THE UNIVERSITY OF MANITOBA

THE EFFECT OF CHLORIDE FERTILIZATION ON GROWTH AND YIELD OF BARLEY AND SPRING WHEAT

by

Ramona Maria Mohr

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment for the Degree
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Department of Soil Science

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ABSTRACT

Recent studies conducted in the Northern Great Plains have confirmed that the Cl^- component of fertilizers can reduce disease severity, increase grain yield and improve grain quality for wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*). Field and growth chamber studies were conducted in Manitoba from 1989 to 1991 to study the effect of Cl^- fertilization on midseason plant tissue nutrient concentration, disease severity, grain yield and grain quality for spring wheat and barley cultivars grown in Western Canada.

The application of Cl^-, regardless of placement or source, substantially and significantly increased the concentration of Cl^- in plant tissue for wheat and barley sampled at the boot to heading stage. Applications of Cl^- occasionally resulted in reductions in the concentration of NO_3^- in plant tissue. However, Cl^- applications were not found to have a consistent effect on concentrations of K, Cu, Mn, Zn and NH_4^+ in plant tissue. In field studies, rates of 25 and 50 kg Cl^- ha^{-1} resulted in small, statistically significant reductions in the severity of common root rot (*Cochliobolus sativus*) for Bedford barley in two of six experiments and for Katepwa wheat in one of four experiments. Rates of 25 or 50 kg Cl^- ha^{-1} did not result in visible reductions in spot blotch severity (*Cochliobolus sativus*) for Bedford barley in either of two experiments conducted. However, the application of 50 kg Cl^- ha^{-1} produced visible reductions in foliar disease (complex of diseases) for Marshall wheat in two experiments and for Roblin wheat in one experiment. Significant increases in grain yield with the application of Cl^- were observed in several cases. However, neither soil Cl^- content nor Cl^- concentration in plant tissue reliably predicted yield responses to Cl^-. Yield increases were not consistently

associated with observed reductions in foliar or root diseases, or with the effects of Cl^- applications on any of the parameters measured. Overall, the spring wheat cultivars tested responded to Cl^- more frequently than the barley cultivars tested. However, cultivars differed in responsiveness to Cl^- applications. The application of 50 kg Cl^- ha^{-1} significantly increased grain yield for Bedford barley by an average 393 kg ha^{-1} in two of twelve experiments and for Heartland barley by 905 kg ha^{-1} in one of four experiments. The application of 50 kg Cl^- ha^{-1} did not significantly increase grain yield for Brier or Argyle in any of four experiments conducted. In wheat, the application of 50 kg Cl^- ha^{-1} significantly increased grain yield for Roblin by 492 kg ha^{-1} in one of four experiments, for Biggar by an average 333 kg ha^{-1} in two of four experiments and for Marshall by an average 363 kg ha^{-1} in two of four experiments. The application of Cl^- did not significantly increase grain yield for Katepwa wheat in any of twelve experiments conducted. In several cases, Cl^- applications significantly increased thousand kernel weight and hectolitre weight for spring wheat. In barley, Cl^- applications generally had inconsistent or deleterious effects on thousand kernel weight, hectolitre weight and kernel plumpness.

The application of Cl^- can, on occasion, provide a modest increase in grain yield for spring wheat and barley cultivars grown under Manitoba conditions, and may, on occasion, reduce the severity of foliar and root diseases and improve grain quality. Reliable prediction of responses to the application of Cl^--containing fertilizers remains difficult.

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1. INTRODUCTION

Recent studies conducted in the Northern Great Plains have confirmed that the chloride (Cl^-) component of fertilizers can, on occasion, result in modest increases in grain yield of wheat and barley (Fixen et al. 1986a,b; Goos et al. 1987a; Wang 1987; Goos et al. 1989; Engel and Grey 1991). In several studies, additional benefits, including reductions in disease severity and improvements in grain quality have also been associated with the application of Cl^--containing fertilizers. The fundamental mechanism by which Cl^- acts to enhance grain yield and quality, and to improve crop growth has not been firmly established, however. Crop responses to Cl^- remain difficult to predict.

Information regarding the efficacy of Cl^- fertilization for cereal crops under Western Canadian conditions is limited. Data and recommendations available at present are based primarily on research conducted in the Northern Great Plains of the United States. Due to regional differences in crops, soils and climate between Western Canada and the Northern United States, the current information and recommendations based on American research may not be directly applicable to cereal production under Western Canadian conditions.

A series of studies were conducted to obtain information about the effects of Cl^- fertilization on spring wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) grown under Manitoba conditions. Studies were conducted to:

1) investigate the effect of Cl^- fertilizers on grain yield, grain quality and plant nutrient status of spring wheat and barley.

2) determine the effect of Cl^- fertilization on the severity of two diseases incited by *Cochliobolus sativus* (Ito and Kurib.) Dreschsl. ex Dastur. Plant

diseases studied were common root rot for Katepwa wheat and Bedford barley and spot blotch for Bedford barley.

3) determine the responsiveness to Cl^- applications of several wheat and barley cultivars grown in Western Canada.

2. LITERATURE REVIEW

2.1 Factors Affecting the Chloride Content of Soil

The majority of chlorine occurs as the singly charged soluble anion, Cl^- (Goldschmidt 1954; Rendig and Taylor 1989). Cl^- is widely distributed throughout the environment and readily cycled through the atmosphere, lithosphere, hydrosphere and biosphere.

The initial sources of soil Cl^- are thought to be volcanic emissions, marine aerosols and salts trapped in soil parent material (Tisdale et al. 1985). Magmatic and sedimentary rocks and minerals generally contain in the order of 500 μg Cl^- g^{-1}. However, little Cl^- is derived directly from their weathering. Rather, the majority of Cl^- is considered to be 'cyclic', that is Cl^- that cycles between ocean and land (Goldschmidt 1954).

Distance from the ocean and prevailing winds largely determine the amounts of Cl^- deposited on land by precipitation (Goldschmidt 1954). Because Cl^- is one of the six major components of seawater (McSween 1989), ocean aerosols or evaporated sea spray contribute significant amounts of Cl^- to precipitation developed over the ocean. Precipitation in coastal areas often contains 1 to 2 μg Cl^- g^{-1} while further inland, precipitation may contain as little as 0.1 to 0.2 μg Cl^- g^{-1}. As a result, precipitation often provides in excess of 112 kg Cl^- ha^{-1} yr^{-1} in coastal areas (Tisdale et al. 1985) but approximately 1 to 2 kg ha^{-1} yr^{-1} in arid areas of the Great Plains (Eriksson 1960). Harapiak and Flore (1984) state in their review of literature that precipitation supplies an estimated 3.4 kg Cl^- ha^{-1} yr^{-1} on the Canadian prairies.

In the soil system, much of the Cl^- is present in the soil solution (Corey and Schulte 1973). This Cl^- is considered to be chemically inert, although Cl^--containing

fertilizers have been shown to affect biological activity. For example, Cl^- has been shown to inhibit nitrification, particularly in acidic soils (Christensen and Brett 1985), and also to stimulate mineralization (Heilman 1975). Cl^- is a component of several common soluble salts including NaCl, $CaCl_2$ and $MgCl_2$ (Tisdale et al. 1985), but is not known to form any insoluble compounds in the soil (Corey and Schulte 1973). Small amounts of Cl^- may be electrostatically and non-specifically attracted to positively charged surfaces of acidic soils containing iron or aluminum oxides or kaolinite (Mott 1981; Goos 1987). However, negligible amounts of exchangeable Cl^- occur in neutral and calcareous soils (Tisdale et al. 1985). Cl^- does not tend to be held in the soil by ligand bonds (Mott 1981). As a result, Cl^- is readily mobile and easily leached (Endelman et al. 1974).

Precipitation patterns and soil texture influence soil Cl^- distribution through effects on leaching. An application of 2.5 cm irrigation water per day was shown to result in Cl^- movement of 15 to 20 cm day^{-1} in a loamy sand (Endelman et al. 1974). Studies conducted in a subhumid area on a loam showed maximum Cl^- concentrations at a depth of 50 cm one growing season after fertilizer application, at 120 cm after two seasons and between 1 and 2 m after three seasons (Schumacher and Fixen 1989). These rapid losses of Cl^- from the top 120 cm of the profile were considered above-normal due to higher than average rainfall and large rainfall events which occurred during the course of the study.

Agricultural activities may significantly influence soil Cl^- concentration and distribution. Potash fertilizer (KCl) contains 48% Cl^- and constitutes approximately 95% of the K used in world agriculture (von Uexkull and Sanders 1986). Chlorine is also a common element in herbicides, insecticides and fungicides (Worthing and Walker 1987). Irrigation water may provide substantial and, in some instances, injurious amounts of Cl^-

in certain regions (Eaton 1942).

Crop selection also affects soil Cl^- concentration and distribution. Less than 1 kg Cl^- ha^{-1} is removed in the grain of wheat and oats while greater than 10 kg Cl^- ha^{-1} may be removed by red clover and meadow hay during one season (Russell 1973). Redistribution by sugarbeets of Cl^- from lower depths to the surface 0 to 15 cm of soil has been demonstrated (Moraghan and Ananth 1985). Inclusion of a sugar beet crop in a rotation increased Cl^- in the top 60 cm of soil from a concentration less than, to a concentration at or greater than, the critical Cl^- concentration established for cereal production by Fixen et al. (1986a) (Moraghan 1987).

Cultural practices may indirectly affect soil Cl^- concentration through effects on leaching. Schumacher and Fixen (1989) found greater leaching of Cl^- under no-till than under conventional till conditions. A higher number of open macropores at the soil surface of the no-till plot in combination with high moisture conditions which saturated these macropores may have allowed rapid downward movement of Cl^- (Schumacher 1988).

Thus, soil Cl^- concentrations may vary widely from region to region, from field to field within a region and also within a field. Substantial spatial variations in soil Cl^- concentration over small areas are common (Cameron et al. 1979; Lund 1982; Moraghan 1987). Much of this variability has been attributed to uneven applications of Cl^--containing fertilizers and to soil physical and microtopographical properties which may result in differential leaching (Cameron et al. 1979).

2.2 Plant Uptake of Chloride

Cl^- movement within the soil system may occur by mass flow. Mass flow results

when plants absorb water through roots to replace water lost due to transpiration (Wild 1981) thereby reducing the water potential of the soil near the root. Non-conducting or 'blind' pores in the soil and anion exclusion of non-adsorbed ions often result in greater movement of Cl^- by mass flow than would be expected in theory (Wild 1981). Plant uptake of Cl^- due to mass flow is a product of both the volume of water taken up and the concentration of Cl^- in the soil solution (Passioura 1963). Similar to NO_3^-, Cl^- is generally soluble and concentrations of Cl^- in the soil solution are sufficiently high that most of the plant's requirement for Cl^- is supplied by mass flow (Olsen and Kemper 1968).

When the amount of Cl^- provided by mass flow is less than that taken up by the plant root a concentration gradient develops and diffusive flow may become important (Passioura 1963). Plant uptake of Cl^- due to diffusive flow is a function of the diffusion coefficient of the ion, root length, root radius and surface area, rate of root growth, amount of water taken up, and concentration of Cl^- in the soil solution (Passioura 1963; Nye 1966). Restricted diffusive flow may occur as a result of anion exclusion in heterogenous systems where anions must diffuse through alternating large and small pores (van Schaik and Kemper 1966).

Cl^- uptake by plants occurs through active inward transport across the plasmalemma of epidermal and cortical cells (Pierce and Higinbotham 1970; Davis and Higinbotham 1976) by a gradient-coupled H^+-Cl^- symport (Jacoby and Rudich 1980; Sanders 1984). Passive movement of Cl^- from the symplasm into the xylem vessels appears most probable (Davis and Higinbotham 1976), although Pitman (1972) suggested that in barley roots a "two pump" system operates. The first stage is comprised of active transport into the symplasm; the second, between the symplasm and the xylem.

Cl^- concentrations within the cytoplasm are strictly controlled (Leigh and Wyn

Jones 1986) in order to maintain a constant and controlled environment suitable for protein synthesis and membrane stability (Wyn Jones et al. 1979). Generally, eukaryotic cytoplasm has been shown to contain a Cl^- concentration of <20-30 mM (Wyn Jones et al. 1979). In contrast, the Cl^- concentrations of extracytoplasmic compartments such as the vacuole often vary widely (Leigh and Wyn Jones 1986). In certain non-salt-tolerant plants such as wheat, compartmentalization of ions within the vacuole and exclusion from the cytoplasm do not appear to occur (Harvey and Thorpe 1986). Generally, however, major changes in the concentrations of nutrients in plant tissue are often a reflection of changes in the composition of vacuolar sap rather than in the make-up of the cytoplasm (Leigh and Wyn Jones 1986).

The mechanism by which Cl^- uptake is controlled has not been firmly established. Concentrations of anions like NO_3^- and SO_4^{2-} are commonly regulated by assimilatory needs. Since Cl^- is not metabolized by the plant in significant amounts but rather is accumulated as a free ion, different regulatory mechanisms are likely responsible (Cram 1988).

Several studies have indicated that a negative feedback mechanism dependent on NO_3^-+Cl^- concentrations in the vacuole may exist (Cram 1973; Smith 1973; Glass and Siddiqui 1985). This implies that the vacuolar concentration of NO_3^-+Cl^- is a primary factor controlling Cl^- influx into the plant. Organic anion concentrations (Smith 1973) and inhibition of Cl^- influx at the plasmalemma by external NO_3^- (Glass and Siddiqui 1985) may also be important in the control of Cl^- accumulations. Field studies have shown reductions in the concentration of Cl^- in plant tissue with increasing soil NO_3^--N where soil Cl^- measured less than 42 kg Cl^- ha^{-1} to 60 cm (Fixen et al. 1987).

The concentration of Cl^- in plant tissue varies during the growing season. In

spring wheat, concentrations of Cl^- in plant tissue were shown to rise rapidly early in the growing season and to peak 9 to 16 days prior to head emergence (Schumacher 1988). After peaking, the Cl^- concentration for plants harvested from low Cl^- treatments decreased rapidly then plateaued; the Cl^- concentration for plants from high Cl^- treatments decreased until maturity. Decreases in the concentration of Cl^- in plant tissue were attributed in part to the dilution of plant tissue Cl^- by accumulated dry matter. Differences in the pattern of Cl^- loss from high and low Cl^- treatments were attributed to greater leaching losses of Cl^- from plant tissue in the high Cl^- treatments. Growth stage was shown to have a stronger influence on Cl^- concentrations in plant tissue when the soil on which the plant was grown was high in Cl^- (Schumacher 1988).

The concentration of Cl^- in plant tissue for wheat at heading has been found to be linearly related to both indigenous soil Cl^- content to 60 cm (Fixen et al. 1986a) and to applied Cl^- (Engel and Grey 1991). In contrast, Schumacher (1988) found a curvilinear relationship between soil Cl^- content to 60 cm and Cl^- concentration in plant tissue of spring wheat at head emergence. The concentration of Cl^- in plant tissue peaked at 14,000 μg Cl^- g^{-1} which corresponded to a soil Cl^- content of 183 kg ha^{-1} to 60 cm.

Of interest is the apparent ability of plants to acquire Cl^- from the atmosphere. In studies by Johnson et al. (1957), barley appeared to obtain substantial amounts of Cl^- from the atmosphere. In coastal regions, Cl^- containing aerosols have been shown to enter the stomata of rice plants thereby increasing Cl^- content. No evidence of entry through the cuticle was noted (Cassidy 1968). In this study, distribution of Cl^- within the plant depended on whether Cl^- was supplied by the atmosphere or by the rooting media (Cassidy 1968).

Cl^- uptake by plants may alter the uptake of other plant nutrients. Cl^- has been

shown to increase K^+ and Ca^{2+} uptake through its effects on the cation/anion balance (Beaton and Sekhon 1985). Reductions in the concentrations of NO_3^-, SO_4^{2-} and P in plant tissue with the application of KCl has been demonstrated (Lundegardh 1959; Garvin et al. 1981). Reductions by Cl^- in NO_3^- concentration in plant tissue for barley under field conditions are well documented (Timm et al. 1986; Goos et al. 1987a; Goos et al. 1989) and may be the result of one or a combination of mechanisms. Goos et al. (1987a) suggest that through its role in photosynthesis, Cl^- may indirectly enhance NO_3^- reduction by increasing photosynthate production. Inhibition of nitrification by Cl^- occurs in acidic soils (Golden et al. 1981; Roseberg et al. 1986) and to a lesser extent in neutral to calcareous soils (Agrawal et al. 1985; Roseberg et al. 1986) and may decrease the concentration of plant available NO_3^- in soil. This inhibition of nitrification by Cl^--containing fertilizers has been attributed to the Cl^- ion or to a reduction in soil osmotic potential (Agrawal et al. 1985; Darrah et al. 1986; Roseberg et al. 1986). As stated previously, Cl^- influx may be controlled by a combination of a negative feedback signal for NO_3^-+Cl^- concentrations in the vacuole and the inhibition of Cl^- influx by external NO_3^- (Glass and Siddiqui 1985). Inhibition of NO_3^- uptake by Cl^- does not appear to be the direct result of competition between external NO_3^- and Cl^- for a common transport route (Smith 1973) as has been suggested (Martinez and Cerda 1989).

2.3 The Role of Chloride in the Plant-Soil System

Cl^- was first discovered to be an essential plant nutrient in 1954 (Broyer et al. 1954). However, Cl^- concentrations adequate for the nutritional needs of crop plants have not yet been firmly established. Flowers (1988) stated that an internal concentration of 1 to 50 μmol Cl^- g^{-1} dry weight was adequate for the nutritional needs of crop plants.

Maas (1986) indicated that deficiency symptoms in most plants occur at concentrations of 70 to 700 μg Cl^- g^{-1} dry weight. Cl^- is a distinctive element in that, although considered to be a micronutrient, it is often present in plant tissue at high concentrations. For example, cereals crops often accumulate Cl^- to concentrations of 1000 to 10,000 μg Cl^- g^{-1} dry weight (Fixen et al. 1986a,b; Goos et al. 1987a).

2.3.1 The Role of Chloride in Nutritional Processes in the Plant

The specific reason for restricted plant growth under Cl^- deficient conditions has not been fully explained. Several studies have shown Cl^- to be necessary for the evolution of O_2 in photosystem II of photosynthesis (Hind et al. 1969; Izawa et al. 1969).

More recent studies have cast doubt on the essentiality of Cl^- in photosynthesis. Sugar beet plants displaying symptoms of Cl^- deficiency and a significant reduction in leaf expansion were found to maintain high rates of photosynthesis (Terry 1977). Recent studies indicated that Cl^- concentrations in the chloroplasts may be stable regardless of leaf Cl^- concentration (Robinson and Downton 1985); thus photosynthesis may be unaffected by Cl^- deficient conditions.

Cl^- is required for optimal activity of the enzymes alpha-amylase, asparagine synthetase and ATPase (Maas 1986). Enzyme activity may be enhanced by the acidification of plant cells by Cl^- (Haas 1945). Cl^- has been shown to directly stimulate ATPase activity of oat roots (Churchill and Sze 1984). Cl^-, which also stimulates asparagine synthetase activity, may be required specifically for nitrogen metabolism in plants which transport soluble nitrogen in the form of asparagine (Marschner 1986). Stimulation by Cl^- of the activity of phosphofructokinase, an essential enzyme of glycolysis, has also been demonstrated (Turner et al. 1980).

Cl^- is utilized in the maintenance of charge-balance in the protoplast and thus may enhance growth by replacing other nutrients such as NO_3^- in this role. This replacement by Cl^- may allow the diversion of these other nutrient to alternate functions within the plant (Flowers, 1988).

Until the early 1980's, Cl^- fertilization of cereals was not a concern since yield increases specifically due to the nutritional effect of Cl^- are highly unlikely under field conditions. Interest in Cl^- as a fertilizer has increased in the past decade partly as a result of unexpected yield responses of cereals to KCl applications on soils testing high in potassium (Skogley and Haby 1981; Blair 1984). Recent studies in the Northern Great Plains confirm that the Cl^- component of fertilizers can increase the yield of wheat and barley (Fixen et al. 1986a,b; Goos et al. 1987a; Wang 1987; Goos et al. 1989; Engel and Grey 1991). These yield responses are not typical of yield increases that might be expected from the addition of Cl^- to plants in which the concentration of Cl^- in plant tissue is below that required to meet specific nutritional needs of the plant. The mechanism or mechanisms through which Cl^- operates to produce these "non-nutritional" yield increases may be a non-specific physiological role rather than a specific nutritional role as described above. Several mechanisms have been proposed.

2.3.2 The Role of Chloride in Plant Water Relations

Cl^- plays an important role in plant water relations due to its biochemically stable nature and its ability to be taken up rapidly (Maas 1986).

Certain plants which lack starch in their guard cells appear to have an absolute requirement for Cl^- for stomatal regulation (Schnable and Raschke 1980). All plant species appear able to utilize Cl^- for stomatal regulation (Maas 1986) although the

amount of Cl^- has been shown to vary both within and among species (Willmer 1983). Certain plant species may use Cl^- uptake either in combination with H^+ excretion (or OH^- uptake) or in combination with organic acid formation to counterbalance K^+ utilized for stomatal regulation (Willmer 1983). Environmental conditions, particularly external Cl^- concentration, may influence the extent to which Cl^- is used as a counterion (Maas 1986).

Cl^- also participates in osmotic regulation of the plant system. Accumulation of Cl^- within the cell reduces cell water potential to levels below that outside the cell and consequent passive movement of water into the cell results in hydrostatic or turgor pressure (Maas 1986). The addition of Cl^- containing fertilizers has been shown to decrease leaf water potential and osmotic potential and to increase turgor potential of wheat under field conditions. Osmotic potential was found to decrease linearly with increases in the concentration of Cl^- in plant tissue. This reduction in osmotic potential was found to be the result of increased Cl^- concentrations in the symplasm (Christensen et al. 1981). Cl^- containing fertilizers have also been shown to increase the relative water content of wheat (Fixen et al. 1986a). These effects of Cl^- on water relations have, in some instances, been attributed to the suppression of foliar diseases by Cl^- and not to a direct effect of Cl^- on plant water stress (Schumacher et al. 1986; Fixen et al. 1986a). Cl^- effects on plant water relations may be restricted under hot, dry conditions (Schumacher pers. comm.).

