such as midday stress, while the non-restricted plant reacted to midday stress by closing its stomates. The plants watered with a very high level of Cl had larger stomatal conductance readings. The non-restricted plants treated with medium and high levels of Cl had the lowest stomatal conductance. These plants were probably never stressed

Table 2. The effect of chloride and water-stress on plant water relations.

Water Level	Cl Level	Water Potential	Solute Potential	Solute Potential at full Turgor	Pressure Potential	Relative Water Content	Stomatal Conductance
	mg kg^{-1}	-MPa				%	mg m^{-2} s^{-1}
Ave.	0	1.59	1.77	1.63	0.18	91.8	1505
Ave.	2.5	1.58	1.83	1.67	0.25	91.3	1262
Ave.	5.0	1.61	1.85	1.69	0.24	91.3	1247
Ave.	10.0	1.78	1.78	1.64	0.00	92.2	1422
<u>Sign.</u>		NS	NS	NS	NS	NS	0.14
N-R	Ave.	1.62	1.83	1.69	0.12	92.3	1280
R	Ave.	1.66	1.78	1.62	0.12	91.1	1440
<u>Sign.</u>		NS	NS	0.21	NS	NS	0.09
N-R	0	1.59	1.74	1.63	0.15	93.9	1456
	2.5	1.53	1.89	1.71	0.36	90.4	1222
	5.0	1.67	1.89	1.77	0.22	93.7	964
	10.0	1.68	1.78	1.63	0.10	91.0	1480
R	0	1.58	1.80	1.62	0.22	89.7	1555
	2.5	1.62	1.76	1.62	0.14	92.3	1303
	5.0	1.56	1.80	1.60	0.24	88.9	1532
	10.0	1.88	1.76	1.65	-0.12	93.4	1364
<u>Sign.</u>		NS	NS	NS	NS	0.11	0.07
CV		16.1	11.1	12.2	25.2	5.2	20.8

, = Indicates significance at the 0.05 or 0.01 probability levels, respectively. NS = probability is greater than 0.30.

N-R = Water was not restricted.

R = Water was restricted.

and were sensitive to the midday stress. The low stomatal conductance readings indicate the stomates were almost closed and the readings should have been taken earlier in the day to obtain greater treatment differences. There was no significant ($P(F) < 0.10$) water treatment effect on plant water relationship measurements except for stomatal conductance.

SUMMARY:

A Cl by water interaction occurred for plant Cl^- concentration. The plant Cl^- concentrations were increased 13% more in the water restricted treatment relative to the control between 0 and 2.5 kg Cl^- mg^{-1}, 12% between 2.5 and 5.0 kg Cl^- mg^{-1}, but only by 2% between 5 and 10 kg Cl^- mg^{-1}. A significant relationship existed between Hoagland solution Cl^- concentration and plant Cl^- concentration. The correlation between solution Cl^- concentration and the plant Cl^- concentration was 0.99. The plant Cl^- concentrations found in the greenhouse were similar to the plant tissue concentrations found in the field. Leaf water potential, solute potential, and turgor potential were not significantly affected by the addition of Cl but leaf water potential and solute potential tended to decrease, while turgor potential was increased. This is similar to what Christensen et al. (1981) found in wheat. However, the 10 mg kg^{-1} level of Cl caused an increase in solute potential and a decrease in the pressure potential. The high level of Cl and its companion ions may have caused an increase in the apoplast solution concentration, which in turn would cause a loss of cell turgor. Also, the high concentration of Cl may have reduced carbohydrate production and caused a reduction in solutes. A significant Cl by water interaction occurred for stomatal conductance. Stomatal conductance was greater for high Cl and/or water-restricted plants. These plant may have adapted to stress conditions and were not as sensitive to daily stress as the non-restricted plants. Osmotic adjustment in Moore under water-restricted conditions or increased Cl concentration did not occur in this study.

In conclusion, (1) Chloride did not affect dry matter production or leaf area; (2) Chloride did not significantly decrease solute potential, solute potential at full turgor, or leaf water potential but some trends were apparent; (3) Stomates were not as sensitive to stress conditions if they had previously been stressed or if a high level of Cl was present; (4) Chloride addition did not significantly affect pressure potential but an increase in Cl tended to increase the pressure potential; and (5) Osmotic adjustment in Moore did not occur under water-restricted conditions or increased Cl concentrations.

V. CONCLUSION:

The effect of chloride (Cl) addition on oat (A. sativa L.) was evaluated in three studies. A field study was conducted to evaluate the effect Cl had on 5 cultivars (Benson, Froker, Lancer, Moore, and Ogle). Chloride addition significantly increased oat grain yield at some sites. The addition of 32 kg Cl ha^{-1} was sufficient in obtaining near maximum oat grain yields. At the Cl responsive sites, 86H and 86L, the average oat grain yield response to 32 kg Cl ha^{-1} was 120 kg ha^{-1}. The 2 sites in which significant yield responses to Cl addition occurred, also had significant increases in 1000 kernel weight. Thus, it appears that part of the increase in grain yield is due to an increase in 1000 kernel weight. Chloride addition did not increase tillers $meter^{-1}$ or seeds $tiller^{-1}$.