Minor variations in plant water relations caused by Cl^- may significantly affect plant function. Various physiological processes within the plant can be significantly affected by slight reductions in relative water content (Hsiao and Bradford 1983). Leaf water status has been shown to regulate stomatal movement. Water stress may trigger

stomatal closure which may in turn decrease CO_2 assimilation (Hsiao and Bradford 1983). If applied Cl^- maintains leaf turgor above the threshold level at which stomatal closure occurs, a decrease in CO_2 assimilation may be avoided. The resulting enhancement of photosynthesis may enhance yield. Field studies have shown the application of Cl^- containing fertilizers to increase stomatal conductance of spring wheat (Schumacher et al. 1986).

2.3.3 The Role of Chloride in Plant Morphological Development

Cl^- has been shown to hasten early season maturity and thus to lengthen grain fill duration of Marshall wheat (Schumacher 1990). Under conditions conducive to high yield, increases in kernel weight resulting from a lengthened grain fill period may produce higher grain yields. Also, the application of Cl^- to Marshall wheat has been shown to increase the number of florets per spike which may, under favourable growing conditions, contribute to yield increases (Kooiman 1989)

2.3.4 The Role of Chloride in the Suppression of Plant Disease

Cl^--containing fertilizers have been shown to suppress both foliar diseases (Christensen et al. 1982; Timm et al. 1986) and root diseases (Powelson et al. 1985; Shefelbine et al 1986; Timm et al. 1986; Goos et al. 1989) of cereals in the Northern Great Plains. Common root rot, one of the most prevalent diseases of cereal crops on the Prairies, has been suppressed in barley (Garvin et al. 1981; Shefelbine et al. 1986; Timm et al. 1986; Goos et al. 1987a; Goos et al. 1989) and in spring wheat (Wang 1987). Reductions by Cl^- in the severity of common root have generally been modest in magnitude and do not tend to occur consistently. In a study conducted in South Dakota,

the application of Cl^--containing fertilizers was also shown to cause a visible reduction in the severity of spot blotch in barley in one of five field experiments (Timm et al. 1986). Spot blotch is produced by one of the organisms responsible for common root rot.

2.4 Mechanisms of Disease Suppression by Chloride

The specific mechanism by which Cl^- suppresses common root rot and spot blotch has not been firmly established (Timm et al. 1986). Numerous proposals have been suggested to explain the suppression by Cl^- of other prevalent root and foliar diseases of cereals. Possibly, these mechanisms also function in the suppression by Cl^- of common root rot and spot blotch.

Reductions in NO_3^- concentrations in plant tissue by Cl^- may reduce the severity of common root rot (Goos et al. 1987a). N form is known to influence the severity of numerous plant diseases (Huber and Watson 1974) including common root rot. N applications to soils with adequate N levels have been shown to increase common root rot severity (Ledingham 1970). Goos et al. (1987a) found NO_3^- accumulated to higher concentrations in a common root rot susceptible than in a more resistant barley cultivar.

Cl^- may indirectly affect the development of cereal diseases through its effects on water potentials in the plant and soil systems (Griffin 1969; Cook et al. 1972; Cook and Papendick 1972; Cook and Baker 1983). For example, it has been suggested that high concentrations of Cl^- in plant tissue may substantially decrease osmotic potential in plant cells thereby producing a less suitable environment for the growth of pathogens (Goos et al. 1987b). Due to differences among pathogens in their ability to survive and grow under different plant and soil water potentials, however, the overall effect of Cl^- on the infection and development of pathogens on cereal crops is not easily predicted.

The application of Cl^--containing fertilizers may increase the availability of soil Mn thereby increasing the concentration of Mn in plant tissue. Cl^--containing solutions have been shown to increase extractable soil Mn (Westerman et al. 1971; Krishnamurti and Huang 1988). This effect has been noted most frequently in acidic soil (Westerman et al. 1971) although it has also been shown to occur in soils with a pH>7 (Khattak and Jarrell 1988). Increased susceptibility to fungal and bacterial pathogens is often associated with plants containing low concentrations of Mn (Huber and Wilhelm 1988). Furthermore, Mn additions have been shown to reduce a variety of foliar and root diseases of cereals (Huber and Wilhelm 1988) including take-all of wheat (Rovira et al. 1985; Wilhelm et al. 1988).

Thus, Cl^- appears to act through one or more mechanisms to either directly or indirectly reduce the severity of foliar and root diseases. In most instances, disease suppression by Cl^- might best be regarded as a manifestation of the effect of Cl^- on some fundamental feature of the plant system rather than directly on disease development *per se*.

2.5 Effect of Chloride Fertilization on Cereal Crops

As stated previously, the addition of Cl^- containing fertilizers has been shown to increase the yield of spring wheat (Fixen et al. 1986a,b; Engel and Mathre 1988;), winter wheat (Christensen and Brett 1985; Scheyer et al. 1987; Engel and Grey 1991) and barley (Fixen et al. 1986b; Goos et al. 1987a; Goos et al. 1989). Increases in grain yield of wheat due to the residual effects of applied Cl^- have also been demonstrated (Schumacher and Fixen 1989).

The size of yield increases from Cl^- fertilizer has generally been modest. Yield

increases in the order of 150 to 200 kg ha^{-1} (Goos et al. 1987a; Goos et al. 1989) have been measured in barley. Slightly higher yield increases averaging approximately 360 kg ha^{-1} have been noted for spring wheat (Fixen et al. 1987). Substantially greater yield increases of 1200 kg ha^{-1} have been demonstrated for take-all infected winter wheat in studies conducted in Oregon (Christensen and Brett 1985), while more modest increases averaging 227 kg ha^{-1} have been reported in studies conducted in Montana (Engel and Grey 1991).

Yield responses to Cl^- have been linked to the suppression of foliar (Fixen et al. 1986a) or root diseases (Christensen and Brett 1985; Timm et al. 1986; Lamond et al. 1990). However, the suppression of disease by Cl^- does not always result in a yield increase (Gärvin et al. 1981; Shefelbine et al. 1986; Timm et al. 1986). Yield responses to Cl^- which were not attributable to disease suppression have also been observed (Fixen et al. 1986a; Bonczkowski et al. 1988; Goos et al. 1989; Engel and Grey 1991). In these instances, responses have been attributed to a variety of mechanisms including a nutritional effect, effects of Cl^- on crop maturation and the effects of Cl^- on water relations.

The effect of Cl^- applications on grain quality is unclear. Cl^- applications increased kernel weight of only certain cultivars of spring wheat (Cholick et al. 1986; Schumacher 1990). Topdressed KCl had inconsistent effects on thousand kernel weight for winter wheat in studies conducted in Kansas (Sunderman and Mikesell 1990). Cl^- applications do not appear, in general, to consistently and significantly increase test weight of barley (Gelderman et al. 1988) or winter wheat (Sunderman and Mikesell 1990; Engel and Grey 1991). Foliar disease suppression by Cl^- was shown to produce a proportional increase in test weight for spring wheat (Buchenau et al. pers. comm.).

However, the ability of Cl^- to increase test weight for take-all infected wheat was found to depend upon the form of N fertilizer applied (Engel and Mathre 1988). Cl^- applications did not affect grain protein of spring wheat (Lamb et al. 1986; Lamb et al. 1987) or barley (Garvin et al. 1981). Cl^- has been shown, in some instances, to decrease concentrations of NO_3^- (Goos et al. 1987a) and N (Grant 1989) in plant tissue for barley. If Cl^- concentrations are such that Cl^- replaces NO_3^- in the vacuole without inhibiting N uptake, N use efficiency might be improved (Leigh and Wyn Jones 1986).

Yield responses to Cl^- fertilizers remain difficult to predict. Placement of Cl^- fertilizer does not appear to be an important factor affecting yield response. The soluble, mobile behavior of Cl^- in the soil results in similar yield responses for broadcasted and banded Cl^- fertilizer (Fixen et al. 1986a). However, because Cl^- is often applied in combination with other plant nutrients such as K^+ and NH_4^+, the placement requirements of these other nutrients should be considered.

Factors which appear to influence the probability of a Cl^- response include soil Cl^- test level, crop species and crop cultivar. Soil Cl^- levels of >43.5 kg ha^{-1} to 60 cm or of 75 kg ha^{-1} to 120 cm have been found to be adequate for optimal growth of spring wheat (Fixen et al. 1986a). The frequency of yield increases for spring wheat to Cl^- applications was 69% in soils testing low (0 to 33 kg ha^{-1} to 60 cm), 31% in soils testing medium (34 to 66 kg ha^{-1} to 60 cm) and 0% in soils testing high (>66 kg ha^{-1} to 60 cm) in Cl^-. Based on these frequencies, a recommendation to fertilize up to a total soil (to 60 cm) plus fertilizer Cl^- content of 66 kg ha^{-1} was implemented in South Dakota (Fixen et al. 1987). The authors advised caution in the extrapolation of this recommendation to areas outside of South Dakota due to local differences in climate, soil and cropping practices. A critical plant tissue concentration for spring wheat at heading stage of 1.5 g Cl^- kg^{-1} dry

weight in the above ground plant was also established (Fixen et al. 1986a).

Poor correlations between yield response of winter wheat and Cl^- soil test level have been observed in experiments conducted in Kansas (Sunderman and Mikesell 1990). Neither plant tissue Cl^- at heading nor soil Cl^- concentration were found to be good indicators of potential yield responses to Cl^- in studies with winter wheat conducted in Montana (Engel and Grey 1991). Rather, seasonal effects were considered more important. Other studies also acknowledge the importance of environmental influences. For example, Buchenau et al. (pers. comm.) found yield responses to Cl^- were infrequent under droughty conditions.

Crop species differ in their responsiveness to Cl^- applications. In studies conducted in South Dakota, Cl^- applications resulted in yield increases for spring wheat at four of six field sites, for barley at three of six field sites and for oats at zero of five field sites (Fixen et al. 1986b). When comparing species, it is important to remember that cultivars within species may differ significantly in the magnitude of yield response to Cl^- applications. This is evident in American experiments conducted with spring wheat in which the cultivar Guard was consistently less responsive to Cl^- applications than was Marshall. Cl^- applications increased grain yield by an average 470 kg ha^{-1} at three of three sites for Marshall, but did not significantly increase grain yield for Guard at any of three field sites (Cholick et al. 1986). The majority of spring wheat varieties commonly grown in the United States appear to be responsive to Cl^- (Cholick et al. 1986). Cl^- responsiveness among barley cultivars commonly grown in the United States was not found to be significantly different although trends were apparent. In a study of five barley cultivars tested for two site-years, the application of KCl resulted in an average increase in grain yield of 215 kg ha^{-1} for each of three cultivars tested, but had little effect

on grain yield for the other two cultivars included in the study (Gelderman et al. 1988). Information regarding the Cl^- responsiveness of Canadian wheat and barley cultivars is very limited.

2.6 Research Needs

Currently, crop responses to Cl^- are difficult to predict. The fundamental physiological mechanism by which Cl^- acts to enhance yield and improve grain quality has not been firmly established. A better understanding of this, and consequently of the factors governing economic responses to Cl^- would improve the ability of agronomists to predict when cereal crop responses to Cl^- fertilization are likely to occur.

At present, information regarding the efficacy of Cl^- fertilization in Western Canada is limited. Information in the literature is based primarily on research conducted in the Northern Great Plains of the United States. Due to regional differences in crops, soils and climate, current recommendations based on American research may not be directly applicable to the Western Canadian agronomic environment. Thus, field research under Western Canadian conditions would facilitate the development and refinement of Cl^- fertilizer recommendations for Western Canada.

3. COMMON ROOT ROT AND SPOT BLOTCH STUDIES

3.1 Introduction

As mentioned in the literature review, Cl^--containing fertilizers have been shown to suppress a number of foliar diseases (Christensen et al. 1982; Timm et al. 1986; Goos et al. 1987b) and root diseases (Powelson et al 1985; Shefelbine et al. 1986; Timm et al. 1986; Goos et al. 1989) of cereals. Suppression of common root rot by Cl^- has been of particular interest in the Northern Great Plains. Several studies conducted in North Dakota have demonstrated reductions in common root rot with the application of Cl^--containing fertilizers (Timm et al. 1986; Goos et al. 1987a, 1989). Reductions in common root rot were observed at three of three field sites in a study by Goos et al. (1989) but at only approximately 50% of field sites in studies by Timm et al. (1986) and Goos et al. (1987). Observed reductions in the severity of common root rot were generally small and did not result in consistent and significant increases in grain yield. The effect of Cl^- on spot blotch has been of interest also, because spot blotch is produced by *C. sativus*, one of the organisms responsible for common root rot. Information regarding the effect of Cl^- fertilizers on spot blotch severity is somewhat limited, however. In a study conducted in North Dakota, Timm et al. (1986) found that the application of approximately 84 kg Cl^- ha^{-1} as KCl resulted in visible reductions in the severity of spot blotch on the flag leaves of barley at one of five field sites. A significant increase in grain yield was not observed at this site, however.

A series of plant disease studies were designed to determine the effect of Cl^--containing fertilizers on plant tissue nutrient concentrations, severity of common root rot and spot blotch, yield and grain quality for cereals grown under Manitoba conditions. At

experimental sites used in the plant disease studies, common root rot or spot blotch inoculum was applied to selected treatments in order to increase disease pressure, and to determine if the frequency of yield responses to Cl^- was a function of the ability of Cl^- to reduce the severity of either common root rot or spot blotch.

3.1.1 Common Root Rot

Much of the interest in Cl^- fertilization has been focused on suppression of common root rot. Common root rot is a prevalent disease of cereal crops on the Canadian prairies. In fact, most plants in the field will exhibit at least some symptoms of this disease (Martens et al. 1984). Annual yield reductions of 5.7% in wheat (Ledingham et al. 1973) and 10.3% in barley (Piening et al. 1976) have been estimated for the Canadian prairie region. Yield losses caused by common root rot tend to be greater under dry than under moist conditions (Ledingham et al. 1973; Piening et al. 1976).

Symptoms of common root rot may be produced by the fungal species *C. sativus*, *Fusarium culmorum* and *Fusarium graminearum* (Mathre 1982). However, *C. sativus* appears to be the most common causal agent of common root rot on the Canadian prairies (Sallans and Tinline 1969; Harding 1973).

C. sativus may occur on host debris or on seed, but survives primarily as thick-walled conidia (Mathre 1982) in the surface 10 to 15 cm of soil (Duczek 1981). These conidia can survive for several years in the soil. Upon contact with root exudates of a susceptible plant, conidia germinate (Piening 1987) and form infection cushions on the surface of the host plant. Fungal hyphae enter the subcrown internode via epidermal cells and can extend into the cortex and endodermis resulting in tissue damage (Huang and Tinline 1976). Early season infections by *C. sativus* can cause seedling blight;

affected seedlings may brown and die (Martens et al. 1984).

Common root rot often exists unnoticed in the field. Slight stunting of scattered plants can occur (Martens et al. 1984). Above ground symptoms are infrequent, however. (Conner and Atkinson 1989). Characteristic symptoms of common root rot are brown lesions or discolourations on the subcrown internode, root tissue, lower leaf sheaths and crown of the host plant. In some instances, lesions may coalesce resulting in constriction and browning or blackening of the subcrown internode (Mathre 1982; Martens et al. 1984).

A measurement of the severity and intensity of lesions on the subcrown internode has been used to determine the severity of common root rot (Ledingham et al. 1973). According to this system, plants having sufficiently long subcrown internodes are placed into disease classes of clean, slight, moderate and severe based on a visual rating of the subcrown internode. Ledingham et al. (1973) found that as the severity of common root rot increased according to this system, the percent loss in grain yield also increased. Relationships between the percent loss in grain yield and the severity and intensity of common root rot lesions on subcrown internodes are not always consistent, however (Duczek 1984; Tinline and Ledingham 1979).

Common root rot may reduce thousand kernel weight, number and weight of grains per head and number of tillers and thus heads per plant in wheat (Ledingham et al. 1973; Verma et al. 1976) and in barley (Piening et al. 1976). Yield reductions in barley have been shown to be more closely correlated to reductions in the number of heads than to reductions in 1000 kernel weight (Duczek 1984). Under conditions of adequate moisture, plants may compensate for fewer tillers by increasing the number of kernels per head and increasing kernel weight (Mathre 1982). Early infection may

restrict tiller production such that remaining tillers cannot compensate for yield loss (Duczek 1989). Common root rot may be especially damaging under dry conditions when plants are moisture stressed (Mathre 1982).

3.1.2 Spot Blotch

Infections by *C. sativus* of aboveground parts of barley may result in symptoms of spot blotch (Martens et al. 1984). Under moist, humid conditions where extended periods of leaf wetness conducive to the development of spot blotch occur, yield losses may be significant (Clark 1979). Yield losses are closely related to leaf area affected (Martens et al. 1984) particularly to the proportion of the flag leaf affected (Mathre 1982). Yield losses in barley of 10% to 20% could result from a 1 to 2 week epidemic while prolonged epidemics of 3 to 4 weeks could result in yield losses of 20 to 30% (Clark 1979). Accompanying reductions in kernel size of approximately 10% have been recorded (Clark 1979).

Spot blotch is characterized by brown to black elongate lesions with definite margins. These lesions may occur on the leaf blade, leaf sheath, neck and head (Marten et al. 1984). A chlorotic halo may occur around lesions. Under conditions conducive to disease, lesions may enlarge and coalesce resulting in necrotic areas (Mathre 1982).

Spot blotch may arise from *C. sativus* present on the seed, as conidia present in the soil, and as conidia and mycelium on plant residues (Mathre 1982). Dispersal of inoculum may occur by wind and rain (Martens et al. 1984).

3.2 Materials and Methods

Field plots of barley (*Hordeum vulgare* cv. Bedford) were established at three sites

in each of 1989 and 1990. In addition, field plots of wheat (*Triticum aestivum* cv. Katepwa) were established at two sites in each of 1989 and 1990. These field experiments were conducted across southern Manitoba to study the effects of Cl^- fertilization of Bedford barley and Katepwa wheat on the severity of common root rot incited by *Cochliobolus sativus* (Ito and Kurib.) Dreschsl. ex Dastur. One field plot was established at Winnipeg in each of 1989 and 1990 to study the effects of Cl^- fertilization of Bedford barley on the severity of spot blotch incited by *Cochliobolus sativus* (Ito and Kurib.) Dreschsl. ex Dastur.

Soil samples were taken in the spring just prior to plot establishment and analyzed for extractable Cl^- using the mercuric thiocyanate method described by Fixen et al. (1988). Soils at all 1989 and 1990 field sites contained less than 66 kg Cl^- ha^{-1} to 60 cm (Tables 3.1 and 3.2). According to current South Dakota soil test guidelines, Cl^- fertilizer applications would have been recommended at all sites (Fixen et al. 1987).

A complete factorial experiment consisting of broadcast Cl^- at rates of 0, 25 and 50 kg Cl^- ha^{-1}, two sources of Cl^- (KCl and NaCl) and two disease inoculation treatments (with and without) was used. In the common root rot experiments, two additional treatments of 25 kg Cl^- ha^{-1} as KCl placed in the seedrow with and without common root rot inoculum were included. A randomized complete block design using six replications was employed at all sites. Subplots consisted of eight drill rows (18 cm spacing) 6 m in length. Alleys and border areas were seeded to either wheat or barley to reduce edge effects.

Cl^- fertilizer treatments were hand broadcast within several days after seeding. Commercial grade KCl and reagent grade NaCl were used. Common root rot inoculum was applied in the seedrow through the drill to either the two, three or four innermost

Table 3.1. Physical and chemical characteristics of soils used in 1989 field studies

Characteristic†	Depth (cm)	Site		
		Carman	Portage	Winnipeg
Legal Location		NE25-5-5W	NW33-10-8W	-
Soil Name		Altona	Burnside	Riverdale
Texture		loam	clay loam	silty clay
pH	0 to 15	7.5	6.6	7.2
Organic C (%)	0 to 15	2.6	3.0	3.7
	15 to 30	2.2	2.5	3.5
Carbonates (% CO_3)	0 to 15	0.25	0.01	0.11
	15 to 30	1.21	0.03	0.08
NO_3^--N (mg kg^{-1})‡	0 to 60	16	20	29
	60 to 120	14	18	17
$NaHCO_3$-extr. P (mg kg^{-1})	0 to 15	13	24	56
	15 to 30	3	7	39
CH_3COONH_4-extr. K (mg kg^{-1})	0 to 15	164	280	535
	15 to 30	89	127	451
SO_4^{2-}-S (mg kg^{-1})‡	0 to 60	5	5	5
	60 to 120	28	44	4
Cl^- (mg kg^{-1})	0 to 15	3.4	2.0	3.0
	15 to 30	3.3	1.4	2.7
	30 to 60	3.6	2.5	1.8
	60 to 90	3.6	2.7	1.6
	90 to 120	4.2	3.3	1.5
(Estimated kg ha^{-1})	0 to 60	28	17	19
	60 to 120	31	24	12
DTPA-extr. Cu (mg kg^{-1})	0 to 15	0.6	1.1	2.6
	15 to 30	0.8	0.9	2.9
DTPA-extr. Mn (mg kg^{-1})	0 to 15	18	34	37
	15 to 30	12	19	34
DTPA-extr. Zn (mg kg^{-1})	0 to 15	0.6	1.8	3.3
	15 to 30	0.2	0.5	3.0

† Methods used for soil analysis are described in Appendix A.

‡ Concentrations of NO_3^--N and SO_4^{2-}-S in 0 to 60 cm depth established according to weighted average of concentrations in 0 to 15, 15 to 30 and 30 to 60 cm depths; concentrations in 60 to 120 cm depth established according to weighted average of 60 to 90 and 90 to 120 cm depths.

Table 3.2. Physical and chemical characteristics of soils used in 1990 field studies

Characteristic†	Depth (cm)	Site		
		Carman	Portage	Winnipeg
Legal Location		NE25-5-5W	NW33-10-8W	-
Soil Name		Altona	Burnside	Riverdale
Texture		loam	clay loam	silty clay
pH	0 to 15	6.6	6.9	7.0
Organic C (%)	0 to 15	2.6	3.6	3.1
	15 to 30	2.6	2.8	3.2
Carbonates (% CO_3)	0 to 15	0.07	0.06	0.09
	15 to 30	0.33	0.23	0.07
NO_3^--N (mg kg^{-1})‡	0 to 60	7	15	16
	60 to 120	11	23	11
$NaHCO_3$-extr. P (mg kg^{-1})	0 to 15	13	13	41
	15 to 30	3	4	33
CH_3COONH_4-extr. K (mg kg^{-1})	0 to 15	211	220	592
	15 to 30	141	175	556
SO_4^{2-}-S (mg kg^{-1})‡	0 to 60	31	38	4
	60 to 120	126	738	4
Cl^- (mg kg^{-1})	0 to 15	1.2	3.8	1.8
	15 to 30	1.2	4.6	1.4
	30 to 60	1.0	7.2	1.4
	60 to 90	9.3	3.7	1.5
	90 to 120	4.8	1.4	1.5
(Estimated kg ha^{-1})	0 to 60	9	45	12
	60 to 120	57	20	12
DTPA-extr. Cu (mg kg^{-1})	0 to 15	0.8	1.0	2.8
	15 to 30	0.6	1.0	3.7
DTPA-extr. Mn (mg kg^{-1})	0 to 15	23.4	28.7	24.3
	15 to 30	15.0	12.4	21.4
DTPA-extr. Zn (mg kg^{-1})	0 to 15	0.7	1.4	2.5
	15 to 30	0.5	0.4	2.1

† Methods used for soil analysis are described in Appendix A.

‡ Concentrations of NO_3^--N and SO_4^{2-}-S in 0 to 60 cm depth established according to weighted average of concentrations in 0 to 15, 15 to 30 and 30 to 60 cm depths; concentrations in 60 to 120 cm depth established according to weighted average of 60 to 90 and 90 to 120 cm depths.

rows (depending on supply of inoculum) of each subplot at time of seeding. A rate of approximately 20 g air-dried millet (*Panicum miliaceum* cv. Crown) inoculum per 6 m drill row was applied.

In 1989, *C. sativus* inoculum for the common root rot experiments was prepared as follows. Millet seed was irradiated for 24 hours and soaked over night. Millet seeds were autoclaved for a period of one hour on each of two consecutive days and then autoclaved for a final time. Approximately 1 to 1.5 L of moist millet seed was then inoculated with the contents of 1 petri dish of potato dextrose agar (PDA) on which *C. sativus* was growing. To inoculate, 1/4 inch pieces of PDA were thoroughly mixed with the millet. The millet-inoculum mixture was then stored in plastic bags and mixed daily for a two week period. Prior to application in the field, the millet seed was air dried. The same basic procedure was used in 1990 with the following modifications. Millet seed was autoclaved for one hour per day on three consecutive days. Moist millet seed was stored in 500 mL jars to which one petri dish of PDA on which *C. sativus* was growing had been added. *C. sativus* was allowed to grow through the millet for a three to four week period.

The source of *C. sativus* used in 1989 differed from that used in 1990. Isolates applied in 1989 were from laboratory samples and were less virulent than had been anticipated. The source of inoculum was thought to be partly responsible. Conner and Atkinson (1989) found that *C. sativus* isolates from wheat and barley tended to be highly virulent on their original host species, but weakly virulent on other host species. Therefore, in 1990, *C. sativus* isolates indigenous to the plot sites to which they were applied and specific to either wheat or barley were isolated from the subcrown internodes of wheat and barley collected from the 1989 field plots. A mixture of two isolates for

each species at each site was made just prior to application in the field in attempts to ensure virulent inoculum.

Basal applications of macronutrients were made to meet or exceed recommendations of the Manitoba Provincial Soil Testing Laboratory. At Portage, anhydrous ammonia at a rate of 100 kg N ha^{-1} was applied by the producer in the fall of 1989, prior to establishment of the 1990 plot. At all other sites, N in the form of urea was broadcast in the spring prior to seeding. At Carman and Portage, urea was incorporated. At Winnipeg, no tillage was done in the spring prior to seeding; the crop was direct drilled into summerfallow. Rates of fertilizer applied were 46 kg N ha^{-1} at Portage in 1989 and at Winnipeg in 1990, 69 kg N ha^{-1} at the Winnipeg in 1989 and 92 kg N ha^{-1} at Carman in 1989 and 1990. At all sites, approximately 13 kg P ha^{-1} and 7 kg N ha^{-1} as monoammonium phosphate were placed in the seedrow at time of seeding. At Carman in 1989 and 1990 and at Portage in 1989, approximately 19 kg N ha^{-1} and 22 kg S ha^{-1} as ammonium sulphate was broadcast and incorporated in the spring prior to seeding.

Herbicides were applied at recommended rates to control weeds. In 1989, insecticides were applied as required to control grasshopper infestations.

In the common root rot experiments, the number of plants per 1 m of drill row was determined from one of the two innermost rows of each subplot at the one to three leaf stage.

In the spot blotch experiments, approximately one month after seeding, once the canopy had closed, spot blotch inoculum was applied. A rate of approximately 40 g per 6 m drill row was evenly applied to the soil immediately adjacent to the base of the two innermost rows of each subplot. Inoculum consisted of a mixture of millet and oats

prepared by the same method used to produce common root rot inoculum.

In the common root rot experiments, plant samples were taken at the heading stage, at the soft dough stage and again at maturity. Unless otherwise stated, at all harvests, samples from common root rot inoculated subplots were taken only from those drill rows to which *C. sativus* inoculum had been applied. In the spot blotch experiments, harvests were taken at the heading stage and again at maturity.

For both sets of experiments in 1989, at the heading stage, a random sample of 25 plants was taken from the outer 2 of the 4 innermost rows of each subplot. The shoot portion was dried at 68°C and ground with a Wiley mill to pass a 2 mm sieve. The concentration of Cl^- in plant tissue was determined by $AgNO_3$ titration procedure (LaCroix et al. 1970). NO_3^- and NH_4^+ were extracted from plant tissue with 2 M KCl (Milham et al. 1970) and determined by steam distillation (Keeney and Nelson 1982). Concentrations of K, Cu, Mn and Zn in plant tissue were determined on a nitric-perchloric digest by atomic absorption spectrophotometer (Isaac and Kerber 1971). (A complete description of procedures used for plant tissue analysis has been included in Appendix B.)

In 1990, midseason harvest procedures were modified slightly in order to allow a measurement of midseason dry matter yield and consequently the calculation of Cl^- uptake by wheat and barley (few measurements of midseason dry matter yield and Cl^- uptake are currently found in the literature). Cl^- uptake was calculated as the product of midseason dry matter yield and Cl^- concentration in plant tissue. At heading, the shoot portion of 0.5 m of the two innermost drill rows of each subplot was harvested at Carman and Portage. In the common root rot experiment at the Winnipeg site, dry matter yield was not determined. However, approximately 20 plants were randomly sampled from the

2 innermost rows of each subplot for determination of nutrient concentrations in plant tissue. In the spot blotch experiment at Winnipeg, the shoot portion of 3 m of one inner drill row was collected. Samples from all experiments were dried at 68° C, weighed to determine dry matter yield and ground with a Wiley mill to pass a 2 mm sieve. Concentrations of Cl^-, NO_3^-, NH_4^+, K, Cu, Mn and Zn in plant tissue were determined as described for 1989. In 1990 only, total N concentration in plant tissue samples from non-inoculated plots treated with no Cl^-, 50 kg Cl^- ha^{-1} as KCl and 50 kg Cl^- ha^{-1} as NaCl was determined using a modified Kjeldahl procedure (Bowman et al. 1988).

In the common root rot experiments, in 1989, at approximately the soft dough stage, a random sample of 25 plants with subcrown internodes was excavated from the outer two of the four innermost rows of each subplot. The root and crown portion of the plants was placed in plastic bags and stored at cool temperatures (approx. 5° C) until disease ratings were completed. Subcrown internodes were rated for common root rot (Ledingham et al. 1973). (A complete description of the rating system used for disease assessment has been included in Appendix C.) Due to the subjective nature of the disease rating system used, a blind rating system was adopted. That is, samples were coded so that individuals conducting the rating were unaware of which treatments had been applied to the individual samples. In 1990, only two or three of the innermost drill rows of each subplot were inoculated with *C. sativus*. Therefore, sampling techniques were modified to allow sampling at soft dough from the two innermost rows of each subplot. Sections of drill row measuring 0.33 m were sampled from three areas 1.5 m apart. Of the plants sampled for each subplot, twenty-five plants with subcrown internodes were randomly selected and rated for common root rot (Ledingham et al. 1973). As in 1989, a blind rating system was used.

In the spot blotch experiments, at approximately the soft dough stage, a cursory spot blotch rating was conducted. This rating was based on a combination of disease severity and height of disease lesions in the canopy. (A description of the rating system used for foliar disease assessment has been included in Appendix C.)

In both 1989 and 1990, final harvest consisted of the shoot portion of plants from 3 m of the two innermost drill rows of each subplot. Samples were cut by hand approximately 2.5 cm from the soil surface. Samples were air dried, then threshed with a stationary thresher. Measurements taken included grain yield, straw yield, thousand kernel weight, hectolitre weight and barley kernel plumpness. Hectolitre weights and barley plumpness were determined using methods outlined by the Canadian Grain Commission (1990). Thousand kernel weight was based on a subsample of 200 kernels. In 1990, grain samples were ground with a Wiley mill to pass a 2 mm sieve. Total N concentration in grain was determined for non-inoculated plots treated with no Cl^-, 50 kg Cl^- ha^{-1} as KCl and 50 kg Cl^- ha^{-1} as NaCl. A conventional Kjeldahl procedure was used (Schuman et al. 1973).

Analysis of variance and calculation of LSD's, regression analysis and correlation analysis were conducted using the PROC GLM, PROC REG and PROC CORR procedures, respectively (SAS Institute Inc. 1988). Single degree of freedom contrasts were used to further analyze treatment effects.

3.3 Results and Discussion

In 1989, moisture deficits from midseason through the grain fill period restricted crop yield. This was particularly evident at Carman where droughty conditions in combination with grasshopper damage and weed competition limited crop yield. In 1990,

moisture was adequate early in the season. Final grain yields appeared to have been somewhat restricted by hot, dry conditions during the grain fill period.

3.3.1 Barley

Early Season Plant Density

Plant density was determined for common root rot experiments only. The addition of *C. sativus* inoculum significantly reduced plant density for Bedford barley at Carman in 1989 (Table 3.3). Seedling blight arising from early season infections by *C. sativus* may have been the cause. The addition of inoculum also tended to reduce plant density for Bedford barley at Carman in 1990, but the effect was not significant (P=0.10) (Table 3.4). No other significant effects of inoculum on plant density of Bedford barley were observed. The addition of 50 kg Cl^- ha^{-1} as NaCl significantly reduced plant density of Bedford barley at Portage in 1990 (Table 3.4) likely due to an adverse effect of Na^+ on soil structure. The soil surface of subplots treated with NaCl, particularly the 50 kg Cl^- ha^{-1} rate of NaCl, was visibly crusted and appeared to impede seedling emergence. Adverse effects of Na^+ on soil structure had not been anticipated due to the fairly high Ca^{2+} concentrations present in most Manitoba soils. No other significant effects of source or fertilizer rate on plant density were noted for Bedford barley.

Dry Matter Yields and Plant Tissue Nutrient Concentrations at Midseason

Midseason dry matter yield was determined in 1990 only. Common root rot inoculum significantly reduced midseason dry matter yield of Bedford barley at Carman and at Portage in 1990 (Table 3.5). A small, statistically insignificant (P=0.10) reduction in plant density early in the season (Table 3.4) may have been responsible, in part, for the

Table 3.3. Effect of chloride fertilizer and *C. sativus* inoculum on plant density for Bedford barley in 1989

Treatment			Plant density (number of plants per 1m row) †		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg‡
Treatment means					
KCl	0	-	39.0	40.5	48.5
KCl	25	-	36.8	38.0	53.0
KCl	50	-	40.0	45.7	53.2
NaCl	0	-	40.0	45.7	50.0
NaCl	25	-	41.8	45.3	57.3
NaCl	50	-	43.7	44.8	47.5
KCl	0	+	35.5	42.7	53.8
KCl	25	+	34.5	41.8	48.3
KCl	50	+	37.2	42.2	49.7
NaCl	0	+	33.7	40.2	51.8
NaCl	25	+	35.7	45.8	47.7
NaCl	50	+	35.6	41.3	50.3
KCl (S)§	25	-	42.3	46.0	51.2
KCl (S)	25	+	38.5	43.7	45.0
Group means					
KCl			37.2	41.8	51.1
NaCl			38.5	43.9	50.8
LSD (P=0.05)			ns	ns	ns
	0		37.0	42.3	51.0
	25		37.2	42.8	51.6
	50		39.1	43.5	50.2
LSD (P=0.05)			ns	ns	ns
		-	40.2	43.3	51.6
		+	35.3	42.3	50.3
LSD (P=0.05)			3.5	ns	ns

ANOVA	df	Pr > F		
Inoculum (I)	1	0.007 **	0.53	0.39
Source (S)	1	0.52	0.20	0.84
Rate (R)	2	0.57	0.81	0.74
S*R	2	0.70	0.24	0.51
I*R	2	0.96	0.33	0.02 *
S*I	1	0.24	0.25	0.81
I*S*R	2	0.94	0.61	0.26
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.34	0.24	0.86
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.18	0.05 *	0.63
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.32	0.65	0.38
all 0 vs 25 KCl	1	0.58	0.35	0.87
all 0 vs 50 KCl	1	0.52	0.50	0.87
all 0 vs 25 NaCl	1	0.49	0.18	0.53
all 0 vs 50 NaCl	1	0.32	0.74	0.36
C.V. (%)		18.3	16.2	12.8

† Plant density determined at the one to three leaf stage.
‡ Plant density determined for the common root rot experiment only.
§ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.4. Effect of chloride fertilizer and *C. sativus* inoculum on plant density for Bedford barley in 1990

Treatment			Plant density (number of plants per 1m row) †		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg‡
Treatment means					
KCl	0	-	41.3	32.5	39.5
KCl	25	-	40.0	38.3	37.5
KCl	50	-	42.5	32.8	46.0
NaCl	0	-	40.7	35.2	40.0
NaCl	25	-	38.5	33.2	42.0
NaCl	50	-	44.2	27.2	40.2
KCl	0	+	43.8	34.0	39.7
KCl	25	+	38.8	34.7	38.0
KCl	50	+	39.8	32.8	40.2
NaCl	0	+	36.8	34.2	38.8
NaCl	25	+	39.5	27.8	41.2
NaCl	50	+	35.0	25.8	38.5
KCl (S)§	25	-	41.7	35.7	38.2
KCl (S)	25	+	41.3	34.0	38.8
Group means					
KCl			41.1	34.2	40.1
NaCl			39.1	30.6	40.1
LSD (P=0.05)			ns	2.5	ns
	0		40.7	34.0	39.5
	25		39.2	33.5	39.7
	50		40.4	29.7	41.2
LSD (P=0.05)			ns	3.0	ns
		-	41.2	33.2	40.9
		+	39.0	31.6	39.4
LSD (P=0.05)			ns	ns	ns

ANOVA	df	Pr > F		
Inoculum (I)	1	0.10	0.19	0.23
Source (S)	1	0.15	0.005 **	0.98
Rate (R)	2	0.64	0.01 **	0.45
S*R	2	0.57	0.02 *	0.04 *
I*R	2	0.16	0.26	0.41
S*I	1	0.19	0.46	0.84
I*S*R	2	0.33	0.98	0.56
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.56	0.0001 **	0.98
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.63	0.37	0.82
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.46	0.82	0.78
all 0 vs 25 KCl	1	0.55	0.17	0.33
all 0 vs 50 KCl	1	0.81	0.54	0.05 *
all 0 vs 25 NaCl	1	0.43	0.06	0.25
all 0 vs 50 NaCl	1	0.60	0.0001 **	0.93
C.V. (%)		14.6	15.7	12.7

† Plant density determined at the one to three leaf stage.
‡ Plant density determined for the common root rot experiment only.
§ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.5. Effect of chloride fertilizer and *C. sativus* inoculum on midseason dry matter yield for Bedford barley in 1990

Treatment			Midseason dry matter yield (kg ha^{-1})		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg†
Treatment means					
KCl	0	-	6077	5287	7393
KCl	25	-	5179	4874	7268
KCl	50	-	5544	5043	7502
NaCl	0	-	6001	5362	7608
NaCl	25	-	5892	4490	7049
NaCl	50	-	6243	4950	6880
KCl	0	+	5592	5165	7496
KCl	25	+	4949	4518	6971
KCl	50	+	5219	4734	7381
NaCl	0	+	4865	4425	6768
NaCl	25	+	5150	3600	6937
NaCl	50	+	5537	3703	7140
KCl (S)‡	25	-	6494	4443	-
KCl (S)	25	+	5604	4424	-
Group means					
KCl			5427	4937	7335
NaCl			5615	4421	7064
LSD (P=0.05)			ns	447	ns
	0		5634	5060	7316
	25		5293	4371	7056
	50		5636	4607	7226
LSD (P=0.05)			ns	547	ns
		-	5823	5001	7283
		+	5219	4357	7115
LSD (P=0.05)			461	447	ns

ANOVA	df	Pr > F		
Inoculum (I)	1	0.01 **	0.006 **	0.34
Source (S)	1	0.42	0.02 *	0.13
Rate (R)	2	0.38	0.04 *	0.48
S*R	2	0.20	0.83	0.78
I*R	2	0.82	0.90	0.59
S*I	1	0.27	0.09	0.72
I*S*R	2	0.97	0.93	0.26
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.08	0.02 *	0.20
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.02 **	0.40	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.24	0.86	-
all 0 vs 25 KCl	1	0.09	0.25	0.46
all 0 vs 50 KCl	1	0.45	0.59	0.64
all 0 vs 25 NaCl	1	0.74	0.002 **	0.23
all 0 vs 50 NaCl	1	0.45	0.02 *	0.25
C.V. (%)		16.9	19.2	10.4

† Dry matter yield determined for the spot blotch experiment only.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

significant reduction in midseason dry matter yield at Carman. Although the inoculum did not significantly reduce plant density, it may have reduced seedling vigour and consequently restricted crop growth for part of the growing season. Spot blotch inoculum had no significant effect on midseason dry matter yield. The addition of Cl^- at rates of 25 and 50 kg Cl^- ha^{-1} as NaCl resulted in significant decreases in midseason dry matter yield of Bedford barley at Portage in 1990 (Table 3.5) likely due to significant decreases in plant density early in the season (Table 3.4).

The concentration of Cl^- in plant tissue for Bedford barley significantly increased with increasing rates of Cl^- in all field experiments in both 1989 and 1990 (Tables 3.6 and 3.7). The addition of inoculum did not have a significant effect on Cl^- concentration in plant tissue at any of the sites. Overall, NaCl appeared to be equivalent to KCl in providing Cl^- to the crop although, in several cases, small differences in the concentration of Cl^- in plant tissue were observed between Cl^- sources. Placement of KCl did not have a consistent, significant effect on the concentration of Cl^- in plant tissue. In 3 of 12 contrasts, however, seedrow placed KCl resulted in significantly lower Cl^- concentrations in plant tissue than broadcast KCl. Differences in Cl^- concentration in plant tissue due to fertilizer placement had not been anticipated since Cl^- is readily mobile in the soil and easily leached. Cl^- concentrations in plant tissue were highly variable and likely due to inherent variability in soil Cl^- concentration. In both 1989 and 1990, in the 25 and 50 kg Cl^- ha^{-1} treatments, the concentrations of Cl^- in plant tissue for samples taken from the spot blotch experiment were lower than those taken at the same stage of plant development from a common root rot experiment located 10 m away. These differences between experiments were substantial in 1990. According to soil tests conducted in the spring prior to plot establishment, soil Cl^- contents to 120 cm were equivalent in both

Table 3.6. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue chloride concentration for Bedford barley in 1989

Treatment			Plant tissue Cl^- concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	6324	2567	1323	1079
KCl	25	-	11147	6677	6164	4032
KCl	50	-	12530	10173	9055	6558
NaCl	0	-	6188	2106	1397	1298
NaCl	25	-	9489	7015	5091	4414
NaCl	50	-	13157	9816	8643	7549
KCl	0	+	6789	2655	1306	1797
KCl	25	+	9700	6515	5670	4265
KCl	50	+	12713	9611	9057	7666
NaCl	0	+	4281	2791	1468	1113
NaCl	25	+	11483	7411	5397	4375
NaCl	50	+	13530	10739	7996	7404
KCl (S)‡	25	-	9573	6482	4961	-
KCl (S)	25	+	8824	6859	5703	-
Group means						
KCl			9746	6357	5429	4233
NaCl			9462	6687	4999	4359
LSD (P=0.05)			ns	ns	407	ns
	0		5895	2548	1373	1321
	25		10422	6914	5580	4272
	50		12960	10096	8688	7294
LSD (P=0.05)			~1200.§	794	498	625
		-	9767	6410	5279	4155
		+	9430	6620	5149	4437
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.83	0.35	0.52	0.27
Source (S)	1	0.61	0.37	0.04 *	0.62
Rate (R)	2	0.0001 **	0.0001 **	0.0001 **	0.0001 **
S*R	2	0.26	0.40	0.17	0.60
I*R	2	0.66	0.88	0.78	0.83
S*I	1	0.69	0.19	0.85	0.12
I*S*R	2	0.04 *	0.78	0.35	0.73
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.60	0.12	0.004 **	0.33
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.17	0.84	0.02 *	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.47	0.93	0.95	-
all 0 vs 25 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 50 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 25 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 50 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
C.V. (%)		21.8	19.5	15.8	25.1

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
§ LSD for comparison between rates 0 and 25 is 1160, 0 and 50 is 1188 and 25 and 50 is 1200.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.7. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue chloride concentration for Bedford barley in 1990

Treatment			Plant tissue Cl^- concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	1862	7159	981	1170
KCl	25	-	6419	9495	6327	2351
KCl	50	-	9905	12408	10465	3437
NaCl	0	-	2048	6672	1046	980
NaCl	25	-	6198	9565	6575	2932
NaCl	50	-	8782	12103	12876	4103
KCl	0	+	1976	6669	977	1123
KCl	25	+	4099	11335	6159	2263
KCl	50	+	9422	12254	12271	3453
NaCl	0	+	2400	7151	971	1099
NaCl	25	+	5845	10496	6045	2707
NaCl	50	+	8463	12020	12308	3916
KCl (S)‡	25	-	5896	8287	3796	-
KCl (S)	25	+	5395	9836	4338	-
Group means						
KCl			5614	9886	6197	2299
NaCl			5623	9668	6637	2623
LSD (P=0.05)			ns	ns	ns	ns
	0		2017	6913	994	1093
	25		5640	10223	6277	2563
	50		9143	12196	11980	3727
LSD (P=0.05)			841	1043	612	519
		-	5869	9567	6378	2496
		+	5367	9987	6455	2427
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.15	0.33	0.76	0.75
Source (S)	1	0.98	0.61	0.08	0.13
Rate (R)	2	0.0001 **	0.0001 **	0.0001 **	0.0001 **
S*R	2	0.09	0.93	0.09	0.36
I*R	2	0.18	0.28	0.28	0.93
S*I	1	0.25	0.96	0.07	0.89
I*S*R	2	0.48	0.67	0.13	0.93
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.73	0.53	0.03 *	0.04 *
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.52	0.24	0.0001 **	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.12	0.15	0.003 **	-
all 0 vs 25 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0003 **
all 0 vs 50 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 25 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 50 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
C.V. (%)		25.1	18.3	17.0	36.4

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

plots. Equivalent Cl^- fertilizer treatments had been applied in both plots. Based on observations in the field, differential leaching of soil Cl^- due to differences in soil physical and microtopographical properties did not appear to account for the differences observed between the plots. Differential leaching of Cl^- from plant tissue may be, in part, responsible for the observed differences in Cl^- concentration in plant tissue. Foliar disease in the spot blotch experiment was more severe than in the common root rot experiment and produced higher amounts of necrotic tissue from which Cl^- could have been leached. Also, a higher degree of variability in Cl^- concentration in plant tissue was evident in the spot blotch experiment which suggested that greater foliar losses of Cl^- may have occurred in the spot blotch experiment than in the adjacent common root rot experiment. As mentioned previously, a substantial difference in Cl^- concentration in plant tissue between the common root rot and spot blotch experiments was observed in only the 25 and 50 kg Cl^- ha^{-1} treatments and not in the control treatments. Schumacher (1988) noted greater leaching losses of Cl^- from plant tissue in high Cl^- treatments than in low Cl^- treatments.