The effect Cl had on plant water relations, crown rust, plant Cl concentration and plant K concentration was also evaluated. Crown rust, relative water content, leaf water potential, and stomatal conductance were not affected by the addition of Cl. However, Cl^- decreased solute potential and solute potential adjusted for full turgor during boot stage and/or grain fill at three sites. Data illustrating the relationship between the decrease in osmotic potential or osmotic potential adjusted for full turgor and an increase in grain yield was inconclusive.

The plant analysis for Cl^- and K^+ ion concentration indicated that KCl fertilizer increased plant Cl^- concentration and had no effect on plant K^+ concentration. Therefore, the grain yield response was most likely due to Cl addition. Soil Cl levels greater than 60 kg Cl ha^{-1} (0-60cm) were adequate in obtaining near maximum yields. Even though the increases in grain yield were significant, they were generally too small to be profitable for the year of application under current economic conditions. This analysis does not take into consideration residual Cl.

A second field study was conducted to determine the effect different rates of N and Cl have on grain yield, lodging, and plant NO_3-N and Cl^- concentration at 5 sites. Nitrogen addition increased grain yield at 3 sites while Cl addition increased grain yield at 2 sites. The optimum N level was 88.48 kg ha^{-1} and resulted in a yield of 2.49 Mg ha^{-1}. Nitrogen addition increased lodging while Cl reduced lodging. The sites where lodging occurred generally had lower 1000 kernel weights and test weights. Chloride additions at the lodging sites increased 1000 kernel weights. Of the three locations in which lodging was reduced by Cl, only one had a significant yield increase due to Cl. Nitrogen addition decreased the plant Cl^- concentration and Cl addition reduced plant NO_3 concentration. The antagonism was greatest earlier in the growing season due likely to the higher levels of each ion in the plant tissue and soil solution.

The final study was conducted in the greenhouse. The study evaluated the effect Cl and different water schedules had on oat plant water relations and stomatal conductance. Leaf water potential, solute potential, solute potential adjusted for full turgor were not significantly ($P < 0.10$) affected by the addition of Cl. However, leaf water potential, solute potential, solute potential adjusted for full turgor tended to decrease while turgor pressure was increased. At high levels of Cl or water-restrictions the stomatal conductance was higher. This suggests the plants may have adapted to stressful conditions and were not as sensitive to daily stress as the non-stressed plants.

The results of these studies indicate Cl may increase oat grain yield, however the increases in grain yield were generally too small to be profitable for the year of application under current economic conditions. Chloride tended to decrease lodging and affect plant water relations. However, the cause of the yield responses is still not clear. Further research is need to determine the amount of soil + fertilizer Cl need to obtain maximum oat grain yield. The effect Cl has on basal culm internode length and how that effects lodging should also be evaluated.

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APPENDICES

Appendix A

Means and LSD for Oat Cultivars by Chloride Study

Appendix A

Means and AOV for Oat Cultivar by Chloride Study

The effect of Cl fertilization on tillers meter^{-1} in oat.

		Site				
Cultivar	Cl	86H	86L	87H	87L	87B
	kg ha^{-1}	tillers meter^{-1}				
Moore	0	68.2	53.0	54.7	41.0	79.2
	32	69.7	50.6	64.5	47.2	77.0
	64	67.5	55.2	57.3	43.2	73.4
Ogle	0	66.8	58.6	50.8	51.8	78.7
	32	60.3	49.6	56.2	49.8	85.8
	64	69.8	50.2	58.5	48.5	83.3
Benson	0	59.5	53.6	42.7	39.2	74.5
	32	58.7	47.6	46.2	43.5	74.7
	64	53.2	48.4	49.8	49.5	84.5
Froker	0	54.7	41.8	32.0	45.0	84.5
	32	53.2	45.2	63.0	51.0	81.7
	64	58.8	48.2	59.3	54.2	82.3
Lancer	0	69.7	52.6	57.5	51.2	100.0
	32	69.2	56.2	69.8	46.7	96.7
	64	65.5	49.4	56.2	46.3	92.8
<u>Significance</u> <u>of</u> <u>F</u>						
Cult.		**	0.06	**	0.06	**
Cl		NS	NS	0.11	NS	NS
Cult. x Cl		NS	NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on seeds tiller^{-1} in oat.