In 1990, Cl^- uptake was determined for the common root rot experiments at Carman and Portage and for the spot blotch experiment at Winnipeg. Increasing rates of Cl^- fertilizer significantly increased Cl^- uptake for Bedford barley at all sites (Table 3.8) due to significant increases in the concentration of Cl^- in plant tissue (Table 3.7). At Carman, the addition of inoculum resulted in a significant reduction in Cl^- uptake due to a significant reduction in midseason dry matter yield (Table 3.5). At Portage, Cl^- uptake was significantly lower in NaCl treatments than in KCl treatments due to a significant reduction in midseason dry matter yields in NaCl treatments (Table 3.5).

According to guidelines utilized by the Manitoba Provincial Soil Testing

Table 3.8. Effect of chloride fertilizer and *C. sativus* inoculum on midseason chloride uptake by Bedford barley in 1990

Treatment			Cl^- uptake (kg ha^{-1})		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg†
Treatment means					
KCl	0	-	11.6	37.5	8.7
KCl	25	-	33.1	47.5	17.3
KCl	50	-	55.8	61.8	25.5
NaCl	0	-	12.6	36.2	7.5
NaCl	25	-	36.4	42.4	21.0
NaCl	50	-	55.9	58.0	28.0
KCl	0	+	11.1	35.0	8.5
KCl	25	+	20.1	51.6	15.9
KCl	50	+	48.7	58.2	25.6
NaCl	0	+	12.0	30.7	7.5
NaCl	25	+	30.4	37.5	18.8
NaCl	50	+	47.9	45.3	28.2
KCl (S)‡	25	-	37.8	38.0	-
KCl (S)	25	+	30.7	44.0	-
Group means					
KCl			30.1	48.6	16.9
NaCl			32.5	41.7	18.5
LSD (P=0.05)			ns	6.4	ns
	0		11.8	34.9	8.0
	25		30.0	44.8	18.2
	50		52.1	55.8	26.8
LSD (P=0.05)			6.9	7.9	4.0
		-	34.2	47.2	18.0
		+	28.4	43.1	17.4
LSD (P=0.05)			5.6	ns	ns

ANOVA	df	Pr > F		
Inoculum (I)	1	0.04 *	0.20	0.73
Source (S)	1	0.38	0.04 *	0.33
Rate (R)	2	0.0001 **	0.0001 **	0.0001
S*R	2	0.54	0.65	0.51
I*R	2	0.39	0.62	0.87
S*I	1	0.72	0.28	0.97
I*S*R	2	0.82	0.90	0.99
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.32	0.02 *	0.15
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.47	0.21	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.10	0.30	-
all 0 vs 25 KCl	1	0.0004 **	0.002 **	0.001
all 0 vs 50 KCl	1	0.0001 **	0.0001 **	0.0001
all 0 vs 25 NaCl	1	0.0001 **	0.27	0.0001
all 0 vs 50 NaCl	1	0.0001 **	0.0005 **	0.0001
C.V. (%)		35.2	29.1	39.2

† Chloride uptake determined for the spot blotch experiment at Winnipeg only.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Laboratory, concentrations of K in plant tissue for the whole plant at filling of 1.5% to 3.0% are considered sufficient; concentrations of 3.0 to 5.0% are considered high. Using these criteria, concentrations of K in plant tissue for Bedford barley at all sites were adequate to high regardless of treatment (Tables 3.9 and 3.10). The concentration of K in plant tissue was significantly lower in NaCl treatments than in KCl treatments at Portage in 1989 and at Carman in 1990. Although statistically significant, these differences were small and K concentrations in plant tissue were sufficient to high regardless of the effect of fertilizer source. Sufficient concentrations of K in plant tissue in combination with similar concentrations of K in plant tissue across most treatments indicated a low probability for a K response and added further evidence to the claim that Cl^- was responsible for the fertilizer responses observed. The effects of inoculum and fertilizer rate on K concentrations in plant tissue were not consistent.

Treatment did not have a consistent effect on the concentration of Mn in plant tissue for Bedford barley in 1989 or in 1990 (Tables 3.11 and 3.12). The addition of Cl^- significantly reduced the concentration of Mn in plant tissue at Portage in 1990. The concentration of Mn in plant tissue was not significantly increased by Cl^- application at any site. These results contrasted with the suggestion by Beaton et al. (1988) that Cl^- may enhance uptake of Mn and thereby reduce plant disease and increase yield.

In the common root rot experiments, treatment did not have a significant effect on the concentration of Cu in plant tissue for Bedford barley at any of the 1989 field sites (Table 3.13). In 1990, treatment had a significant effect on Cu concentration in plant tissue in several instances, but the effect of treatment was not consistent across sites (Table 3.14). In the spot blotch experiments, the addition of Cl^- tended to increase the concentration of Cu in plant tissue for Bedford barley in 1989 ($P=0.14$) and in 1990

Table 3.9. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue potassium concentration for Bedford barley in 1989

Treatment			Plant tissue K concentration (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	2.48	3.09	2.90	2.66
KCl	25	-	2.78	3.06	3.20	2.63
KCl	50	-	2.68	3.09	2.86	2.64
NaCl	0	-	2.59	2.75	3.07	2.70
NaCl	25	-	2.52	3.00	2.96	2.59
NaCl	50	-	2.52	2.93	3.03	2.62
KCl	0	+	3.03	3.89	3.01	2.65
KCl	25	+	2.70	3.44	2.99	2.53
KCl	50	+	2.78	3.01	2.84	2.64
NaCl	0	+	2.90	3.03	3.09	2.87
NaCl	25	+	2.68	2.99	2.99	2.63
NaCl	50	+	2.56	3.16	2.84	2.54
KCl (S)‡	25	-	2.81	2.95	2.98	-
KCl (S)	25	+	2.65	2.98	3.06	-
Group means						
KCl			2.74	3.28	2.96	2.62
NaCl			2.63	2.98	3.00	2.66
LSD (P=0.05)			ns	0.23	ns	ns
	0		2.75	3.20	3.02	2.72
	25		2.67	3.13	3.03	2.59
	50		2.63	3.05	2.89	2.61
LSD (P=0.05)			ns	ns	0.12	ns
		-	2.59	2.99	3.00	2.64
		+	2.79	3.27	2.96	2.64
LSD (P=0.05)			0.20	0.23	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.07	0.05 *	0.38	0.95
Source (S)	1	0.30	0.008 **	0.51	0.64
Rate (R)	2	0.60	0.60	0.05 *	0.26
S*R	2	0.76	0.26	0.11	0.56
I*R	2	0.20	0.33	0.31	0.74
S*I	1	0.98	0.26	0.96	0.55
I*S*R	2	0.59	0.35	0.24	0.72
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.18	0.13	0.81	0.87
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.89	0.41	0.06	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.85	0.08	0.53	-
all 0 vs 25 KCl	1	0.90	0.60	0.31	0.17
all 0 vs 50 KCl	1	0.83	0.50	0.02 *	0.42
all 0 vs 25 NaCl	1	0.26	0.12	0.54	0.28
all 0 vs 50 NaCl	1	0.16	0.28	0.27	0.18
C.V. (%)		14.1	14.4	6.8	11.1

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.10. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue potassium concentration for Bedford barley in 1990

Treatment			Plant tissue K concentration (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	2.65	2.98	2.69	3.12
KCl	25	-	2.69	2.91	2.89	3.11
KCl	50	-	2.59	3.08	3.06	2.95
NaCl	0	-	2.62	3.14	3.01	3.20
NaCl	25	-	2.51	2.93	2.89	2.94
NaCl	50	-	2.54	2.88	2.96	3.12
KCl	0	+	2.62	3.13	2.90	3.13
KCl	25	+	2.74	2.99	2.84	3.28
KCl	50	+	2.61	3.05	3.02	3.02
NaCl	0	+	2.66	3.19	2.90	3.06
NaCl	25	+	2.44	3.38	3.11	3.18
NaCl	50	+	2.52	3.09	2.98	3.18
KCl (S)‡	25	-	2.61	3.26	2.82	-
KCl (S)	25	+	2.65	3.19	2.95	-
Group means						
KCl			2.65	3.02	2.90	3.10
NaCl			2.55	3.10	2.98	3.11
LSD (P=0.05)			0.10	ns	ns	ns
	0		2.64	3.11	2.88	3.13
	25		2.59	3.05	2.93	3.13
	50		2.56	3.03	3.00	3.07
LSD (P=0.05)			ns	ns	ns	ns
		-	2.60	2.99	2.92	3.07
		+	2.60	3.14	2.96	3.14
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.92	0.09	0.58	0.45
Source (S)	1	0.04	0.37	0.37	0.90
Rate (R)	2	0.48	0.75	0.41	0.82
S*R	2	0.12	0.42	0.42	0.40
I*R	2	0.99	0.67	0.92	0.49
S*I	1	0.81	0.35	0.98	0.85
I*S*R	2	0.73	0.56	0.32	0.88
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.01	0.57	0.74	0.89
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.46	0.13	0.71	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.44	0.38	0.54	-
all 0 vs 25 KCl	1	0.27	0.26	0.91	0.63
all 0 vs 50 KCl	1	0.62	0.76	0.18	0.29
all 0 vs 25 NaCl	1	0.03	0.72	0.29	0.60
all 0 vs 50 NaCl	1	0.14	0.39	0.43	0.87
C.V. (%)		7.8	12.9	11.3	12.4

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.11. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue manganese concentration for Bedford barley in 1989

Treatment			Plant tissue Mn concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	38.5	41.8	16.9	16.7
KCl	25	-	40.7	30.8	15.7	19.2
KCl	50	-	34.9	31.7	15.1	18.1
NaCl	0	-	35.0	35.6	17.2	16.1
NaCl	25	-	36.1	34.4	15.6	19.9
NaCl	50	-	34.4	37.3	16.1	20.2
KCl	0	+	36.8	33.3	16.8	16.9
KCl	25	+	38.2	33.8	14.7	15.7
KCl	50	+	37.2	38.8	16.7	16.4
NaCl	0	+	36.3	35.5	16.7	18.1
NaCl	25	+	33.2	31.5	15.5	17.7
NaCl	50	+	32.6	40.1	17.7	18.0
KCl (S)‡	25	-	39.6	38.4	14.6	-
KCl (S)	25	+	35.7	34.1	14.6	-
Group means						
KCl			37.7	35.2	16.0	17.2
NaCl			34.7	35.9	16.5	18.3
LSD (P=0.05)			2.1	ns	ns	ns
	0		36.6	36.6	16.9	16.9
	25		37.0	32.7	15.4	18.1
	50		34.9	37.0	16.4	18.2
LSD (P=0.05)			ns	3.7	ns	ns
		-	36.5	35.4	16.1	18.4
		+	35.9	35.6	16.4	17.1
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.29	0.91	0.66	0.18
Source (S)	1	0.01 **	0.68	0.38	0.21
Rate (R)	2	0.12	0.04 *	0.09	0.48
S*R	2	0.44	0.37	0.77	0.79
I*R	2	0.58	0.03	0.25	0.19
S*I	1	0.99	0.80	0.92	0.64
I*S*R	2	0.56	0.17	0.90	0.86
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.04 *	0.37	0.29	0.16
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.77	0.08	0.46	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.39	0.94	0.94	-
all 0 vs 25 KCl	1	0.15	0.08	0.04 *	0.72
all 0 vs 50 KCl	1	0.50	0.47	0.21	0.84
all 0 vs 25 NaCl	1	0.29	0.07	0.10	0.18
all 0 vs 50 NaCl	1	0.11	0.38	0.96	0.13
C.V. (%)		14.2	17.1	14.1	22.1

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.12. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue manganese concentration for Bedford barley in 1990

Treatment			Plant tissue Mn concentration (mg kg^{-1})			
Cl$^-$ source	kg ha^{-1} Cl$^-$ applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	42.0	20.6	12.7	13.4
KCl	25	-	42.4	22.7	12.0	13.6
KCl	50	-	38.8	19.1	11.6	12.7
NaCl	0	-	39.8	23.1	12.8	12.9
NaCl	25	-	38.9	19.3	12.1	13.2
NaCl	50	-	40.2	18.7	12.9	12.3
KCl	0	+	41.2	21.2	12.3	13.4
KCl	25	+	41.4	19.5	11.9	12.6
KCl	50	+	39.2	19.4	12.4	12.3
NaCl	0	+	41.7	21.0	12.8	14.0
NaCl	25	+	38.6	19.3	11.5	13.0
NaCl	50	+	40.8	18.0	13.0	13.3
KCl (S)‡	25	-	39.0	19.2	12.0	-
KCl (S)	25	+	38.2	18.8	12.5	-
Group means						
KCl			40.8	20.4	12.1	13.0
NaCl			40.0	19.9	12.5	13.1
LSD (P=0.05)			ns	ns	ns	ns
	0		41.2	21.5	12.6	13.4
	25		40.3	20.2	11.9	13.1
	50		39.8	18.8	12.4	12.6
LSD (P=0.05)			ns	1.3	0.6	ns
		-	40.4	20.6	12.3	13.0
		+	40.5	19.7	12.3	13.1
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.89	0.14	0.76	0.85
Source (S)	1	0.33	0.33	0.08	0.69
Rate (R)	2	0.38	0.0008 **	0.03 *	0.21
S*R	2	0.08	0.08	0.10	0.89
I*R	2	0.81	0.58	0.46	0.44
S*I	1	0.48	0.88	0.62	0.13
I*S*R	2	0.81	0.07	0.69	0.95
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.43	0.05 *	0.10	0.66
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.11	0.01 **	0.99	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.12	0.62	0.31	-
all 0 vs 25 KCl	1	0.57	0.69	0.05 *	0.53
all 0 vs 50 KCl	1	0.09	0.01 **	0.03 *	0.07
all 0 vs 25 NaCl	1	0.06	0.01 **	0.02 *	0.53
all 0 vs 50 NaCl	1	0.60	0.0005 **	0.36	0.27
C.V. (%)		9.0	12.0	7.7	11.5

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.13. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue copper concentration for Bedford barley in 1989

Treatment			Plant tissue Cu concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	6.39	4.16	7.43	6.31
KCl	25	-	5.41	4.84	6.69	5.50
KCl	50	-	6.11	4.44	7.18	5.55
NaCl	0	-	5.36	4.09	6.62	4.82
NaCl	25	-	4.68	4.32	7.63	6.27
NaCl	50	-	6.66	5.08	8.17	6.53
KCl	0	+	5.40	5.19	7.00	5.79
KCl	25	+	4.99	3.94	6.56	6.10
KCl	50	+	4.15	4.60	6.79	5.92
NaCl	0	+	5.99	4.75	6.37	5.64
NaCl	25	+	5.97	3.96	7.29	5.79
NaCl	50	+	6.36	4.79	6.27	6.89
KCl (S)‡	25	-	5.58	3.81	5.96	-
KCl (S)	25	+	5.35	3.93	7.78	-
Group means						
KCl			5.44	4.53	6.94	5.86
NaCl			5.84	4.53	7.06	5.99
LSD (P=0.05)			ns	ns	ns	ns
	0		5.78	4.59	6.85	5.64
	25		5.27	4.25	7.04	5.91
	50		5.88	4.74	7.10	6.22
LSD (P=0.05)			ns	ns	ns	ns
		-	5.81	4.50	7.29	5.83
		+	5.46	4.55	6.71	6.02
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.28	0.90	0.19	0.42
Source (S)	1	0.19	0.93	0.79	0.58
Rate (R)	2	0.24	0.56	0.89	0.14
S*R	2	0.11	0.63	0.35	0.01 **
I*R	2	0.20	0.26	0.65	0.85
S*I	1	0.007 **	0.97	0.55	0.86
I*S*R	2	0.94	0.77	0.71	0.11
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.08	0.82	0.32	0.04 *
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.97	0.17	0.36	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.60	0.99	0.26	-
all 0 vs 25 KCl	1	0.27	0.73	0.73	0.65
all 0 vs 50 KCl	1	0.25	0.91	0.84	0.79
all 0 vs 25 NaCl	1	0.42	0.40	0.36	0.27
all 0 vs 50 NaCl	1	0.15	0.44	0.58	0.003 **
C.V. (%)		21.4	29.0	26.4	16.7

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.14. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue copper concentration for Bedford barley in 1990

Treatment			Plant tissue Cu concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	4.20	5.65	4.87	5.62
KCl	25	-	4.00	5.42	5.75	6.51
KCl	50	-	4.01	5.21	5.58	6.08
NaCl	0	-	3.73	5.07	5.18	5.32
NaCl	25	-	3.68	4.97	5.30	5.55
NaCl	50	-	3.59	5.54	5.75	5.57
KCl	0	+	3.59	5.55	4.90	5.38
KCl	25	+	3.07	5.46	5.22	5.61
KCl	50	+	3.23	6.22	5.40	5.67
NaCl	0	+	3.36	5.28	4.92	4.99
NaCl	25	+	3.67	5.84	5.36	5.32
NaCl	50	+	3.53	5.75	5.40	5.64
KCl (S)‡	25	-	3.78	5.40	5.44	-
KCl (S)	25	+	3.75	5.99	5.80	-
Group means						
KCl			3.68	5.59	5.28	5.81
NaCl			3.59	5.41	5.32	5.40
LSD (P=0.05)			ns	ns	ns	0.34
	0		3.72	5.39	4.97	5.33
	25		3.60	5.42	5.41	5.75
	50		3.59	5.68	5.53	5.74
LSD (P=0.05)			ns	ns	0.35	ns
		-	3.87	5.31	5.41	5.77
		+	3.41	5.68	5.20	5.44
LSD (P=0.05)			0.30	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.003 **	0.06	0.16	0.05 *
Source (S)	1	0.55	0.36	0.84	0.02 *
Rate (R)	2	0.74	0.41	0.005 **	0.08
S*R	2	0.40	0.67	0.65	0.68
I*R	2	0.98	0.48	0.91	0.63
S*I	1	0.04 *	0.77	0.89	0.31
I*S*R	2	0.63	0.23	0.39	0.64
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.84	0.82	0.82	0.04 *
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.58	0.96	0.36	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.09	0.28	0.09	-
all 0 vs 25 KCl	1	0.44	0.85	0.02 *	0.006 **
all 0 vs 50 KCl	1	0.69	0.26	0.02 *	0.04 *
all 0 vs 25 NaCl	1	0.86	0.94	0.09	0.67
all 0 vs 50 NaCl	1	0.51	0.38	0.005 **	0.29
C.V. (%)		18.7	15.1	11.1	13.0

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

(P=0.08), but the effect was not significant.

Treatment had a significant effect on the concentration of Zn in plant tissue for Bedford barley in several cases, but the effects were not consistent across sites or across years (Tables D.1 and D.2 in Appendix).