Cultivar	Cl	86H	86L	87H	87L	87B
	kg ha^{-1}	seeds tiller^{-1}				
Moore	0	32.0	31.4	29.2	44.3	44.4
	32	32.5	30.4	24.7	42.3	43.8
	64	30.8	28.4	26.6	39.9	47.6
Ogle	0	23.2	24.8	27.3	35.2	43.6
	32	25.7	27.2	26.3	34.3	42.8
	64	22.2	29.4	27.9	35.7	45.0
Benson	0	30.0	30.0	26.2	34.4	37.7
	32	32.7	26.4	24.6	34.7	44.4
	64	44.0	27.0	29.5	31.5	38.1
Froker	0	26.5	29.2	24.4	37.3	41.1
	32	29.8	31.4	22.8	34.9	39.3
	64	26.5	27.0	21.6	31.7	40.9
Lancer	0	29.7	24.2	25.0	33.9	38.9
	32	31.0	25.2	22.3	32.8	33.5
	64	31.8	25.6	24.6	35.7	36.5
<u>Significance</u> <u>of</u> <u>F</u>						
Cult.		**	0.02	0.27	0.25	**
Cl		NS	NS	0.30	NS	NS
Cult. x Cl		0.17	NS	NS	NS	0.06

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl^- fertilization on 1000 kernel weight.

Cultivar	Cl	86H	86L	87H	87L	87B
	kg ha^{-1}	g				
Moore	0	16.8	22.1	22.9	25.4	20.9
	32	19.7	22.9	23.7	25.5	21.4
	64	19.5	21.5	23.8	25.9	21
Ogle	0	19.4	21.7	27.3	26.9	23.4
	32	19.4	21.6	27.6	27.4	23.6
	64	21.1	22.1	27.5	27.3	23.9
Benson	0	22.9	23.8	27.3	31.0	25.8
	32	23.3	24.4	28.1	31.0	25.8
	64	23.3	25.2	27.0	31.4	27.2
Froker	0	19.3	18.8	22.9	25.6	18.9
	32	19.8	20.7	22.4	23.5	18.9
	64	19.9	20.2	22.4	26.4	19.0
Lancer	0	18.6	22.1	22.1	25.8	19.5
	32	20.2	22.6	23.3	25.5	20.1
	64	20.1	23.3	22.4	26.1	18.5
<u>Significance</u> <u>of</u> <u>F</u>						
Cult.		**	**	**	**	**
Cl		**	**	NS	0.21	NS
Cult. x Cl		NS	NS	NS	NS	0.19

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Effect of Cl fertilization on plant Cl concentration at the three leaf stage.

		Site	
Cultivar	Cl	87H	87B
	kg ha^{-1}	g kg^{-1}	
Moore	0	2.5	7.9
	32	4.9	12.8
	64	5.6	16.3
Ogle	0	1.9	6.3
	32	4.0	12.0
	64	5.6	13.6
<u>Significance</u> <u>of</u> <u>F</u>			
Cult.		0.09	*
Cl		**	**
Cult. x Cl		NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on relative water content at boot stage.

Cultivar	Cl	Site 86H	 86L	 87H	 87B
	kg ha^{-1}	%			
Moore	0	90.1	89.7	91.4	92.3
	32	90.6	91.4	90.9	92.8
	64	90.7	91.0	87.3	93.2
Ogle	0	90.9	91.8	89.6	91.2
	32	90.3	91.8	89.8	91.6
	64	92.0	91.9	89.6	91.4
Benson	0	91.4	90.7	92.6	92.5
	32	92.1	91.4	91.2	93.0
	64	90.6	91.1	90.7	93.0
Froker	0	91.3	89.9	90.6	90.9
	32	92.1	90.2	91.7	92.2
	64	90.9	89.3	90.3	93.2
Lancer	0	90.8	91.5	91.2	91.4
	32	91.0	90.6	89.4	92.4
	64	90.7	90.7	89.6	91.8
<u>Significance of F</u>					
Cult.		NS	0.09	NS	0.28
Cl		NS	NS	0.17	0.13
Cult. x Cl		NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on osmotic potential at boot stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	MPa			
Moore	0	0.99	1.84	1.10	0.92
	32	1.06	1.85	1.33	0.88
	64	1.00	1.95	1.29	0.99
Ogle	0	1.09	1.83	1.22	0.90
	32	1.26	1.89	1.20	0.98
	64	1.06	1.84	1.24	1.01
Benson	0	1.28	1.84	1.11	0.90
	32	1.07	1.87	1.25	0.98
	64	1.17	1.93	1.32	1.03
Froker	0	1.17	1.82	1.23	0.95
	32	1.21	1.76	1.12	0.91
	64	1.24	1.86	1.19	0.87
Lancer	0	1.37	1.92	1.25	1.03
	32	1.30	2.01	1.37	0.88
	64	1.44	2.27	1.39	0.99
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	*	0.18	NS
Cl		NS	*	*	NS
Cult. x Cl		NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on solute potential adjusted for full turgor at boot stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	MPa			
Moore	0	0.89	1.65	1.00	0.85
	32	0.96	1.69	1.21	0.82
	64	0.91	1.77	1.13	0.92
Ogle	0	0.99	1.68	1.09	0.82
	32	1.14	1.74	1.08	0.90
	64	0.98	1.69	1.11	0.92
Benson	0	1.17	1.67	1.03	0.83
	32	0.99	1.71	1.14	0.91
	64	0.88	1.75	1.20	0.95
Froker	0	1.07	1.63	1.11	0.87
	32	1.12	1.59	1.03	0.84
	64	1.13	1.66	1.07	0.81
Lancer	0	1.24	1.66	1.14	0.94
	32	1.18	1.76	1.22	0.81
	64	1.31	1.82	1.25	0.91
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		*	*	0.29	NS
Cl		NS	*	0.10	NS
Cult. x Cl		NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on relative water content at heading stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	%			
Moore	0	92.4	87.7	87.2	91.3
	32	90.6	89.8	86.3	90.4
	64	92.9	87.7	88.5	90.7
Ogle	0	93.2	88.6	85.2	90.8
	32	95.7	90.7	84.7	90.7
	64	94.1	89.2	84.6	91.5
Benson	0	93.3	89.7	88.3	89.4
	32	93.0	88.6	89.2	91.1
	64	93.2	89.4	87.7	89.9
Froker	0	92.1	89.2	88.2	91.2
	32	91.8	89.7	89.6	90.4
	64	92.7	90.8	89.0	90.7
Lancer	0	92.7	89.0	87.7	89.4
	32	93.4	89.4	87.6	91.4
	64	93.6	90.4	91.7	89.0
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		NS	NS	**	0.11
Cl		0.11	NS	0.29	NS
Cult. x Cl		NS	NS	0.14	0.16

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on solute potetial at heading stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	MPa			
Moore	0	1.47	2.11	1.93	1.32
	32	1.45	1.93	1.76	1.41
	64	1.44	2.26	1.87	1.29
Ogle	0	1.27	1.71	1.91	1.54
	32	1.39	1.94	1.78	1.38
	64	1.30	1.81	1.63	1.43
Benson	0	1.58	2.28	1.75	1.24
	32	1.67	2.10	1.96	1.20
	64	1.78	2.31	1.78	1.47
Froker	0	1.63	2.06	2.01	1.27
	32	1.66	1.86	1.86	1.20
	64	1.49	2.16	1.83	1.26
Lancer	0	1.51	2.30	1.82	1.46
	32	1.54	2.24	1.81	1.46
	64	1.69	2.37	1.83	1.61
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		NS	**	NS	**
Cl		**	NS	0.21	NS
Cult. x Cl		*	NS	0.10	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on solute potential adjusted for full turgor at heading stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	-MPa			
Moore	0	1.36	1.86	1.68	1.21
	32	1.31	1.73	1.52	1.28
	64	1.34	1.97	1.66	1.17
Ogle	0	1.18	1.52	1.62	1.40
	32	1.33	1.76	1.51	1.25
	64	1.22	1.62	1.37	1.31
Benson	0	1.47	2.04	1.55	1.10
	32	1.55	1.87	1.75	1.09
	64	1.66	2.07	1.56	1.32
Froker	0	1.50	1.84	1.78	1.16
	32	1.53	1.67	1.66	1.08
	64	1.38	1.96	1.63	1.14
Lancer	0	1.40	2.05	1.60	1.30
	32	1.44	2.00	1.59	1.33
	64	1.58	2.14	1.68	1.44
Significance of F					
Cult.		**	**	0.16	**
Cl		NS	NS	NS	NS
Cult. x Cl		*	NS	*	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on relative water content at grain fill.

Cultivar	Cl	Site 86H	86L	87H	87B
	kg ha^{-1}	%			
Moore	0	90.8	82.7	89.0	90.7
	32	90.0	82.1	87.2	89.3
	64	88.9	85.5	87.6	91.8
Ogle	0	72.6	47.5	88.6	88.9
	32	65.5	59.7	86.7	90.2
	64	78.3	65.5	88.0	90.2
Benson	0	90.6	84.0	90.0	89.8
	32	90.5	86.9	88.2	90.3
	64	89.5	85.6	88.9	90.4
Froker	0	82.1	70.1	86.7	90.5
	32	81.3	72.6	86.9	91.2
	64	77.9	75.0	87.3	91.8
Lancer	0	65.7	71.7	88.9	91.2
	32	78.0	69.8	87.6	88.7
	64	66.8	70.1	89.4	87.4
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	**	NS	0.16
Cl		0.13	0.15	0.17	NS
Cult. x Cl		NS	NS	NS	0.12

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on solute potential at grain fill.