The common root rot experiment at Carman in 1989 was the only site where Cl^- fertilization significantly reduced the concentration of NO_3^- in plant tissue (Tables 3.15 and 3.16). At this site, only the higher rate of 50 kg Cl^- ha^{-1} as KCl or NaCl significantly reduced the concentration of NO_3^- in plant tissue harvested at midseason. A significant negative correlation (-0.347 **) between Cl^- and NO_3^- concentrations in plant tissue was observed at this site only (Table 3.17). The application of Cl^- resulted in modest, but statistically insignificant decreases in the concentration of NO_3^- in plant tissue for Bedford barley at Portage in 1989 (P=0.09) and 1990 (P=0.06) and at Carman in 1990 (P=0.11). Cl^- applications did not have a significant effect on the concentration of NO_3^- in plant tissue in the common root rot experiments at Winnipeg in 1989 and 1990. However, in the spot blotch experiment at Winnipeg in 1990, the addition of 50 kg Cl^- ha^{-1} tended (P=0.07) to decrease the concentration of NO_3^- in plant tissue. In a study conducted in North Dakota, Goos et al. (1987a) found that the application of KCl fertilizer significantly reduced NO_3^- concentrations in plant tissue for two cultivars of barley. In general, the magnitude of the reductions observed by Goos et al. (1987a) was greater than that observed in our study. The high rate of KCl (90 kg Cl^- ha^{-1}) used in the North Dakota study was, however, substantially higher than that used in our study (50 kg Cl^- ha^{-1}). In general, in our study, the magnitude of increase in the concentration of plant Cl^- resulting from the addition of Cl^- fertilizers did not appear to affect the probability of significant reductions in NO_3^- concentration in plant tissue. Inoculum did not have a significant

Table 3.15. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue nitrate concentration for Bedford barley in 1989

Treatment			Plant tissue NO_3^- concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	5397	8988	6274	3644
KCl	25	-	4433	6843	6629	4467
KCl	50	-	3858	7475	6371	4032
NaCl	0	-	4467	7394	6833	3434
NaCl	25	-	4169	7571	6664	4332
NaCl	50	-	3361	7333	6650	4336
KCl	0	+	4460	8415	5643	4439
KCl	25	+	4144	6977	6139	3734
KCl	50	+	4147	7589	5969	3826
NaCl	0	+	4042	7650	6958	5142
NaCl	25	+	4142	7483	6733	4768
NaCl	50	+	3104	8205	5841	4163
KCl (S)‡	25	-	4849	8209	6662	-
KCl (S)	25	+	3943	7351	7380	-
Group means						
KCl			4414	7739	6171	4024
NaCl			3903	7612	6607	4362
LSD (P=0.05)			398	ns	ns	ns
	0		4591	8148	6430	4165
	25		4216	7235	6541	4325
	50		3618	7651	6208	4089
LSD (P=0.05)			~485§	ns	ns	ns
		-	4277	7629	6563	4041
		+	4029	7720	6214	4345
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.11	0.81	0.24	0.23
Source (S)	1	0.02 *	0.74	0.15	0.18
Rate (R)	2	0.0002 **	0.09	0.66	0.74
S*R	2	0.28	0.09	0.48	0.95
I*R	2	0.42	0.65	0.86	0.03 *
S*I	1	0.97	0.49	0.66	0.16
I*S*R	2	0.56	0.83	0.73	0.63
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.11	0.30	0.60	0.21
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.22	0.12	0.90	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.67	0.62	0.05 *	-
all 0 vs 25 KCl	1	0.18	0.02 *	0.90	0.86
all 0 vs 50 KCl	1	0.02 *	0.20	0.55	0.53
all 0 vs 25 NaCl	1	0.14	0.20	0.58	0.31
all 0 vs 50 NaCl	1	0.0001 **	0.43	0.67	0.82
C.V. (%)		19.5	17.0	19.8	25.3

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
§ LSD for the comparison between rates of 0 and 25 is 482, 0 and 50 is 487 and 25 and 50 is 492.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.16. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue nitrate concentration for Bedford barley in 1990

Treatment			Plant tissue NO_3^- concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	4450	2824	2544	2055
KCl	25	-	4600	2982	2671	2006
KCl	50	-	4583	1722	2814	1528
NaCl	0	-	5400	2676	2948	1791
NaCl	25	-	5430	1940	2792	2198
NaCl	50	-	4651	3025	2649	1539
KCl	0	+	5267	3056	2817	2138
KCl	25	+	4115	2553	1882	1881
KCl	50	+	3767	2518	2272	1763
NaCl	0	+	5635	3522	2890	1708
NaCl	25	+	4553	2872	2612	1750
NaCl	50	+	4629	1930	2681	1617
KCl (S)‡	25	-	5040	2071	2555	-
KCl (S)	25	+	5815	3030	3006	-
Group means						
KCl			4464	2609	2500	1895
NaCl			5050	2661	2762	1767
LSD (P=0.05)			ns	ns	ns	ns
	0		5188	3020	2800	1923
	25		4675	2587	2489	1959
	50		4408	2299	2604	1612
LSD (P=0.05)			ns	ns	ns	ns
		-	4852	2528	2736	1853
		+	4661	2742	2526	1810
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.53	0.38	0.35	0.74
Source (S)	1	0.06	0.83	0.24	0.34
Rate (R)	2	0.11	0.06	0.52	0.07
S*R	2	0.96	0.46	0.85	0.48
I*R	2	0.23	0.51	0.55	0.39
S*I	1	0.92	0.95	0.53	0.42
I*S*R	2	0.60	0.02 *	0.62	0.96
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.13	0.99	0.30	0.91
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.54	0.15	0.83	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.02 *	0.44	0.04 *	-
all 0 vs 25 KCl	1	0.06	0.51	0.11	0.92
all 0 vs 50 KCl	1	0.03 *	0.02 *	0.43	0.17
all 0 vs 25 NaCl	1	0.66	0.11	0.76	0.80
all 0 vs 50 NaCl	1	0.22	0.16	0.68	0.09
C.V. (%)		25.8	40.9	34.4	30.6

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.17. Correlation coefficient for the relationship between midseason plant tissue concentrations of nitrate and chloride for Bedford barley

Site	r	
	1989	1990
Carman	-0.347 **	-0.068 ns
Portage	-0.195 ns	0.136 ns
Winnipeg (Common root rot)	-0.096 ns	-0.080 ns
Winnipeg (Spot blotch)	-0.007 ns	-0.078 ns

** Significant at the 0.01 level.

effect on the concentration of NO_3^- in plant tissue. The effect of Cl^- source on the concentration of NO_3^- in plant tissue was not consistent. Caution must be exercised in the interpretation of these data, however, due to the high degree of variability in NO_3^- concentrations in plant tissue which occurred at all sites.

As was the trend in Cl^- concentrations in plant tissue, in both 1989 and 1990, NO_3^- concentrations in plant tissue of samples taken from the spot blotch experiment were substantially lower than NO_3^- concentrations in plant tissue of samples taken at the same stage of plant development from a common root rot experiment located immediately adjacent. According to analysis of soil samples collected in the spring immediately prior to plot establishment, soil NO_3^- content to 120 cm was similar in both plots. Equivalent N fertilizer treatments were applied to both plots. Differences in the concentration of NO_3^- in plant tissue may be attributable, in part, to differential leaching of NO_3^- from plant tissue as appeared to have been the case for Cl^-.

No treatments had consistent effects on the concentration of NH_4^+ in plant tissue for barley in 1989 or in 1990 (Tables D.3 and D.4 in Appendix).

Total N concentration in plant tissue at midseason was determined in 1990 for non-inoculated subplots treated with 0 Cl^-, 50 kg Cl^- ha^{-1} as KCl and 50 kg Cl^- ha^{-1} as

NaCl. The addition of 50 kg Cl^- ha^{-1} did not have a consistent effect on total N concentration in plant tissue for barley in 1990 (Table D.5 in Appendix).

Common Root Rot and Spot Blotch Ratings at the Soft Dough Stage

The addition of Cl^- significantly reduced common root rot disease severity of Bedford barley at Winnipeg in 1989 and at Carman in 1990 (Tables 3.18 and 3.19). Cl^- application caused small, statistically insignificant decreases in common root rot severity at Carman in 1989 (P=0.08) and at Portage in 1989 (P=0.09). There was little or no difference in common root rot severity between the 25 and 50 kg Cl^- ha^{-1} treatments. In studies conducted in North Dakota, Cl^- produced similarly small reductions in the severity of common root rot of barley at three of five sites (Timm et al. 1986). In our study, the observed decreases by Cl^- in the severity common root rot were associated with statistically significant or small, statistically insignificant reductions in the concentration of NO_3^- in plant tissue at three of the four sites. Simple coefficients of determination did not indicate a strong, consistent relationship between common root rot severity and either of Cl^- or NO_3^- concentrations in plant tissue harvested at midseason (Table 3.20). In studies conducted in North Dakota, Goos et al. (1987a) found that common root rot severity was more closely related to NO_3^- concentration in plant tissue than to Cl^- concentration in plant tissue. He concluded from this that Cl^- indirectly reduced common root rot severity by decreasing NO_3^- concentrations in plant tissue.

C. sativus inoculum significantly decreased common root rot disease severity of Bedford barley at Carman in 1989 and at Winnipeg in 1989. These reductions in common root rot severity were unexpected, particularly at Carman in 1989. At the Carman site, reductions in plant density early in the season were thought to have been

Table 3.18. Effect of chloride fertilizer and *C. sativus* inoculum on common root rot severity for Bedford barley in 1989

Treatment			Common root rot disease rating †		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg
Treatment means					
KCl	0	-	2.46	2.27	2.65
KCl	25	-	2.48	2.15	2.51
KCl	50	-	2.55	2.05	2.65
NaCl	0	-	2.61	2.37	2.90
NaCl	25	-	2.45	1.95	2.63
NaCl	50	-	2.49	2.30	2.62
KCl	0	+	2.63	2.33	2.49
KCl	25	+	2.21	2.12	2.17
KCl	50	+	2.30	2.11	2.02
NaCl	0	+	2.41	2.05	2.15
NaCl	25	+	2.22	2.22	2.13
NaCl	50	+	2.25	2.04	2.08
KCl (S)‡	25	-	2.49	2.29	2.62
KCl (S)	25	+	2.41	2.13	2.07
Group means					
KCl			2.44	2.17	2.42
NaCl			2.41	2.15	2.42
LSD (P=0.05)			ns	ns	ns
	0		2.53	2.25	2.55
	25		2.34	2.11	2.36
	50		2.40	2.13	2.34
LSD (P=0.05)			ns	ns	0.17
		-	2.51	2.18	2.66
		+	2.34	2.14	2.17
LSD (P=0.05)			0.14	ns	0.14

ANOVA	df	Pr > F		
Inoculum (I)	1	0.02 *	0.50	0.0001 **
Source (S)	1	0.55	0.77	0.96
Rate (R)	2	0.08	0.09	0.04 *
S*R	2	0.96	0.41	0.87
I*R	2	0.28	0.16	0.61
S*I	1	0.40	0.26	0.12
I*S*R	2	0.38	0.04 *	0.14
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.62	0.75	0.74
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.93	0.29	0.54
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.24	0.96	0.54
all 0 vs 25 KCl	1	0.10	0.16	0.06
all 0 vs 50 KCl	1	0.34	0.04 *	0.05 *
all 0 vs 25 NaCl	1	0.06	0.05 *	0.12
all 0 vs 50 NaCl	1	0.14	0.32	0.07
C.V. (%)		11.5	10.9	12.3

† Disease classes based on severity of lesions on subcrown internode: 1=clean 2=slight 3=moderate 4=severe (Ledingham et al., 1973)
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.19. Effect of chloride fertilizer and *C. sativus* inoculum on common root rot severity for Bedford barley in 1990

Treatment			Common root rot disease rating †		
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg
Treatment means					
KCl	0	-	2.48	3.16	3.44
KCl	25	-	2.49	3.09	3.55
KCl	50	-	2.20	3.21	3.46
NaCl	0	-	2.63	3.17	3.40
NaCl	25	-	2.29	3.14	3.36
NaCl	50	-	2.23	3.13	3.42
KCl	0	+	2.45	3.05	3.71
KCl	25	+	2.24	3.06	3.54
KCl	50	+	2.47	3.11	3.63
NaCl	0	+	2.62	3.09	3.70
NaCl	25	+	2.45	3.08	3.44
NaCl	50	+	2.37	3.13	3.62
KCl (S)‡	25	-	2.33	3.15	3.61
KCl (S)	25	+	2.53	2.92	3.53
Group means					
KCl			2.39	3.11	3.55
NaCl			2.43	3.12	3.49
LSD (P=0.05)			ns	ns	ns
	0		2.55	3.12	3.56
	25		2.37	3.09	3.47
	50		2.32	3.15	3.53
LSD (P=0.05)			0.15	ns	ns
		-	2.39	3.15	3.44
		+	2.43	3.09	3.61
LSD (P=0.05)			ns	ns	0.08

ANOVA	df	Pr > F		
Inoculum (I)	1	0.43	0.15	0.0001 **
Source (S)	1	0.49	0.80	0.10
Rate (R)	2	0.009 **	0.60	0.15
S*R	2	0.41	0.82	0.35
I*R	2	0.21	0.88	0.03 *
S*I	1	0.42	0.68	0.51
I*S*R	2	0.17	0.85	0.95
Contrasts				
KCl vs NaCl at 25 and 50 Cl	1	0.84	0.95	0.09
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.28	0.62	0.53
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.05 *	0.20	0.89
all 0 vs 25 KCl	1	0.05 *	0.55	0.75
all 0 vs 50 KCl	1	0.02 *	0.52	0.79
all 0 vs 25 NaCl	1	0.06	0.92	0.008 **
all 0 vs 50 NaCl	1	0.008 **	0.80	0.48
C.V. (%)		10.5	6.0	4.7

† Disease classes based on severity of lesions on subcrown internode: 1=clean 2=slight 3=moderate 4=severe (Ledingham et al., 1973)
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.20. Relationship between common root rot severity and midseason plant tissue nitrate and chloride concentrations for Bedford barley

Site	Simple r^2			
	Plant tissue Cl^-		Plant tissue NO_3^-	
	1989	1990	1989	1990
Carman	0.020 ns	0.154 **	0.018 ns	0.017 ns
Portage	0.092 **	0.008 ns	0.007 ns	0.009 ns
Winnipeg	0.046 ns	0.001 ns	0.075 *	0.123 **

*,** Significant at the 0.05 and 0.01 levels respectively.

the result of seedling blight; Pua et al. (1985) found a high correlation between seedling blight intensity and common root rot intensity in barley. The unexpected reduction in common root rot severity observed in our study indicated that, although the introduced strains of *C. sativus* applied as inoculum may have been capable of producing seedling blight early in the season at Carman, they were less effective than the indigenous strains in causing common root rot later in the growing season. The significant reduction in common root rot by inoculum also indicated that the less virulent, introduced strains of *C. sativus* may have outcompeted the more virulent, indigenous populations of *C. sativus* for at least part of the growing season thereby depressing common root rot severity.

Changes to the method by which inoculum was produced appeared to have resulted in a more virulent common root rot inoculum in 1990. *C. sativus* inoculum significantly increased common root rot severity of Bedford barley at Winnipeg in 1990 although it did not have a significant effect on plant density earlier in the season. At this site only, a significant inoculum × rate interaction occurred. The application of Cl^- resulted in a decrease in the severity of common root rot in the inoculated treatments, but not in the non-inoculated treatments. However, in the inoculated treatments at this site, only the 25 kg Cl^- ha^{-1} treatment applied as NaCl resulted in a common root rot

rating significantly lower than the control treatment. Inoculum did not have a significant effect on common root rot disease severity of Bedford barley at Portage or Carman in 1990.

The effect of fertilizer source on common root rot severity was not significant at any of the sites.

In the spot blotch studies conducted at Winnipeg, the addition of Cl^- did not produce a visible reduction in spot blotch of Bedford barley in either 1989 or 1990. The severity of disease was very high in both years, however, and may have masked the effects of Cl^-. In studies conducted in North Dakota, Timm et al. (1986) observed visible reductions in the severity of spot blotch in barley at only one of five experimental sites.

Yields and Grain Quality at Maturity

Significant increases by Cl^- in the grain yield of Bedford barley were observed at only two sites. In 1989 at Winnipeg, the application of 50 kg Cl^- ha^{-1} significantly increased grain yield of Bedford barley in the spot blotch experiment, but not in the adjacent common root rot experiment (Table 3.21); in 1990, Cl^- applications significantly increased grain yield of Bedford barley in the common root rot experiment but not in the adjacent spot blotch experiment (Table 3.22). None of the measurements taken during the course of these experiments indicated the reason for yield responses in one plot but not in another plot 10 m away. Yield increases were not related to a reduction in the severity of the plant disease being monitored at either of the sites. In the common root rot and spot blotch experiments conducted at Winnipeg in 1989 and 1990, the Cl^- concentration in plant tissue for the control treatments was less than the critical concentration of 1500 μg Cl^- g^{-1} dry weight established for spring wheat by Fixen et al.

Table 3.21. Effect of chloride fertilizer and *C. sativus* inoculum on grain yield for Bedford barley in 1989

Treatment			Grain yield (kg ha^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	2907	4478	4799	4315
KCl	25	-	2970	4022	4760	4212
KCl	50	-	3348	4413	4295	4352
NaCl	0	-	3173	4242	4613	4465
NaCl	25	-	3096	4521	4880	3995
NaCl	50	-	2728	5136	4897	4845
KCl	0	+	2646	4252	4335	4408
KCl	25	+	3012	4314	4614	4533
KCl	50	+	3060	4608	4704	4829
NaCl	0	+	2706	4319	4624	4242
NaCl	25	+	2864	4280	4688	4240
NaCl	50	+	2935	4319	4451	4591
KCl (S)‡	25	-	2857	4340	4166	-
KCl (S)	25	+	3183	3334	4471	-
Group means						
KCl			2989	4348	4585	4441
NaCl			2910	4469	4692	4396
LSD (P=0.05)			ns	ns	ns	ns
	0		2858	4323	4593	4357
	25		2981	4284	4736	4245
	50		3014	4619	4587	4654
LSD (P=0.05)			ns	ns	ns	283
		-	3037	4469	4707	4364
		+	2861	4348	4569	4474
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.25	0.45	0.17	0.34
Source (S)	1	0.69	0.44	0.29	0.70
Rate (R)	2	0.51	0.18	0.39	0.02 *
S*R	2	0.34	0.65	0.88	0.39
I*R	2	0.47	0.67	0.68	0.47
S*I	1	0.84	0.19	0.48	0.11
I*S*R	2	0.30	0.24	0.03 *	0.51
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.34	0.23	0.27	0.65
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.75	0.40	0.02 *	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.56	0.01 **	0.56	-
all 0 vs 25 KCl	1	0.50	0.50	0.53	0.93
all 0 vs 50 KCl	1	0.09	0.41	0.53	0.18
all 0 vs 25 NaCl	1	0.54	0.73	0.20	0.17
all 0 vs 50 NaCl	1	0.86	0.08	0.58	0.04 *
C.V. (%)		17.1	14.9	9.1	11.1

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.22 Effect of chloride fertilizer and *C. sativus* inoculum on grain yield for Bedford barley in 1990

Treatment			Grain yield (kg ha^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	4325	4949	5500	6269
KCl	25	-	4408	5197	5770	6271
KCl	50	-	3971	5110	6286	6507
NaCl	0	-	3975	5227	5714	6107
NaCl	25	-	3896	5180	5747	6429
NaCl	50	-	4639	5482	6217	6202
KCl	0	+	4300	5076	5181	5867
KCl	25	+	4768	5142	5728	6034
KCl	50	+	4376	4999	5668	6062
NaCl	0	+	4516	5004	5393	6169
NaCl	25	+	4234	4930	5275	6272
NaCl	50	+	4376	4786	5575	6327
KCl (S)‡	25	-	4246	5262	5745	-
KCl (S)	25	+	3835	4855	5293	-
Group means						
KCl			4358	5079	5689	6168
NaCl			4273	5102	5653	6251
LSD (P=0.05)			ns	ns	ns	ns
	0		4279	5064	5447	6103
	25		4326	5112	5630	6251
	50		4340	5094	5936	6275
LSD (P=0.05)			ns	ns	252	ns
		-	4202	5191	5872	6297
		+	4428	4990	5470	6122
LSD (P=0.05)			ns	ns	206	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.18	0.11	0.002 **	0.07
Source (S)	1	0.61	0.86	0.73	0.39
Rate (R)	2	0.95	0.95	0.001 **	0.29
S*R	2	0.12	0.74	0.20	0.65
I*R	2	0.78	0.50	0.29	0.99
S*I	1	0.90	0.14	0.46	0.06
I*S*R	2	0.32	0.81	0.63	0.55
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.63	0.91	0.22	0.45
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.68	0.83	0.92	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.02 *	0.34	0.10	-
all 0 vs 25 KCl	1	0.20	0.57	0.06	0.73
all 0 vs 50 KCl	1	0.66	0.96	0.001 **	0.21
all 0 vs 25 NaCl	1	0.37	0.96	0.69	0.09
all 0 vs 50 NaCl	1	0.34	0.70	0.006 **	0.26
C.V. (%)		15.8	10.1	7.9	6.5

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

(1986a). As stated previously, soil Cl^- concentrations were similar in both plots. In both 1989 and 1990, soil tested well below the 66 kg Cl^- ha^{-1} (to 60 cm) critical level recommended in current South Dakota soil test guidelines (Fixen et al. 1987). Equivalent rates of Cl^- were applied to both plots. Cl^- additions did not have a significant effect on grain yield for Bedford barley in the remaining five common root rot experiments conducted even though the application of Cl^- had significantly reduced or tended to reduce the severity of common root rot in four of these five trials - at Winnipeg in 1989, at Carman in 1989 and 1990 and at Portage in 1989 (Tables 3.18 and 3.19). Observed reductions in the severity of common root rot were very small, however, and likely not of agronomic significance. At the spot blotch site in 1990, Cl^- applications did not have a visible effect on spot blotch severity and did not produce a significant increase in grain yield. The lack of a relationship between the effect of Cl^- on plant disease and the effect of Cl^- on grain yield was similar to the results of studies conducted in North Dakota. In North Dakota, Cl^- applications have significantly reduced the severity of common root rot but have seldom significantly increased yield as a result (Timm et al. 1986; Goos et al. 1987a, 1989). Similarly, in studies conducted in North Dakota, Cl^- applications resulted in a visible reduction in spot blotch at one of five sites; however, a significant increase in grain yield did not result (Timm et al. 1986).