Cultivar	Cl	Site 86H	 86L	 87H	 87B
	kg ha^{-1}	MPa			
Moore	0	1.04	1.34	1.70	1.50
	32	1.02	1.20	1.64	1.48
	64	1.00	1.00	1.79	1.46
Ogle	0	1.05	1.34	1.68	1.42
	32	1.12	1.11	1.66	1.46
	64	1.13	1.35	1.83	1.54
Benson	0	1.02	1.27	1.85	1.67
	32	1.12	1.24	1.85	1.56
	64	1.10	1.44	2.19	1.66
Froker	0	1.04	1.46	1.77	1.58
	32	1.07	1.48	1.83	1.5
	64	1.11	1.57	1.86	1.59
Lancer	0	1.18	1.48	1.85	1.65
	32	1.14	1.46	1.86	1.56
	64	1.23	1.06	1.77	1.71
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		~~NS~~**	0.11	**	*
Cl		~~**~~NS	0.25	0.06	0.12
Cult. x Cl		NS	NS	0.08	0.26

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on solute potential adjusted for full turgor at grain fill.

Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	-------------- -MPa			---------------
Moore	0	0.94	1.11	1.51	1.36
	32	0.92	0.97	1.43	1.32
	64	0.89	0.86	1.57	1.34
Ogle	0	0.76	0.61	1.48	1.26
	32	0.73	0.66	1.44	1.31
	64	0.88	0.87	1.61	1.39
Benson	0	0.93	1.07	1.67	1.50
	32	1.01	1.07	1.63	1.41
	64	0.98	1.23	1.95	1.50
Froker	0	0.85	1.06	1.53	1.43
	32	0.87	1.08	1.59	1.37
	64	0.86	1.16	1.62	1.45
Lancer	0	0.77	1.01	1.64	1.51
	32	0.89	0.98	1.63	1.38
	64	0.81	0.74	1.58	1.50
<u>Significance of F</u>					
Cult.		0.07	**	**	0.07
Cl		NS	NS	*	0.09
Cult. x Cl		0.19	NS	0.08	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on stomatal conductance at boot stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	mg m^{-2} s^{-1}			
Moore	0	4194	1872	5076	5274
	32	4338	1818	4842	5760
	64	4338	2124	4680	5562
Ogle	0	4338	1746	5598	5328
	32	4392	2286	5328	5688
	64	4284	2070	5490	5580
Benson	0	4518	1836	5400	6030
	32	4464	1890	5436	6084
	64	4860	1620	5418	5814
Froker	0	4212	2286	5256	5562
	32	3978	2412	5490	5364
	64	3798	2412	5202	5328
Lancer	0	4428	2016	5274	5778
	32	4032	1926	5526	6012
	64	4266	2088	5598	5778
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	NS	0.11	0.11
Cl		**	NS	NS	0.25
Cult. x Cl		NS	0.11	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on stomatal conductance at heading stage.

Cultivar	Cl	Site			
		86H	86L	87H	87B
	kg ha^{-1}	mg m^{-2} s^{-1}			
Moore	0	3546	3780	3204	2682
	32	3744	3726	3330	2646
	64	3708	3816	3456	2664
Ogle	0	3384	3870	3546	3060
	32	2916	4194	3564	3204
	64	3240	4158	3474	2682
Benson	0	4500	4140	3240	2628
	32	4194	4158	3456	2466
	64	4266	3834	3240	2484
Froker	0	3204	4122	3474	3186
	32	3132	3798	4068	2988
	64	2862	3906	3906	3456
Lancer	0	2538	4194	3870	2880
	32	2520	4176	3906	2718
	64	2844	4266	3726	2862
<u>Significance of F</u>					
Cult.		**	*	NS	*
Cl		NS	NS	NS	NS
Cult. x Cl		NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

The effect of Cl fertilization on stomatal conductance at grain fill.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	mg m^{-2} s^{-1}			
Moore	0	1314	702	2574	4068
	32	1170	738	3186	4284
	64	1296	666	3492	4230
Ogle	0	810	522	3600	4572
	32	864	540	3600	4500
	64	1116	648	3564	4212
Benson	0	1656	864	2376	4464
	32	1062	900	2628	3942
	64	1530	900	2502	4050
Froker	0	1080	630	2592	4014
	32	972	576	3294	3618
	64	1242	504	2754	3546
Lancer	0	846	666	2718	4518
	32	594	540	2700	3168
	64	828	432	2592	3978
Significance of F					
Cult.		**	NS	NS	0.13
Cl		NS	NS	0.20	0.23
Cult. x Cl		NS	NS	NS	NS

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Effect of Cl fertilization on plant Cl concentration at boot stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	g kg^{-1}			
Moore	0	1.1	1.5	1.5	5.4
	32	10.7	6.4	5.7	10.0
	64	13.8	10.4	8.3	14.5
Ogle	0	1.1	1.7	1.3	5.3
	32	8.6	6.3	5.7	9.8
	64	13.4	10.0	7.0	13.0
Benson	0	1.1	1.5	2.4	5.2
	32	10.0	6.9	6.5	10.6
	64	14.4	11.5	8.6	15.1
Froker	0	1.3	3.1	1.9	6.3
	32	7.1	5.3	5.8	10.5
	64	15.2	11.1	8.6	15.3
Lancer	0	1.0	1.6	1.3	5.3
	32	6.7	6.7	5.0	9.6
	64	14.0	10.5	7.2	13.1
Significance of *F*					
Cult.		0.17	0.20	*	**
Cl		**	**	**	**
Cult. x Cl		**	**	NS	0.13

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Effect of Cl fertilization on plant Cl concentration at heading stage.