In our study, the effect of Cl^- source on grain yield was not significant at any of the sites despite significant reductions in early season plant density by NaCl applications at certain field sites. Plants appeared to have compensated for the deleterious effects of Na^+ observed earlier in the season. *C. sativus* inoculum significantly reduced the grain yield for Bedford barley at Winnipeg in 1990, apparently as a result of an increase in common root rot severity rather than a decrease in plant stand. Although inoculum

significantly reduced plant density at Carman in 1989, a resultant decrease in grain yield did not occur at this site. At Carman in 1989, the potentially deleterious effects of reductions in plant stand on grain yield may have been compensated for, at least in part, by a significant reduction in common root rot severity where inoculum had been applied. No other significant effects of inoculum on grain yield were observed for Bedford barley.

The application of Cl^- fertilizer did not have a consistent effect on straw yield of Bedford barley in 1989 or in 1990 (Tables D.5 and D.6 in Appendix). At Winnipeg in 1990, Cl^- significantly increased grain yield only, not straw yield, in the common root rot experiment, but significantly increased straw yield only, not grain yield, in the adjacent spot blotch experiment. Inoculum and fertilizer source did not have a significant effect on straw yield for Bedford barley at any sites in 1989 or in 1990.

Treatment did not have a significant effect on thousand kernel weight for Bedford barley in 1989 (Table 3.23). Cl^- significantly increased thousand kernel weight for Bedford barley in both field experiments at Winnipeg in 1990 (Table 3.24). Although statistically significant, increases were small and did not result in an accompanying significant increase in grain yield in the spot blotch experiment. However, the small increase in thousand kernel weight may have contributed to the significant increase in grain yield observed in the common root rot experiment at Winnipeg. Inoculum significantly increased thousand kernel weight for Bedford barley at Carman in 1990, likely in response to the reduction in plant stand caused by inoculum early in the season. Inoculum caused a slight but significant decrease in thousand kernel weight at Winnipeg in 1990 likely due to the significant increase in common root rot severity caused by the application of inoculum at this site (Table 3.19).

Treatment had inconsistent effects on the hectolitre weight of Bedford barley in

Table 3.23. Effect of chloride fertilizer and *C. sativus* inoculum on thousand kernel weight for Bedford barley in 1989

Treatment			Thousand kernel weight (g/1000 kernels)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	30.3	29.5	35.7	34.3
KCl	25	-	30.1	29.5	35.0	33.8
KCl	50	-	30.2	29.1	34.7	35.1
NaCl	0	-	29.8	29.1	34.9	34.7
NaCl	25	-	29.4	28.9	34.5	35.0
NaCl	50	-	29.1	30.7	35.4	34.2
KCl	0	+	29.6	28.2	34.5	33.4
KCl	25	+	30.1	30.6	33.6	35.3
KCl	50	+	30.4	29.8	36.6	35.0
NaCl	0	+	28.6	28.8	35.3	34.8
NaCl	25	+	28.9	29.2	34.9	33.5
NaCl	50	+	29.9	29.1	34.7	34.8
KCl (S)‡	25	-	29.5	29.5	33.9	-
KCl (S)	25	+	30.4	28.9	34.9	-
Group means						
KCl			30.1	29.5	35.0	34.5
NaCl			29.2	29.3	34.9	34.5
LSD (P=0.05)			ns	ns	ns	ns
	0		29.6	28.9	35.1	34.3
	25		29.6	29.6	34.5	34.4
	50		29.9	29.7	35.3	34.8
LSD (P=0.05)			ns	ns	ns	ns
		-	29.8	29.5	35.0	34.5
		+	29.5	29.3	34.9	4.5
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.63	0.56	0.76	0.91
Source (S)	1	0.15	0.74	0.83	0.93
Rate (R)	2	0.91	0.13	0.13	0.53
S*R	2	0.97	0.27	0.50	0.19
I*R	2	0.64	0.13	0.38	0.75
S*I	1	1.00	0.32	0.75	0.49
I*S*R	2	0.90	0.11	0.02 *	0.04 *
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.21	0.55	0.82	0.33
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.56	1.00	0.20	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.84	0.04 *	0.12	-
all 0 vs 25 KCl	1	0.43	0.02 *	0.11	0.64
all 0 vs 50 KCl	1	0.42	0.25	0.27	0.17
all 0 vs 25 NaCl	1	0.60	0.60	0.43	0.92
all 0 vs 50 NaCl	1	0.98	0.06	0.93	0.73
C.V. (%)		7.5	4.7	4.0	4.4

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.24. Effect of chloride fertilizer and *C. sativus* inoculum on thousand kernel weight for Bedford barley in 1990

Treatment			Thousand kernel weight (g per 1000 kernels)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	33.0	34.9	38.7	38.4
KCl	25	-	34.1	35.7	40.1	40.2
KCl	50	-	31.8	36.2	39.4	40.0
NaCl	0	-	32.2	35.3	39.2	38.5
NaCl	25	-	32.2	36.5	40.1	40.0
NaCl	50	-	32.5	36.6	41.0	40.3
KCl	0	+	32.6	36.0	38.2	39.0
KCl	25	+	34.9	36.0	38.7	40.4
KCl	50	+	32.7	36.0	39.7	40.1
NaCl	0	+	34.0	36.1	38.9	38.0
NaCl	25	+	34.7	36.4	39.8	39.5
NaCl	50	+	33.2	36.3	40.0	40.2
KCl (S)‡	25	-	34.7	37.2	39.6	-
KCl (S)	25	+	33.0	37.1	37.6	-
Group means						
KCl			33.2	35.8	39.1	39.7
NaCl			33.1	36.2	39.8	39.4
LSD (P=0.05)			ns	ns	0.5	ns
	0		32.9	35.6	38.8	38.5
	25		33.9	36.2	39.7	40.0
	50		32.5	36.3	40.0	40.1
LSD (P=0.05)			ns	ns	0.6	0.6
		-	32.6	35.6	39.8	39.5
		+	33.7	36.2	39.2	39.5
LSD (P=0.05)			1.0	ns	0.5	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.05 *	0.37	0.02 *	0.99
Source (S)	1	0.90	0.20	0.005 **	0.26
Rate (R)	2	0.07	0.17	0.0002 **	0.0001 **
S*R	2	0.38	0.92	0.74	0.39
I*R	2	0.69	0.27	0.59	0.91
S*I	1	0.23	0.64	1.00	0.14
I*S*R	2	0.59	0.99	0.15	0.77
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.67	0.19	0.01 **	0.52
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.62	0.04 *	0.35	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.12	0.17	0.07	-
all 0 vs 25 KCl	1	0.04 *	0.50	0.09	0.0001 **
all 0 vs 50 KCl	1	0.37	0.27	0.04 *	0.0001 **
all 0 vs 25 NaCl	1	0.51	0.05 *	0.002 **	0.001 **
all 0 vs 50 NaCl	1	0.88	0.05 *	0.0001 **	0.0001 **
C.V. (%)		6.3	3.5	2.6	2.6

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

1989 and 1990 (Tables D.7 and D.8 in Appendix). The addition of Cl^- significantly decreased hectolitre weight of Bedford barley at Carman in 1990 and at Winnipeg in 1989 and 1990. Although statistically significant, the effects of Cl^- on hectolitre weight were small and not, in themselves, of agronomic significance. Neither did these significant effects of fertilizer rate appear to influence grain yield.

Treatment had inconsistent effects on the percentage of plump and thin kernels in Bedford barley in both 1989 and 1990 (Tables 3.25 and 3.26; Tables D.9 and D.10 in Appendix). In the spot blotch experiment in 1990, however, inoculum tended to decrease the percentage of plump kernels ($P=0.09$). This, in combination with a slight, statistically insignificant ($P=0.07$) reduction in grain yield with the addition of spot blotch inoculum, indicated that inoculum may have increased the severity of foliar disease and, in doing so, affected grain fill. The application of Cl^- was not found to have a consistent and significant effect on the percentage of plump and thin kernels. In contrast, Zubrinski et al. (1970) found that the addition of KCl to soils containing adequate amounts of K significantly increased the percentage of plump kernels in malting barley.

Total N concentration in grain was determined for selected treatments in 1990 (Table 3.27). The application of 50 kg Cl^- ha^{-1} resulted in small, statistically insignificant reductions in total N concentration in grain for the common root rot experiment at Portage ($P=0.06$) and for the spot blotch experiment at Winnipeg ($P=0.14$). At both sites, small, statistically insignificant reductions by Cl^- in NO_3^- concentrations in plant tissue harvested at midseason (Table 3.16) may have contributed to the small reductions in total N concentration in grain observed at maturity. Cl^- applications had also been found to result in a small, statistically insignificant reduction in the total N concentration in plant tissue harvested at midseason in the spot blotch experiment at Winnipeg

Table 3.25. Effect of chloride fertilizer and *C. sativus* inoculum on percent plump kernels for Bedford barley in 1989

Treatment			Plump kernels (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	8.0	10.3	60.8	55.8
KCl	25	-	5.6	9.5	55.9	51.9
KCl	50	-	8.2	8.6	53.1	57.0
NaCl	0	-	5.9	10.8	59.6	58.6
NaCl	25	-	5.7	10.4	54.7	49.5
NaCl	50	-	5.5	11.6	57.9	51.8
KCl	0	+	4.9	6.6	56.8	49.8
KCl	25	+	7.2	12.4	50.9	56.8
KCl	50	+	5.2	8.9	58.1	55.2
NaCl	0	+	4.5	8.6	57.3	56.4
NaCl	25	+	4.4	7.6	53.3	48.5
NaCl	50	+	6.0	8.0	51.1	51.5
KCl (S)‡	25	-	5.7	8.7	45.8	-
KCl (S)	25	+	6.1	10.7	51.4	-
Group means						
KCl			6.6	9.4	55.9	54.4
NaCl			5.3	9.6	55.6	52.7
LSD (P=0.05)			ns	ns	ns	ns
	0		5.8	9.2	58.6	55.1
	25		5.7	10.0	53.7	51.7
	50		6.3	9.2	55.0	53.9
LSD (P=0.05)			ns	ns	3.9	ns
		-	6.5	10.2	57.0	54.1
		+	5.3	8.7	54.6	53.0
LSD (P=0.05)			ns	1.4	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.08	0.04 *	0.14	0.49
Source (S)	1	0.14	0.81	0.85	0.27
Rate (R)	2	0.83	0.50	0.04 *	0.17
S*R	2	0.86	0.15	0.91	0.01 **
I*R	2	0.43	0.21	0.80	0.26
S*I	1	0.57	0.05 *	0.51	0.96
I*S*R	2	0.17	0.14	0.11	0.38
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.31	0.65	0.89	0.01 **
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.93	0.59	0.01 **	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.51	0.30	0.90	-
all 0 vs 25 KCl	1	0.42	0.07	0.03 *	0.73
all 0 vs 50 KCl	1	0.44	0.66	0.20	0.68
all 0 vs 25 NaCl	1	0.67	0.99	0.05 *	0.009 **
all 0 vs 50 NaCl	1	0.77	0.50	0.08	0.13
C.V. (%)		48.7	28.4	12.0	11.8

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.26. Effect of chloride fertilizer and *C. sativus* inoculum on percent plump kernels for Bedford barley in 1990

Treatment			Plump kernels (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	39.1	52.6	74.1	71.4
KCl	25	-	40.1	56.1	76.6	71.7
KCl	50	-	29.3	55.2	73.9	71.7
NaCl	0	-	36.8	54.1	74.7	71.9
NaCl	25	-	31.1	60.8	75.1	72.7
NaCl	50	-	31.9	60.1	79.9	74.5
KCl	0	+	35.9	58.3	67.8	69.2
KCl	25	+	46.3	56.7	70.9	71.7
KCl	50	+	33.5	56.2	70.3	71.4
NaCl	0	+	42.3	57.1	70.7	68.3
NaCl	25	+	41.9	56.6	70.8	70.1
NaCl	50	+	34.4	55.1	73.4	72.7
KCl (S)‡	25	-	41.6	65.1	71.3	-
KCl (S)	25	+	35.1	60.3	61.5	-
Group means						
KCl			37.4	55.8	72.3	71.2
NaCl			36.4	57.3	74.1	71.7
LSD (P=0.05)			ns	ns	ns	ns
	0		38.5	55.5	71.8	70.2
	25		39.8	57.6	73.4	71.6
	50		32.2	56.7	74.4	72.6
LSD (P=0.05)			ns	ns	ns	ns
		-	34.7	56.5	75.7	72.3
		+	39.2	56.7	70.6	70.6
LSD (P=0.05)			ns	ns	2.1	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.12	0.91	0.0001 **	0.09
Source (S)	1	0.71	0.37	0.09	0.61
Rate (R)	2	0.06	0.60	0.16	0.17
S*R	2	0.34	0.85	0.13	0.57
I*R	2	0.52	0.20	1.00	0.72
S*I	1	0.49	0.18	0.89	0.36
I*S*R	2	0.72	0.92	0.57	0.97
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.45	0.26	0.19	0.49
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.82	0.02 *	0.07	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.09	0.33	0.002 **	-
all 0 vs 25 KCl	1	0.25	0.70	0.28	0.33
all 0 vs 50 KCl	1	0.08	0.94	0.89	0.39
all 0 vs 25 NaCl	1	0.62	0.17	0.51	0.44
all 0 vs 50 NaCl	1	0.19	0.36	0.008 **	0.03 *
C.V. (%)		30.5	11.1	6.9	6.0

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

(P=0.09) (Table D.18 in Appendix).

Table 3.27. Effect of chloride fertilizer and *C. sativus* inoculum on total nitrogen concentration of grain for Bedford barley in 1990

Treatment			Total N concentration in grain (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	2.08	2.09	2.16	2.12
KCl	50	-	2.12	2.03	2.16	2.08
NaCl	50	-	2.11	2.01	2.25	2.07

ANOVA	df	Pr > F			
Fertilizer treatment	2	0.77	0.14	0.15	0.29
Contrasts					
0 vs 50 Cl^- as KCl or NaCl	1	0.49	0.06	0.32	0.14
0 vs 50 Cl^- as KCl	1	0.49	0.13	0.97	0.26
0 vs 50 Cl^- as NaCl	1	0.61	0.06	0.09	0.14
KCl vs NaCl	1	0.86	0.67	0.09	0.68
C.V. (%)		4.6	2.9	3.9	2.9

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
*, ** Significant at the 0.05 and 0.01 levels respectively.

3.3.2 Wheat

Early Season Plant Density

C. sativus inoculum significantly reduced plant density for Katepwa wheat at all field sites in 1989 and 1990 (Table 3.28). Reductions in plant stand may have been the result of seedling blight induced by *C. sativus* inoculum. Inoculum more consistently produced significant reductions in plant density for wheat than for barley (Table 3.3 and 3.4). Rates of 25 and 50 kg Cl^- ha^{-1} as NaCl significantly reduced plant density of Katepwa wheat at Carman and Portage in 1990 (Table 3.28). The effect may have been, in part, the result of restricted emergence. Applied Na^+ adversely affected soil structure which consequently resulted in visible crusting of the soil surface. KCl had no consistent effects on plant stand.

Table 3.28. Effect of chloride fertilizer and *C. sativus* inoculum on plant density for Katepwa wheat in 1989 and 1990

Treatment			Plant density (number of plants per 1m row) †			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment Means						
KCl	0	-	42.5	48.3	43.8	48.3
KCl	25	-	43.2	52.5	37.5	43.7
KCl	50	-	42.3	52.8	46.5	42.0
NaCl	0	-	43.3	44.2	45.5	48.7
NaCl	25	-	41.2	50.5	41.8	45.3
NaCl	50	-	41.5	50.3	42.3	40.3
KCl	0	+	25.8	40.7	40.3	39.2
KCl	25	+	28.8	45.0	37.5	37.5
KCl	50	+	31.2	34.7	37.0	36.8
NaCl	0	+	27.3	34.5	40.3	38.0
NaCl	25	+	27.3	35.3	33.7	31.8
NaCl	50	+	27.5	39.2	34.2	33.8
KCl (S)‡	25	-	41.5	53.0	45.7	44.5
KCl (S)	25	+	26.7	34.5	38.7	41.5
Group Means						
KCl			35.6	45.7	40.4	41.3
NaCl			34.7	42.3	39.6	39.7
LSD (P=0.05)			ns	ns	ns	ns
	0		34.8	41.9	42.5	43.5
	25		35.1	45.8	37.6	39.6
	50		35.6	44.3	40.0	38.3
LSD (P=0.05)			ns	ns	3.4	2.6
		-	42.3	49.8	42.9	44.7
		+	28.0	38.2	37.2	36.2
LSD (P=0.05)			2.9	4.2	2.8	2.1

ANOVA	df	Pr > F			
Inoculum (I)	1	0.0001 **	0.0001 **	0.0001**	0.0001 **
Source (S)	1	0.51	0.12	0.56	0.14
Rate (R)	2	0.88	0.32	0.02 *	0.0003 **
S*R	2	0.58	0.35	0.39	0.73
I*R	2	0.57	0.51	0.30	0.20
S*I	1	0.85	0.83	0.31	0.11
I*S*R	2	0.85	0.37	0.37	0.42
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.27	0.34	0.34	0.14
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.64	0.92	0.02 *	0.77
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.55	0.04 *	0.73	0.17
all 0 vs 25 KCl	1	0.57	0.03 *	0.02 *	0.10
all 0 vs 50 KCl	1	0.36	0.56	0.72	0.02 *
all 0 vs 25 NaCl	1	0.82	0.75	0.02 *	0.007 **
all 0 vs 50 NaCl	1	0.91	0.36	0.04 *	0.0005 **
C.V. (%)		17.7	19.9	14.4	12.3

† Plant density determined at the one to three leaf stage.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Dry Matter Yields and Plant Tissue Nutrient Concentrations at Midseason

Midseason dry matter yield was determined in 1990 only. The addition of inoculum significantly reduced midseason dry matter yields for Katepwa wheat at both Carman and Portage in 1990 (Table 3.29). Reductions in plant density caused by inoculum early in the season were likely the cause (Table 3.28). The application of 50 kg Cl^- ha^{-1} as NaCl significantly reduced midseason dry matter yield at Carman in 1990. This reduction was likely due, in part, to a significant reduction in plant stand earlier in the growing season in those subplots treated with NaCl.

In Katepwa wheat, the concentration of Cl^- in plant tissue harvested at midseason was significantly increased by increasing rates of Cl^- at all sites in 1989 and 1990 (Table 3.30). Fixen et al. (1986a) established a critical Cl^- concentration in plant tissue for spring wheat at heading of 1500 μg Cl^- g^{-1} dry weight. In our study, the concentration of Cl^- in plant tissue of the control treatments from all sites was generally greater than 1500 μg Cl^- g^{-1} dry weight even though soil Cl^- contents were considered low according to soil test recommendation guidelines established in South Dakota (Fixen et al. 1987). Regression models developed from South Dakota data to estimate the concentration of Cl^- in plant tissue for spring wheat using soil Cl^- contents (Fixen et al. 1986a) consistently underestimated the concentration of Cl^- in plant tissue for Katepwa wheat grown under Manitoba conditions. Differences between our study and South Dakota studies in cultivars grown, stage of sampling and environment may have influenced the concentrations of Cl^- in plant tissue.

Overall, Cl^- source and inoculum did not have a consistent and significant effect on the concentration of Cl^- in plant tissue. The concentrations of Cl^- in plant tissue were similar with broadcast and seedrow placed applications, likely because of the high mobility

Table 3.29. Effect of chloride fertilizer and *C. sativus* inoculum on midseason dry matter yield for Katepwa wheat in 1990

Treatment			Midseason dry matter yield	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage
Treatment means				
KCl	0	-	3937	4621
KCl	25	-	3965	4265
KCl	50	-	3693	4546
NaCl	0	-	4359	4612
NaCl	25	-	4396	5071
NaCl	50	-	3422	4546
KCl	0	+	3900	4246
KCl	25	+	3818	4171
KCl	50	+	3515	4087
NaCl	0	+	3590	4124
NaCl	25	+	3619	3974
NaCl	50	+	3356	4622
KCl (S)†	25	-	4265	4762
KCl (S)	25	+	3843	4003
Group means				
KCl			3821	4323
NaCl			3790	4492
LSD (P=0.05)			ns	ns
	0		3946	4401
	25		3975	4371
	50		3497	4450
LSD (P=0.05)			390	ns
		-	3962	4610
		+	3650	4204
LSD (P=0.05)			ns	320

ANOVA	df	Pr > F	
Inoculum (I)	1	0.05 **	0.01 **
Source (S)	1	0.85	0.30
Rate (R)	2	0.03 *	0.92
S*R	2	0.72	0.58
I*R	2	0.70	0.59
S*I	1	0.16	0.55
I*S*R	2	0.46	0.15
Contrasts			
KCl vs NaCl at 25 and 50 Cl	1	0.70	0.15
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.44	0.21
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.85	0.67
all 0 vs 25 KCl	1	0.98	0.45
all 0 vs 50 KCl	1	0.15	0.73
all 0 vs 25 NaCl	1	0.80	0.61
all 0 vs 50 NaCl	1	0.02 *	0.45
C.V. (%)		17.3	15.4

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.30. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue chloride concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue Cl^- concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	3147	2026	1105	5701
KCl	25	-	6943	6357	6734	6955
KCl	50	-	7929	7672	7869	8543
NaCl	0	-	4132	2249	2953	5257
NaCl	25	-	6166	6586	5766	7372
NaCl	50	-	8134	8198	6837	7429
KCl	0	+	2860	2381	1663	5406
KCl	25	+	5965	5639	6223	7088
KCl	50	+	7863	7048	7358	7645
NaCl	0	+	3638	2282	1566	5417
NaCl	25	+	6542	6648	6024	6580
NaCl	50	+	8130	8325	8646	7042
KCl (S)†	25	-	6386	5899	5056	7135
KCl (S)	25	+	6284	5652	4748	7043
Group means						
KCl			5785	5187	5159	6890
NaCl			6124	5715	5299	6516
LSD (P=0.05)			ns	ns	ns	324
	0		3444	2235	1822	5445
	25		6404	6307	6187	6999
	50		8014	7811	7678	7665
LSD (P=0.05)			789	704	1016	397
		-	6075	5515	5211	6876
		+	5833	5387	5247	6530
LSD (P=0.05)			ns	ns	ns	324

ANOVA	df	Pr > F			
Inoculum (I)	1	0.45	0.66	0.93	0.04 *
Source (S)	1	0.30	0.07	0.74	0.02 *
Rate (R)	2	0.0001 **	0.0001 **	0.0001 **	0.0001 **
S*R	2	0.45	0.48	0.36	0.11
I*R	2	0.90	0.73	0.56	0.35
S*I	1	0.53	0.49	0.65	0.97
I*S*R	2	0.57	0.67	0.11	0.13
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.86	0.03 *	0.64	0.02 *
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.46	0.50	0.09	0.64
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.67	0.98	0.13	0.91
all 0 vs 25 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 50 KCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 25 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
all 0 vs 50 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
C.V. (%)		21.6	21.3	32.3	9.7

† (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

of Cl^- in the soil. With the exception of Portage in 1990, Cl^- concentrations in plant tissue tended to be highly variable. Inherent variability in soil Cl^- would appear to be a reasonable explanation for this variability in Cl^- concentration in plant tissue since the concentration of Cl^- in plant tissue of wheat has been shown to be closely related to soil Cl^- content (Fixen et al. 1986a). This suggestion cannot be confirmed since soil samples were taken from only the four corners of each field site in our study. At Portage in 1990, soil Cl^- contents measured in the spring prior to plot establishment varied greatly across the plot (ranging from approximately 24 to 83 kg Cl^- ha^{-1} to 60 cm over a distance of 45 m), yet, the coefficient of variation(%) for Cl^- concentration in plant tissue at this site was less than 10.