		Site			
Cultivar	Cl	86H	86L	87H	87B
	kg ha^{-1}	g kg^{-1}			
Moore	0	1.0	2.5	1.3	4.7
	32	3.9	4.9	4.8	7.5
	64	8.3	7.6	7.9	9.8
Ogle	0	0.9	1.7	1.2	4.6
	32	4.6	5.6	4.9	6.7
	64	7.6	6.1	6.4	10.3
Benson	0	1.0	0.9	2.1	4.7
	32	5.9	4.6	5.0	7.0
	64	10.0	8.6	8.0	10.3
Froker	0	0.9	1.2	1.4	4.9
	32	4.6	5.2	4.9	7.5
	64	8.2	7.4	7.6	10.9
Lancer	0	0.7	1.4	1.1	4.8
	32	4.4	4.3	4.5	8.2
	64	7.6	7.2	7.4	10.5
<u>Significance</u> <u>of</u> <u>F</u>					
Cult.		**	NS	*	NS
Cl		**	**	**	**
Cult. x Cl		**	0.08	*	0.20

*,** = Indicates significance at the 0.05 and 0.01 probability, respectively. NS = probability is greater than 0.30.

Appendix B

Means and AOV for Nitrogen by Chloride Study

Analysis of variance table

Source of Variance	Grain Yield	Test Wt.	Tillers per Meter	Seeds per Tiller	1000 kernel Wt.	Lodging Index	Plant Ht.	Crown Rust
Loc	**	**	**	**	**	**	**	**
N	NS	*	*	NS	.07	**	*	*
Cl	NS	NS	NS	NS	**	**	NS	**
Loc*N	**	NS	NS	*	**	NS	NS	**
Loc*Cl	.12	.07	NS	*	NS	NS	NS	NS
N*Cl	NS	NS	NS	.06	NS	NS	NS	NS
Loc*N*Cl	NS	NS	NS	NS	**	*	NS	NS

*,** Indicate significance at the 0.05 and 0.01 probability levels, respectively. NS = probability is greater than 0.15.

Analysis of variance table.

			Boot Stage		Heading Stage	
Source of Variance	Groat Protein Conc.	Groat Oil Conc.	Plant N Conc.	Plant Cl Conc.	Plant N Conc.	Plant Cl Conc.
Loc	**	**	**	**	**	**
N	**	*	**	**	**	NS
Cl	.10	NS	.13	**	.12	**
Loc*N	**	*	**	NS	**	.12
Loc*Cl	NS	*	**	**	*	**
N*Cl	NS	NS	NS	**	NS	NS
Loc*N*Cl	NS	*	**	NS	NS	NS

*,** Indicate significance at the 0.05 and 0.01 probability levels, respectively. NS = probability is greater than 0.15.

The effect N and Cl fertilization has on test weight in oat.

NITROGEN	Cl	86H	86L	87H	87L	87B
		Site				
kg ha^{-1}	kg ha^{-1}	kg m^{-3}				
0	0	366.8	415.7	323.0	371.9	377.1
	65	366.8	404.1	311.5	373.2	374.5
34	0	357.8	415.7	305.0	368.1	359.1
	65	374.5	423.4	303.7	373.2	368.1
68	0	353.9	418.3	279.3	370.7	356.5
	65	350.1	420.8	320.5	352.6	357.8
102	0	333.3	404.1	302.4	366.8	369.4
	65	346.2	410.6	299.9	375.8	355.2
136	0	325.6	393.8	293.4	353.9	370.7
	65	333.3	402.8	306.3	361.6	357.8
<u>Significance of F</u>						
N rate		**	*	0.27	**	NS
Cl rate		0.16	NS	*	NS	NS
N x Cl		0.30	NS	**	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect N and Cl^- fertilization has on 1000 kernel weight in oat.

		Site				
NITROGEN	Cl	86H	86L	87H	87L	87B
kg ha^{-1}	kg ha^{-1}	g				
0	0	25.1	26.9	27.1	30.0	27.4
	65	25.4	27.3	35.0	31.5	26.9
34	0	23.2	26.9	28.3	30.8	27.4
	65	23.9	28.0	27.8	31.2	26.6
68	0	22.4	25.8	28.4	30.9	24.1
	65	22.6	27.2	28.8	30.3	27.9
102	0	21.3	24.8	28.5	30.0	26.8
	65	22.9	27.1	28.8	30.0	27.0
136	0	21.2	24.4	27.7	30.0	26.3
	65	22.1	26.6	28.7	30.9	27.5
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		**	*	NS	NS	NS
Cl rate		0.08	**	0.07	0.13	0.14
N x Cl		NS	0.15	0.11	0.30	0.08

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on seeds tiller^{-1} in oat.

NITROGEN	Cl	86H	86L	87H	87L	87B
kg ha^{-1}	kg ha^{-1}	seeds tiller^{-1}				
0	0	35.6	31.2	26.5	33.4	44.2
	65	41.0	34.7	25.8	30.8	44.5
34	0	40.4	32.8	24.7	33.7	37.8
	65	39.2	35.7	26.3	35.2	43.1
68	0	38.0	30.8	28.0	33.2	47.1
	65	39.8	34.7	26.2	29.0	40.4
102	0	39.2	32.5	27.9	32.3	41.0
	65	38.4	31.7	27.5	29.9	36.1
136	0	37.4	28.0	25.2	38.5	38.9
	65	40.8	34.0	28.0	34.2	36.4
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		NS	NS	NS	**	0.13
Cl rate		0.16	0.23	NS	0.06	NS
N x Cl		0.19	NS	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on lodging in oat.

		Site		
NITROGEN	Cl	86H	86L	87B
kg ha^1	kg ha^1	Belgium Index/1		
0	0	0.8	0.3	4.3
	65	0.4	0.4	3.0
34	0	1.3	1.0	4.0
	65	0.5	1.0	3.6
68	0	1.5	3.3	6.9
	65	2.0	2.5	4.9
102	0	3.2	5.2	6.8
	65	2.4	3.7	5.7
136	0	5.5	7.1	5.7
	65	2.9	4.0	5.6
<u>Significance</u> <u>of</u> <u>F</u>				
N rate		**	**	**
Cl rate		**	*	*
N x Cl		0.12	0.13	NS

/1 Belgium index scale: 0.2 = no lodging, 9.0 = plot 100% lodged
*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively.
NS = probability is greater than 0.30.
Lodging scale (0.2-9.0)

The effect of N and Cl fertilization has on groat protein conc. in oat.

NITROGEN	Cl	86H	86L	87H	87L	87B
kg ha^{-1}	kg ha^{-1}			g kg^{-1}		
0	0	182.0	162.0	227.0	176.0	182.0
	65	174.0	162.0	218.0	168.0	193.0
34	0	179.0	164.0	234.0	182.0	193.0
	65	177.0	169.0	233.0	175.0	196.0
68	0	189.0	175.0	237.0	204.0	199.0
	65	182.0	173.0	232.0	201.0	195.0
102	0	190.0	185.0	232.0	217.0	195.0
	65	190.0	186.0	226.0	206.0	196.0
136	0	198.0	196.0	238.0	204.0	200.0
	65	200.0	193.0	228.0	203.0	194.0
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		**	**	*	**	NS
Cl rate		*	NS	*	*	NS
N x Cl		NS	NS	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on groat oil content in oat.

NITROGEN	Cl	Site 86H	 86L	 87H	 87L	 87B
kg ha^{-1}	kg ha^{-1}	g kg^{-1}				
0	0	76.0	69.0	56.0	65.0	67.0
	65	73.0	70.0	58.0	65.0	66.0
34	0	73.0	70.0	59.0	62.0	67.0
	65	78.0	70.0	59.0	65.0	66.0
68	0	78.0	68.0	56.0	62.0	66.0
	65	74.0	68.0	57.0	63.0	66.0
102	0	77.0	68.0	58.0	61.0	67.0
	65	74.0	67.0	59.0	61.0	67.0
136	0	76.0	69.0	55.0	61.0	66.0
	65	74.0	67.0	58.0	62.0	67.0
<u>Significance</u> <u>of</u> <u>F</u>						
N rate		NS	*	NS	**	NS
Cl rate		0.07	*	*	0.16	NS
N x Cl		**	NS	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on crown rust in oat.

		Site			
NITROGEN	Cl	86H	86L	87L	87B
kg ha^{-1}	kg ha^{-1}	%			
0	0	18.6	4.3	5.0	6.5
	65	13.0	4.7	5.3	5.3
34	0	20.0	12.2	5.3	5.3
	65	26.6	7.3	5.0	5.7
68	0	23.0	15.5	5.7	8.2
	65	24.0	9.3	5.3	5.3
102	0	32.0	19.0	9.0	7.5
	65	32.4	18.3	5.8	6.5
136	0	30.6	14.5	9.0	6.8
	65	25.0	18.3	7.8	5.3
<u>Significance</u> <u>of</u> <u>F</u>					
N rate		**	**	0.08	0.21
Cl rate		NS	NS	0.15	*
N x Cl		NS	0.18	NS	0.12

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on plant Cl conc. in oat at boot stage.