Cl^- uptake was determined in 1990 only. Increasing rates of Cl^- fertilizer significantly increased Cl^- uptake for Katepwa wheat at Carman and Portage in 1990 (Table 3.31). Cl^- uptake by wheat at Portage decreased significantly with the addition of inoculum due to a significant reduction in midseason dry matter yield (Table 3.29). Cl^- source and fertilizer placement did not have a significant effect on Cl^- uptake by the plant. As was observed for barley, the Cl^- uptake data for wheat showed a higher degree of variability than did Cl^- concentration data.

Concentrations of K in plant tissue for Katepwa wheat were adequate to high across all treatments and did not differ significantly with treatment (Table 3.32). Guidelines followed by the Manitoba Provincial Soil Testing Laboratory state that, for cereals, a concentration of K in plant tissue of 1.5 to 3.0% at filling is adequate; 3.0 to 5.0% is considered high. These data lent further support to the claim that the fertilizer responses observed were the result of the Cl^- component of the fertilizers added.

Treatment did not have a consistent effect on the concentration of Mn in plant

Table 3.31. Effect of chloride fertilizer and *C. sativus* inoculum on midseason chloride uptake by Katepwa wheat in 1990

Treatment			Cl^- uptake (kg ha^{-1})	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage
Treatment means				
KCl	0	-	4.5	26.0
KCl	25	-	27.9	29.8
KCl	50	-	29.2	39.2
NaCl	0	-	12.9	24.4
NaCl	25	-	25.5	37.6
NaCl	50	-	23.9	33.9
KCl	0	+	6.7	22.6
KCl	25	+	24.3	29.5
KCl	50	+	26.3	31.4
NaCl	0	+	5.7	22.3
NaCl	25	+	22.0	26.4
NaCl	50	+	28.7	32.5
KCl (S)†	25	-	21.9	34.0
KCl (S)	25	+	18.5	28.2
Group Means				
KCl			19.8	29.7
NaCl			19.8	29.5
LSD (P=0.05)			ns	ns
	0		7.4	23.8
	25		24.9	30.9
	50		27.0	34.2
LSD (P=0.05)			5.1	3.3
		-	20.6	31.8
		+	18.9	27.4
LSD (P=0.05)			ns	2.7

ANOVA	df	Pr > F	
Inoculum (I)	1	0.42	0.002 **
Source (S)	1	0.99	0.87
Rate (R)	2	0.0001 **	0.0001 **
S*R	2	0.44	0.39
I*R	2	0.65	0.67
S*I	1	0.89	0.69
I*S*R	2	0.26	0.04 *
Contrasts			
KCl vs NaCl at 25 and 50 Cl	1	0.43	0.94
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.23	0.21
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.24	0.69
all 0 vs 25 KCl	1	0.0001 **	0.005 **
all 0 vs 50 KCl	1	0.0001 **	0.0001 **
all 0 vs 25 NaCl	1	0.0001 **	0.0001 **
all 0 vs 50 NaCl	1	0.0001 **	0.0001 **
C.V. (%)		42.3	19.1

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.32. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue potassium concentration for Katepwa wheat

Treatment			Plant tissue K concentration (%)			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	3.05	3.10	2.47	3.28
KCl	25	-	2.84	3.11	2.39	3.44
KCl	50	-	2.87	3.15	2.55	3.15
NaCl	0	-	3.05	3.20	2.58	3.08
NaCl	25	-	2.90	3.28	2.40	3.36
NaCl	50	-	3.05	3.35	2.55	3.25
KCl	0	+	3.08	3.26	2.59	3.36
KCl	25	+	3.03	3.77	2.53	3.63
KCl	50	+	2.92	3.23	2.57	3.25
NaCl	0	+	2.99	3.44	2.43	3.51
NaCl	25	+	3.01	3.13	2.47	3.27
NaCl	50	+	3.06	3.29	2.49	3.47
KCl (S)†	25	-	3.05	3.35	2.45	3.51
KCl (S)	25	+	3.02	3.55	2.61	3.43
Group means						
KCl			2.97	3.27	2.52	3.35
NaCl			3.01	3.28	2.49	3.32
LSD (P=0.05)			.ns	.ns	.ns	.ns
	0		3.04	3.25	2.52	3.31
	25		2.95	3.33	2.45	3.42
	50		2.98	3.26	2.54	3.28
LSD (P=0.05)			.ns	.ns	.ns	.ns
		-	2.96	3.20	2.49	3.26
		+	3.02	3.36	2.51	3.41
LSD (P=0.05)			.ns	.ns	.ns	.ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.24	0.08	0.75	0.06
Source (S)	1	0.37	0.85	0.65	0.74
Rate (R)	2	0.22	0.74	0.51	0.31
S*R	2	0.19	0.21	1.00	0.17
I*R	2	0.31	0.47	0.69	0.56
S*I	1	0.41	0.15	0.30	0.69
I*S*R	2	0.97	0.18	0.78	0.28
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.15	0.69	0.68	0.80
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.08	0.28	0.71	0.73
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.91	0.33	0.62	0.36
all 0 vs 25 KCl	1	0.15	0.17	0.57	0.08
all 0 vs 50 KCl	1	0.06	0.66	0.68	0.41
all 0 vs 25 NaCl	1	0.22	0.84	0.40	0.94
all 0 vs 50 NaCl	1	0.86	0.62	0.99	0.66
C.V. (%)		6.8	11.4	11.2	10.8

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

tissue for Katepwa wheat (Table 3.33). These results contrasted with the suggestion by Beaton et al. (1988) that Cl^- may enhance the growth of cereals by increasing the availability of Mn to plants. Enhancement of extractable soil Mn by Cl^- has been shown to occur primarily in acidic soils (Westerman et al. 1971). Soils used in this study were neutral to alkaline (Tables 3.1 and 3.2).

Treatment did not have a significant effect on the concentration of Cu in plant tissue for Katepwa wheat in either 1989 or 1990 (Table D.12 in Appendix).

Overall, treatment did not have a significant effect on the concentration of Zn in plant tissue for Katepwa wheat (Table D.13 in Appendix). The addition of inoculum significantly increased the concentration of Zn in plant tissue at Portage in 1990. This increase was likely due to a significant decrease in midseason dry matter yield (Table 3.29).

The addition of Cl^- significantly decreased the concentration of NO_3^- in plant tissue for Katepwa wheat in all sites and years (Table 3.34). Significant correlations between the concentration of NO_3^- and Cl^- in plant tissue were observed at Carman in 1989 (-0.257*) and at Portage in 1989 (-0.234*) and 1990 (-0.536**) (Table 3.35). Significant reductions by Cl^- in NO_3^- concentration in plant tissue did not appear to be related to the ratio of NO_3^- to Cl^- in plant tissue. Studies with spring wheat conducted in Saskatchewan (Wang 1987) and in South Dakota (Schumacher 1988) have shown the application of Cl^--containing fertilizers to decrease the concentration of NO_3^- in plant tissue. In South Dakota, differences in the concentration of NO_3^- in plant tissue for spring wheat from low and high Cl^- treatments were found to be very small in comparison to differences in the concentration of Cl^- in plant tissue between treatments (Schumacher 1988). In our study, Cl^- source and inoculum did not have a significant effect on the

Table 3.33. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue manganese concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue Mn concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	46.0	36.2	37.3	27.8
KCl	25	-	48.3	37.3	39.7	28.1
KCl	50	-	45.6	39.2	39.5	26.6
NaCl	0	-	58.0	36.9	40.4	28.8
NaCl	25	-	46.5	37.0	41.3	29.3
NaCl	50	-	51.2	44.9	34.3	27.4
KCl	0	+	47.1	40.3	43.2	27.8
KCl	25	+	45.4	40.9	38.6	27.2
KCl	50	+	50.7	38.3	42.9	26.4
NaCl	0	+	44.0	38.6	46.8	27.3
NaCl	25	+	48.2	37.4	45.4	25.8
NaCl	50	+	49.4	39.4	42.1	26.6
KCl (S)†	25	-	49.8	38.6	41.7	29.0
KCl (S)	25	+	44.9	36.5	46.1	29.0
Group means						
KCl			47.1	38.7	40.2	27.3
NaCl			49.5	39.0	41.7	27.5
LSD (P=0.05)			ns	ns	ns	ns
	0		48.8	38.0	41.9	28.0
	25		47.1	38.1	41.2	27.6
	50		49.1	40.5	39.7	26.7
LSD (P=0.05)			ns	ns	ns	ns
		-	49.2	38.6	38.8	28.0
		+	47.4	39.1	43.2	26.8
LSD (P=0.05)			ns	ns	3.6	1.0

ANOVA	df	Pr > F			
Inoculum (I)	1	0.32	0.62	0.02 *	0.04 *
Source (S)	1	0.20	0.78	0.41	0.62
Rate (R)	2	0.63	0.15	0.60	0.11
S*R	2	0.69	0.15	0.21	0.88
I*R	2	0.20	0.07	0.53	0.33
S*I	1	0.13	0.15	0.36	0.16
I*S*R	2	0.10	0.93	0.86	0.70
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.51	0.58	0.79	0.76
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.72	0.64	0.65	0.48
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.92	0.11	0.09	0.17
all 0 vs 25 KCl	1	0.46	0.51	0.30	0.65
all 0 vs 50 KCl	1	0.74	0.64	0.80	0.05 *
all 0 vs 25 NaCl	1	0.59	0.63	0.60	0.57
all 0 vs 50 NaCl	1	0.58	0.01 **	0.17	0.19
C.V. (%)		15.7	12.0	18.4	8.0

† (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.34. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue nitrate concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue NO_3^- concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	3518	4292	2749	2263
KCl	25	-	2666	3793	2741	2260
KCl	50	-	2585	3516	2355	1657
NaCl	0	-	3841	4753	3338	2459
NaCl	25	-	2812	3724	2762	2028
NaCl	50	-	2829	4720	1890	1881
KCl	0	+	3523	5379	3437	2238
KCl	25	+	3112	4350	2681	2084
KCl	50	+	2648	3399	2268	1819
NaCl	0	+	2786	5154	3675	2204
NaCl	25	+	3034	3589	2797	1996
NaCl	50	+	3082	3752	2364	1991
KCl (S)†	25	-	3206	3280	2803	2080
KCl (S)	25	+	2914	4027	2900	2036
Group means						
KCl			3009	4122	2705	2053
NaCl			3064	4282	2804	2093
LSD (P=0.05)			ns	ns	ns	ns
	0		3417	4895	3300	2291
	25		2906	3864	2745	2092
	50		2786	3847	2220	1837
LSD (P=0.05)			478	627	529	251
		-	3042	4133	2639	2091
		+	3031	4271	2870	2055
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.95	0.59	0.29	0.73
Source (S)	1	0.78	0.53	0.65	0.70
Rate (R)	2	0.02 *	0.002 **	0.0007 **	0.003 **
S*R	2	0.52	0.17	0.53	0.35
I*R	2	0.17	0.13	0.61	0.49
S*I	1	0.35	0.15	0.81	0.82
I*S*R	2	0.42	0.99	0.69	0.76
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.44	0.58	0.83	0.88
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.26	0.43	0.91	0.48
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.68	0.62	0.68	0.85
all 0 vs 25 KCl	1	0.07	0.04 *	0.07	0.45
all 0 vs 50 KCl	1	0.008 **	0.0006 **	0.003 **	0.0007 **
all 0 vs 25 NaCl	1	0.09	0.003 **	0.11	0.08
all 0 vs 50 NaCl	1	0.12	0.10	0.0005 **	0.03 *
C.V. (%)		27.1	27.3	32.9	21.2

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

concentration of NO_3^- in plant tissue at any of the sites.

Table 3.35. Correlation coefficient for the relationship between midseason plant tissue concentrations of nitrate and chloride for Katepwa wheat

Site	r	
	1989	1990
Carman	-0.257 *	-0.059 ns
Portage	-0.234 *	-0.536 **

*,** Significant at the 0.05 and 0.01 levels respectively.

In general, treatment did not have a significant effect on the concentration of NH_4^+ in plant tissue for Katepwa wheat in 1989 or in 1990 (Table D.14 in Appendix). At Portage in 1990 the addition of inoculum significantly increased the concentration of NH_4^+ in plant tissue likely due to a significant decrease in midseason dry matter yield (Table 3.29). Any effects of treatment on the concentration of NH_4^+ in plant tissue may have been masked by the very high degree of variability apparent in these data.

The addition of 50 kg Cl^- ha^{-1} did not have a significant effect on total N concentration in plant tissue at midseason (Table D.15 in Appendix) despite statistically significant reductions in the concentration of NO_3^- in plant tissue at midseason (Table 3.34).

Common Root Rot Ratings at the Soft Dough Stage

The only site at which the addition of Cl^- significantly reduced common root rot disease severity for Katepwa wheat was Carman in 1990 (Table 3.36). In studies conducted in North Dakota, Goos et al. (1987a) found that common root rot severity was more closely related to NO_3^- concentration in plant tissue than to Cl^- concentration in plant tissue. In contrast, in our studies which used Katepwa wheat, a relationship between common root rot severity and concentrations of either Cl^- or NO_3^- in plant tissue

Table 3.36. Effect of chloride fertilizer and *C. sativus* inoculum on common root rot severity for Katepwa wheat in 1989 and 1990

Treatment			Common root rot disease rating †			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	2.05	2.09	2.42	3.17
KCl	25	-	2.13	1.97	2.57	3.20
KCl	50	-	1.95	2.00	2.40	2.99
NaCl	0	-	2.01	1.95	2.75	2.95
NaCl	25	-	2.03	1.86	2.53	2.93
NaCl	50	-	2.11	1.71	2.33	3.11
KCl	0	+	2.15	1.87	2.71	3.14
KCl	25	+	2.19	1.91	2.38	3.11
KCl	50	+	1.92	1.76	2.53	2.89
NaCl	0	+	1.81	1.81	2.60	3.03
NaCl	25	+	2.01	2.09	2.57	2.92
NaCl	50	+	2.02	1.82	2.34	3.07
KCl (S)‡	25	-	2.11	2.21	2.32	3.07
KCl (S)	25	+	2.15	1.80	2.67	2.93
Group means						
KCl			2.06	1.93	2.50	3.08
NaCl			2.00	1.87	2.52	3.00
LSD (P=0.05)			ns	ns	ns	ns
	0		2.01	1.93	2.62	3.07
	25		2.09	1.96	2.51	3.04
	50		2.00	1.82	2.40	3.01
LSD (P=0.05)			ns	ns	0.17	ns
		-	2.05	1.93	2.50	3.06
		+	2.02	1.88	2.52	3.03
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.62	0.57	0.77	0.55
Source (S)	1	0.29	0.51	0.78	0.14
Rate (R)	2	0.44	0.42	0.04 *	0.67
S*R	2	0.08	0.76	0.33	0.01 **
I*R	2	0.86	0.49	0.62	0.73
S*I	1	0.23	0.19	0.46	0.44
I*S*R	2	0.70	0.80	0.15	0.96
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.98	0.69	0.76	0.57
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.90	0.25	0.13	0.31
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.79	0.59	0.08	0.19
all 0 vs 25 KCl	1	0.11	0.93	0.16	0.32
all 0 vs 50 KCl	1	0.45	0.69	0.13	0.10
all 0 vs 25 NaCl	1	0.87	0.72	0.50	0.07
all 0 vs 50 NaCl	1	0.51	0.19	0.007 **	0.84
C.V. (%)		12.9	18.8	11.4	7.5

† Disease classes based on severity of lesions on subcrown internode: 1=clean 2=slight 3=moderate 4=severe (Ledingham et al., 1973)
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

could not be confirmed; a significant reduction by Cl^- in common root rot severity for wheat occurred at only one site and significant reductions by Cl^- in the concentration of NO_3^- in plant tissue for wheat occurred at four sites. Regression analysis showed a significant relationship between Cl^- concentration in plant tissue harvested at midseason and common root rot severity only at Carman in 1990 (r^2=0.213**) (Table 3.37).

Table 3.37. Relationship between common root rot severity and midseason plant tissue nitrate and chloride concentrations for Katepwa wheat

Site	Simple r^2			
	Plant tissue Cl^-		Plant tissue NO_3^-	
	1989	1990	1989	1990
Carman	0.002 ns	0.213 **	0.000 ns	0.001 ns
Portage	0.009 ns	0.002 ns	0.025 ns	0.002 ns

*,** Significant at the 0.05 and 0.01 levels respectively.

The effects of inoculum and Cl^- source were not significant for any sites in 1989 or in 1990. At all sites, inoculum significantly reduced plant density early in the season but did not produce a corresponding significant increase in common root rot at soft dough stage as had been anticipated. This observation agrees with observations for barley in our study, however, it contrasts with results of a study by Pua et al. (1985) which showed a strong correlation between seedling blight and common root rot in barley. The inability of inoculum to increase the severity of common root rot suggested that, although inoculum may have been effective in inducing disease early in the season immediately after being added to the soil, competition from indigenous soil organisms may have reduced the population of the introduced strains of *C. sativus* thereby limiting their ability to produce the symptoms of common root rot later in the season. In contrast to the effect of inoculum on Katepwa wheat, inoculum resulted in significant reductions in common root rot for Bedford barley at two sites (Section 3.3.1). In the case of barley,

less virulent, introduced strains of *C. sativus* appeared to outcompete more virulent, indigenous populations of *C. sativus* thereby depressing common root rot severity.

Yields and Grain Quality at Maturity

The addition of Cl^- did not have a significant effect on grain yield for Katepwa wheat at any of the four field sites tested (Table 3.38). This observation agrees with that of Goos (1986) who noted that the application of KCl had not generally been found to increase the grain yield of spring wheat in North Dakota. Although Cl^- significantly reduced the severity of common root rot at Carman in 1990, a significant increase in grain yield did not occur. The observed reduction in common root rot was small, however, and may not have continued throughout the season or had a substantial influence on yield. Recommendations developed for South Dakota would indicate that, on the basis of soil Cl^- content, yield responses to the application of Cl^- fertilizers were likely in our study. In our study, all sites tested less than 66 kg Cl^- ha^{-1} to 60 cm; three of the four sites tested less than 33 kg Cl^- ha^{-1} to 60 cm. Studies conducted in South Dakota by Fixen et al. (1987) demonstrated a frequency of yield response in hard red spring wheat of 31% on soils testing less than 66 kg Cl^- ha^{-1} to 60 cm and of 69% on soils testing less than 33 kg Cl^- ha^{-1} to 60 cm. Another study conducted by Fixen et al. (1986a) demonstrated near maximum yields of spring wheat on soils testing greater than 43.5 kg Cl^- ha^{-1} to 60 cm or 75 kg Cl^- ha^{-1} to 120 cm. On the basis of soil Cl^- content to 60 cm, all sites in our study, with the exception of the 1990 Portage site, would be considered responsive; on the basis of the 120 cm guideline, all sites would be considered responsive.

Lack of a yield response to Cl^- in our study may be attributable, in part, to the cultivar of wheat grown. In cultivar experiments conducted in Manitoba in 1990 and 1991

Table 3.38. Effect of chloride fertilizer and *C. sativus* inoculum on grain yield for Katepwa wheat in 1989 and 1990

Treatment			Grain yield (kg ha^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	1944	3045	4038	4203
KCl	25	-	1954	3045	3850	4356
KCl	50	-	2224	3235	4072	4363
NaCl	0	-	1855	2718	3979	4407
NaCl	25	-	2234	2483	4065	4382
NaCl	50	-	1895	3122	3749	4111
KCl	0	+	1519	2645	3695	4052
KCl	25	+	1825	2892	3720	4176
KCl	50	+	1632	2640	3495	3944
NaCl	0	+	1991	2554	3448	3980
NaCl	25	+	1618	2991	3482	4059
NaCl	50	+	1625	2581	3395	3741
KCl (S)†	25	-	2004	2948	3882	4397
KCl (S)	25	+	1853	2865	3621	3936
Group means						
KCl			1849	2917	3812	4183
NaCl			1870	2742	3686	4113
LSD (P=0.05)			ns	ns	ns	ns
	0		1827	2740	3790	4161
	25		1908	2853	3779	4243
	50		1844	2895	3678	4040
LSD (P=0.05)			ns	ns	ns	ns
		-	2018	2941	3959	4304
		+	1701	2717	3539	3992
LSD (P=0.05)			157	ns	163	157

ANOVA	df	Pr > F			
Inoculum (I)	1	0.0002 **	0.11	0.0001 **	0.0002 **
Source (S)	1	0.80	0.21	0.13	0.38
Rate (R)	2	0.68	0.65	0.47	0.11
S*R	2	0.18	0.90	0.59	0.31
I*R	2	0.30	0.10	0.85	0.74
S*I	1	0.40	0.26	0.39	0.43
I*S*R	2	0.02 *	0.66	0.24	0.70
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.49	0.35	0.25	0.14
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.79	0.78	0.87	0.83
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.88	0.94	0.61	0.19
all 0 vs 25 KCl	1	0.60	0.28	0.97	0.35
all 0 vs 50 KCl	1	0.39	0.35	0.95	0.95
all 0 vs 25 NaCl	1	0.40	0.99	0.89	0.59
all 0 vs 50 NaCl	1	0.57	0.59	0.07	0.04 *
C.V. (%)		17.6	20.7	8.9	7.6

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

(Section 5), the cultivar Katepwa showed yield responses to Cl^- less frequently than the cultivars Roblin, Biggar and Marshall. In addition, the high degree of variability in yield data evident in 1989 may have masked to some degree the effects of treatment. However, this was not a consideration in 1990 since the variability in yield data was very low.