NITROGEN	Cl	86H	86L	87H	87B
		Site			
kg ha^{-1}	kg ha^{-1}	g kg^{-1}			
0	0	1.4	2.5	3.3	7.0
	65	18.1	12.7	9.8	16.5
34	0	2.0	2.0	2.1	7.5
	65	18.4	11.4	9.7	17.3
68	0	2.6	1.1	2.2	6.8
	65	14.4	9.8	9.2	16.5
102	0	1.5	1.5	2.6	7.5
	65	15.1	8.2	8.9	14.9
136	0	1.1	1.3	2.2	6.6
	65	13.9	10.8	9.2	15.5
<u>Significance of F</u>					
N rate		**	**	NS	0.17
Cl rate		**	**	**	**
N x Cl		**	*	NS	0.12

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on plant Cl conc. at heading stage in oat.

		Site			
NITROGEN	Cl	86H	86L	87H	87B
kg ha^{-1}	kg ha^{-1}	g kg^{-1}			
0	0	1.2	2.1	2.7	5.5
	65	9.7	8.0	9.5	10.4
34	0	1.3	2.1	1.8	5.9
	65	9.9	7.3	8.3	11.9
68	0	2.5	.9	2.0	5.7
	65	9.1	6.7	8.4	10.7
102	0	1.0	3.2	1.9	5.6
	65	8.1	8.3	7.9	11.1
136	0	.8	1.0	1.8	5.3
	65	9.8	7.8	6.8	11.9
<u>Significance</u> <u>of</u> <u>F</u>					
N rate		NS	**	0.06	NS
Cl rate		**	**	**	**
N x Cl		NS	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on plant nitrate-N conc. in oat at boot stage.

		Site			
NITROGEN	Cl	86H	86L	87H	87B
$kg\ ha^{-1}$	$kg\ ha^{-1}$	$g\ kg^{-1}$			
0	0	.4	.2	3.5	1.1
	65	.3	.3	2.3	1.3
34	0	1.6	.3	5.1	2.5
	65	.9	.3	4.0	2.0
68	0	4.8	.3	5.7	4.7
	65	2.6	.4	4.2	3.7
102	0	7.4	.9	6.4	5.7
	65	3.4	1.0	5.3	5.3
136	0	9.2	2.0	6.7	7.0
	65	5.8	1.9	6.3	5.8
<u>Significance</u> <u>of</u> <u>F</u>					
N rate		**	**	**	**
Cl rate		**	NS	**	*
N x Cl		**	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on plant nitrate-N conc. in oat at heading stage.

NITROGEN	Cl	86H	86L	87H	87B
		Site			
kg ha^{-1}	kg ha^{-1}	g kg^{-1}			
0	0	.3	.1	2.5	1.2
	65	.4	.2	1.6	1.0
34	0	.7	.2	3.5	2.2
	65	.5	.2	3.1	2.1
68	0	1.3	.2	4.1	3.4
	65	1.1	.2	2.8	3.1
102	0	2.2	.4	4.8	4.7
	65	1.6	.5	3.8	4.4
136	0	3.0	.8	5.1	5.6
	65	3.0	.7	4.3	5.1
<u>Significance</u> <u>of</u> <u>F</u>					
N rate		**	**	**	**
Cl rate		*	NS	**	0.14
N x Cl		NS	NS	NS	NS

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

The effect of N and Cl fertilization has on barley yellow dwarf in oat.

		Site		
NITROGEN	Cl	87H	87L	87B
kg ha^{-1}	kg ha^{-1}	g kg^{-1}		
0	0	3.3	2.7	1.7
	65	3.2	2.2	1.5
34	0	4.2	2.2	1.7
	65	3.2	2.8	2.0
68	0	2.8	2.5	1.5
	65	3.3	2.2	.5
102	0	3.5	2.7	.7
	65	2.7	2.5	.5
136	0	4.0	2.2	.7
	65	4.2	2.3	.8
Significance of F				
N rate		0.10	NS	**
Cl rate		0.16	NS	NS
N x Cl		NS	**	0.30

*,** Indicate signifcance at the 0.05 and 0.01 probability level, respectively. NS = probability is greater than 0.30.

Appendix C

Monthly Precipitation at sites

Monthly precipitation at 5 field sites.

	Month					
Site	April	May	June	July	August	Total
	cm					
86H	16.3	9.3	7.2	13.3	6.0	52.1
86L	16.0	9.3	18.0	6.0	11.9	61.1
87H	1.4	2.4	2.9	18.8	5.0	30.6
87L	1.0	7.6	7.2	19.1	4.4	39.3
87B	0.7	4.2	6.5	13.4	4.8	29.6