As stated previously, in spite of 'low' soil Cl^- levels, Cl^- concentrations in plant tissue of the control treatments at all sites were, in general, higher than the critical concentration of 1500 μg Cl^- g^{-1} dry weight established for spring wheat by Fixen et al. (1986a). This fact, in itself, does not exclude the possibility of a Cl^- response, however. Our study differed from the South Dakota study in cultivar, stage of sampling and environment. Therefore, the critical Cl^- concentration in plant tissue for spring wheat which was established in South Dakota may not be directly applicable to Manitoba.

Cl^- source had no significant effect on grain yield of wheat. *C. sativus* inoculum significantly reduced the grain yield of Katepwa wheat at Carman in 1989 and 1990 and at Portage in 1990. This trend was apparent in Portage in 1989, but the effect was not statistically significant (P=0.11). These decreases in yield appear to be due to reductions in plant stand (Table 3.28) not to increases in common root rot severity (Table 3.36).

Inoculum significantly reduced straw yield for Katepwa wheat at Carman in 1989 and at Portage in 1990 (Table D.16 in Appendix). Small, statistically insignificant reductions by inoculum in straw yield at Portage in 1989 and at Carman in 1990 were likely the result of significant reductions in plant stand early in the season (Table 3.28). Cl^- source had no significant effect on straw yield. However, at Portage in 1990, the addition of 50 kg Cl^- ha^{-1} as either KCl or NaCl significantly reduced the straw yield compared to the control and to the 25 kg ha^{-1} treatments.

The application of NaCl, particularly at the higher fertilizer rate, significantly increased thousand kernel weight for Katepwa wheat over that of KCl at Portage in 1989 and at Carman in 1990 (Table 3.39). Likely, these increases represented a response by the plant to the deleterious effect of NaCl on plant emergence early in the season. At Portage in 1989, NaCl tended (P=0.12) to reduce plant density as compared to KCl (Table 3.28). At Carman in 1990, the 50 kg Cl^- ha^{-1} rate of NaCl significantly reduced midseason dry matter yield (Table 3.29). *C. sativus* inoculum significantly increased thousand kernel weight for Katepwa wheat at all field sites. This increase was also likely due to the response of the plant to reduced plant density early in the season.

Cl^- rate did not have a consistent effect on hectolitre weight of Katepwa wheat at Carman and Portage in 1989 and 1990 (Table D.17 in Appendix). Effects of inoculum and fertilizer source on hectolitre weight were not significant.

Total N concentration in grain was determined for selected treatments in 1990 only. At Portage and Carman, the application of 50 kg Cl^- ha^{-1} resulted in small but significant reductions in total N concentration in the grain (Table 3.40). At Carman in 1990, observed reductions in total N concentration appeared to be due primarily to the application of Cl^- as NaCl. At both Carman and Portage, significant reductions by Cl^- in the concentration of NO_3^- in plant tissue harvested at midseason appeared to have contributed to the observed reduction in total N concentration in grain. At Carman and Portage, differences in grain yield among treatments were small, thus, observed reductions by Cl^- in N concentration in plant tissue were not likely due to a dilution effect. Cl^- applications were not found to have a significant effect on total N concentration in plant tissue harvested at midseason.

Table 3.39. Effect of chloride fertilizer and *C. sativus* inoculum on thousand kernel weight for Katepwa wheat in 1989 and 1990

Treatment			Thousand kernel weight (g per 1000 kernels)			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	22.9	30.2	30.3	37.8
KCl	25	-	22.2	30.3	29.6	37.5
KCl	50	-	24.2	31.0	30.6	37.6
NaCl	0	-	22.6	30.0	31.5	37.2
NaCl	25	-	23.1	32.3	32.2	37.7
NaCl	50	-	23.0	32.3	34.7	37.5
KCl	0	+	23.3	31.8	33.6	38.0
KCl	25	+	24.1	31.3	32.8	38.0
KCl	50	+	23.6	31.9	33.4	37.6
NaCl	0	+	24.9	32.3	31.8	37.7
NaCl	25	+	24.4	32.9	33.8	38.4
NaCl	50	+	24.8	33.2	34.2	38.2
KCl (S)†	25	-	22.6	32.2	33.2	37.5
KCl (S)	25	+	25.2	33.2	33.3	37.4
Group means						
KCl			23.4	31.1	31.7	37.7
NaCl			23.8	32.0	33.0	37.8
LSD (P=0.05)			ns	0.4	0.8	ns
	0		23.4	31.1	31.8	37.7
	25		23.4	31.7	32.1	37.9
	50		23.9	32.1	33.2	37.7
LSD (P=0.05)			ns	0.5	1.0	ns
		-	23.0	31.0	31.5	37.5
		+	24.2	32.2	33.3	38.0
LSD (P=0.05)			0.9	0.4	0.8	0.4

ANOVA	df	Pr > F			
Inoculum (I)	1	0.01 **	0.0001 **	0.0001 **	0.02 *
Source (S)	1	0.34	0.0001 **	0.003 **	0.90
Rate (R)	2	0.61	0.002 **	0.02 *	0.54
S*R	2	0.79	0.009 **	0.02 *	0.21
I*R	2	0.62	0.07	0.51	0.74
S*I	1	0.17	0.88	0.003 **	0.34
I*S*R	2	0.36	0.57	0.65	0.79
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.56	0.0001 **	0.0001 **	0.29
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.67	0.0006 **	0.001 **	0.97
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.28	0.0009 **	0.63	0.16
all 0 vs 25 KCl	1	0.65	0.38	0.34	0.76
all 0 vs 50 KCl	1	0.46	0.27	0.77	0.85
all 0 vs 25 NaCl	1	0.61	0.0001 **	0.06	0.19
all 0 vs 50 NaCl	1	0.47	0.0001 **	0.0001 **	0.58
C.V. (%)		7.8	2.9	5.4	2.1

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 3.40. Effect of chloride fertilizer on total nitrogen concentration in grain for Katepwa wheat in 1990

Treatment			Total N concentration in grain (%)	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage
Treatment means				
KCl	0	-	2.66	3.03
KCl	50	-	2.62	2.66
NaCl	50	-	2.56	2.61

ANOVA	df	Pr > F	
Treatment	2	0.02 *	0.06
Contrasts			
0 vs 50 Cl^- as KCl or NaCl	1	0.02 *	0.02 *
0 vs 50 Cl^- as KCl	1	0.23	0.05 *
0 vs 50 Cl^- as NaCl	1	0.007 **	0.03 *
KCl vs NaCl	1	0.06	0.76
C.V. (%)		1.8	10.2

*, ** Significant at the 0.05 and 0.01 levels respectively.

3.4 Summary and Conclusions

The application of Cl^- consistently and significantly increased the concentration of Cl^- in plant tissue for Bedford barley and Katepwa wheat harvested at midseason. In our study, Cl^- concentrations in plant tissue were consistently higher than estimated from soil Cl^- content using regression models developed by Fixen et al. (1986a) for spring wheat. Overall, neither fertilizer source nor placement were shown to consistently affect availability of Cl^- to the plant. Cl^- applications had negligible or inconsistent effects on concentrations of K, Cu, Mn, Zn and NH_4^+ in plant tissue for Bedford barley and Katepwa wheat.

Yield responses of Bedford barley to Cl^--containing fertilizers were infrequent and did not appear to be associated with measurable reductions in the plant diseases monitored in this study. The application of Cl^- resulted in a significant increase in grain yield of barley in only one of six common root rot experiments; Cl^- did not have a

significant effect on the severity of common root rot at the site at which the significant yield increase was observed. Cl^- significantly reduced or tended to reduce the severity of common root rot in four of six common root rot experiments; however reductions were small and consequent yield increases did not result. At three of the four sites in which the application of Cl^- reduced common root rot, Cl^- applications had significantly reduced or tended to reduce the concentration of NO_3^- in plant tissue harvested at midseason. Results of our study parallel the results of a study conducted by Goos et al. (1987a) in North Dakota. Goos et al. (1987a) found that Cl^- applications resulted in small but significant reductions in the severity of common root rot in barley but that these reductions in disease did not always result in an increase in grain yield. In Goos' studies with barley, regression analysis indicated a relationship between the severity of common root rot and NO_3^- concentration in plant tissue harvested at midseason. On the basis of this relationship, Goos et al. (1987a) suggested that KCl indirectly reduced the severity of common root rot by decreasing the NO_3^- concentration in plant tissue and thereby reduced the predisposition of barley to common root rot. However, in our study with Bedford barley, regression analysis did not indicate a strong relationship between the severity of common root rot and concentrations of either Cl^- or NO_3^- in plant tissue.

The application of Cl^- resulted in a significant increase in grain yield for Bedford barley in one of two spot blotch experiments. Visible reductions in spot blotch with the application of Cl^- were not observed in either of the two spot blotch experiments.

The application of Cl^--containing fertilizers did not increase grain yield for Katepwa wheat in any of the four field experiments. Based on studies conducted in South Dakota (Fixen et al. 1987), yield responses to the application of Cl^--containing fertilizers had been anticipated in our study. Soil Cl^- contents at all experimental sites in

our study measured less than the 66 kg Cl^- ha^{-1} to 60 cm regarded as adequate in soil test guidelines developed in South Dakota (Fixen et al. 1987). In spite of the 'low' soil Cl^- contents at experimental sites in our study, the concentration of Cl^- in plant tissue in all control treatments at all sites was greater than the critical level of 1500 μg Cl^- g^{-1} dry weight established for spring wheat by Fixen et al. (1986a). Results of our study did not indicate a strong relationship between reductions by Cl^- in the severity of common root rot and increases by Cl^- in grain yield. The severity of common root rot was reduced by the application of Cl^- in only one of four field experiments; however, a resultant increase in grain yield was not observed. Similarly, in strip trials conducted in Saskatchewan, KCl applications were found to result in decreases in common root rot of spring wheat in approximately half of the trials conducted; in general, observed decreases were small and did not result in significant increases in grain yield (Wang 1987). In our study, Cl^- applications significantly reduced the concentration of NO_3^- in plant tissue at all sites but, unlike for barley, these reductions in the concentration of NO_3^- in plant tissue did not appear to be consistently associated with the suppression of common root rot. The lack of response to Cl^- by Katepwa wheat may be due, in part, to the cultivar of wheat grown. Results of cultivar trials conducted in 1990 and 1991 showed that the cultivar Katepwa responded to Cl^- less frequently than the cultivars Roblin, Biggar and Marshall (Section 5.3.2).

Although the literature suggested that the effect of Cl^- applications on certain measurements such as disease severity and concentrations of Cl^-, NO_3^- and Mn in plant tissue might give an indication of the probability of yield responses by cereals to Cl^-, none of the measurements taken during the course of this study consistently distinguished responsive from non-responsive situations. The critical levels for soil Cl^- content and Cl^-

concentration in plant tissue developed for spring wheat from studies conducted in South Dakota (Fixen et al. 1986a, 1987) did not reliably predict yield responses to Cl^- for Katepwa wheat or Bedford barley.

Overall, the effects of Cl^- applications on thousand kernel weight and hectolitre weight for Bedford barley and Katepwa wheat were small and inconsistent. Cl^- was not found to have a consistent and significant effect on kernel plumpness for Bedford barley.

4. CHLORIDE NUTRITION STUDY

4.1 Introduction

As mentioned in the literature review, Cl^--containing fertilizers have been shown to significantly increase the yield of wheat (Fixen et al. 1986a,b; Engel and Mathre 1988). Average yield responses ranging from 360 kg ha^{-1} in spring wheat (Fixen et al. 1987) up to 1200 kg ha^{-1} in take-all infected winter wheat (Christensen and Brett 1985) have been reported. As noted in the literature review, the frequency of yield responses to Cl^- may be influenced by soil Cl^- content, concentrations of Cl^- in plant tissue, crop cultivar and disease pressure.

The purpose of this experiment was to determine the effect of Cl^--containing fertilizers on grain and straw yield and grain quality for Katepwa wheat. No specific measurements of disease severity were taken in this experiment.

4.2 Materials and Methods

Four field plots (two in each of 1989 and 1990) of wheat (*Triticum aestivum* cv. Katepwa) were established. Soil samples were taken in the spring just prior to plot establishment and analyzed for extractable Cl^- using the mercuric thiocyanate method described by Fixen et al. (1988). Soils at all 1989 and 1990 field sites contained less than 66 kg Cl^- ha^{-1} to 60 cm (Table 4.1). According to current South Dakota soil test guidelines, the application of Cl^- fertilizers would be recommended at all sites (Fixen et al. 1987).

A complete factorial experiment consisting of broadcast Cl^- at rates of 0, 25 and 50 kg Cl^- ha^{-1} and two sources of Cl^- (KCl and NaCl) was used at all sites. One

Table 4.1. Physical and chemical characteristics of soils used in 1989 and 1990 field studies

Characteristic†	Depth (cm)	Site			
		1989		1990	
		Anola	Darlingford	Anola	Darlingford
Legal Location		NE23-10-6E	NW4-3-7W	NE23-10-6E	NW4-3-7W
Soil Name		Semple	Darlingford	Semple	Darlingford
Texture		silty clay	clay loam	silty clay	clay loam
pH	0 to 15	7.7	7.3	7.8	7.5
Organic C (%)	0 to 15	5.7	4.2	5.3	4.1
	15 to 30	2.8	3.3	3.8	3.2
Carbonates (% CO_3)	0 to 15	3.7	0.3	2.2	0.6
	15 to 30	17.5	0.1	8.5	3.1
NO_3^--N (mg kg^{-1})‡	0 to 60	17	19	19	28
	60 to 120	7	12	14	24
$NaHCO_3$-extr. P (mg kg^{-1})	0 to 15	20	19	13	16
	15 to 30	1	6	2	6
CH_3COONH_4-extr. K (mg kg^{-1})	0 to 15	298	313	526	280
	15 to 30	237	263	411	240
SO_4^{2-}-S (mg kg^{-1})‡	0 to 60	19	6	645	45
	60 to 120	24	12	1103	73
Cl^- (mg kg^{-1})	0 to 15	3.5	6.0	3.9	2.3
	15 to 30	2.6	4.3	3.4	2.9
	30 to 60	2.4	2.6	1.9	3.5
	60 to 90	2.0	2.2	1.2	2.3
	90 to 120	2.4	2.6	1.3	1.9
(Estimated kg ha^{-1})	0 to 60	21	33	21	26
	60 to 120	17	20	10	18
DTPA-extr. Cu (mg kg^{-1})	0 to 15	3.0	1.7	2.5	1.8
	15 to 30	3.7	2.0	3.1	1.9
DTPA-extr. Mn (mg kg^{-1})	0 to 15	12	69	11	44
	15 to 30	6	50	5	35
DTPA-extr. Zn (mg kg^{-1})	0 to 15	0.7	1.9	0.4	1.6
	15 to 30	0.3	0.5	0.1	1.1

† Methods used for soil analysis are described in Appendix A.

‡ Concentrations of NO_3^--N and SO_4^{2-}-S in 0 to 60 cm depth established according to weighted average of concentrations in 0 to 15, 15 to 30 and 30 to 60 cm depths; concentrations in 60 to 120 cm depth established according to weighted average of 60 to 90 and 90 to 120 cm depths.

additional treatment of 25 kg Cl^- ha^{-1} as KCl placed in the seedrow at time of seeding was included. A randomized complete block design using five replications was employed. Subplots consisted of eight drill rows (18 cm spacing) 6 m in length. Alleys and border areas were seeded to wheat to reduce edge effects.

Cl^- fertilizer treatments were hand broadcast within several days after planting. Commercial grade KCl and reagent grade NaCl were used.

Basal applications of macronutrients were made to meet or exceed soil test recommendations of the Manitoba Provincial Soil Testing Laboratory. At all sites, N in the form of urea was broadcast and incorporated in the spring prior to seeding. Rates of N fertilizer applied were 46 kg N ha^{-1} at Darlingford in 1989 and 1990 and at Anola in 1990, and 92 kg N ha^{-1} at Anola in 1989. At all sites, approximately 13 kg P ha^{-1} and 7 kg N ha^{-1} as monoammonium phosphate were placed in the seedrow at time of seeding. At Darlingford in 1989, ammonium sulphate was broadcast and incorporated in the spring prior to planting.

Herbicides were applied at recommended rates to control weeds.

A midseason harvest was conducted in 1990 only. At the heading stage, the shoot portion of 3 m of one drill row was cut approximately 2.5 cm above the soil surface. Samples were dried at 68° C, weighed to determine dry matter yield and ground with a Wiley mill to pass a 2 mm sieve. Cl^- concentration in plant tissue was determined by $AgNO_3$ titration procedure (LaCroix et al. 1970). Plant uptake of Cl^- was calculated as the product of Cl^- concentration in plant tissue and midseason dry matter yield.

Harvests were conducted at maturity in 1989 and 1990. Final harvest consisted of 3 m of the two innermost drill rows of each subplot. Samples were cut by hand approximately 2.5 cm above the soil surface, air dried and threshed with a stationary

thresher. Measurements taken included grain yield, straw yield and thousand kernel weight. Thousand kernel weight was based an a subsample of 200 kernels.

Analysis of variance was conducted and LSD's calculated using the PROC GLM procedure (SAS Institute Inc. 1988). Single degree of freedom contrasts were used to further analyze treatment effects.

4.3 Results and Discussion

Dry Matter Yields and Plant Tissue Chloride Concentrations at Midseason

Midseason dry matter yield was determined in 1990 only. Treatment did not have a significant effect on midseason dry matter yield for Katepwa wheat in either of the two experiments conducted in 1990 (Table 4.2).

Cl^- concentration in plant tissue was determined in 1990 only. Increasing rates of Cl^- significantly increased Cl^- concentration in plant tissue for Katepwa wheat at Anola and Darlingford in 1990 (Table 4.3). The effect of fertilizer source was not significant. At Darlingford in 1990, seedrow placed KCl resulted in a significantly higher Cl^- concentration in plant tissue than broadcast KCl. In contrast, fertilizer placement was not found to have a significant effect on Cl^- concentrations in plant tissue in any of the common root rot studies conducted with Katepwa wheat (Section 3.3.2). Soils at the Anola and Darlingford sites contained less than the 66 kg Cl^- ha^{-1} to 60 cm recommended by Fixen et al. (1987). However, Cl^- concentrations in plant tissue in the control treatments at both the Anola and Darlingford sites were higher than the critical concentration of 1500 μg Cl^- g^{-1} dry weight established by Fixen et al. (1986a) for spring wheat at the heading stage. Similarly, in the common root rot studies conducted in Manitoba using Katepwa wheat (Section 3.3.2), Cl^- concentrations in plant tissue in

Table 4.2. Effect of chloride fertilizer on midseason dry matter yield for Katepwa wheat in 1990

Treatment		Dry matter yield (kg ha^{-1})	
Cl$^-$ source	kg ha^{-1} Cl$^-$ applied	Anola	Darlingford
Treatment means			
KCl	0	3911	5212
KCl	25	3783	5261
KCl	50	4005	4698
NaCl	0	4739	4556
NaCl	25	4136	5122
NaCl	50	3847	5534
KCl (S)†	25	4057	5249
Group means			
KCl		3900	5057
NaCl		4241	5171
LSD (P=0.05)		ns	ns
	0	4325	5034
	25	3960	5191
	50	3926	5116
LSD (P=0.05)		ns	ns

ANOVA	df	Pr > F	
Source (S)	1	0.14	0.67
Rate (R)	1	0.29	0.89
S*R	2	0.22	0.17
Contrasts			
KCl vs NaCl at 25 and 50 Cl	1	0.72	0.27
broadcast vs seedrow (25Cl,KCl)	1	0.47	0.98
all 0 vs 25 KCl	1	0.11	0.55
all 0 vs 50 KCl	1	0.33	0.38
all 0 vs 25 NaCl	1	0.57	0.82
all 0 vs 50 NaCl	1	0.16	0.20
C.V. (%)		14.6	13.5

† (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

control treatments were generally higher than the critical concentration of 1500 μg Cl$^-$ g^{-1} dry weight even though soil Cl$^-$ contents were less than 66 kg Cl$^-$ ha^{-1} to 60 cm. Differences between our study and South Dakota studies in cultivar grown, stage of sampling and environment may have influenced the concentration of Cl$^-$ in plant tissue.

Plant uptake of Cl$^-$ was determined in 1990 only. Increasing rates of Cl$^-$ significantly increased plant uptake of Cl$^-$ (Table 4.3) due to increases in Cl$^-$ concentration in plant tissue with the application of Cl$^-$ fertilizers (Table 4.3), not due to effects of Cl$^-$ fertilization on dry matter yield (Table 4.2).

Table 4.3. Effect of chloride fertilizer on midseason plant tissue chloride concentration and uptake for Katepwa wheat in 1990

Treatment		Plant tissue Cl^- concentration (mg kg^{-1})		Cl^- uptake (kg ha^{-1})	
Cl^- source	kg ha^{-1} Cl^- applied	Anola	Darlingford	Anola	Darlingford
Treatment means					
KCl	0	2750	2799	11.3	14.5
KCl	25	5080	4260	19.0	22.4
KCl	50	5045	5621	20.1	26.1
NaCl	0	2107	2951	9.5	14.3
NaCl	25	4311	4876	17.5	25.0
NaCl	50	6096	5925	23.1	33.1
KCl (S)†	25	4465	5320	16.7	27.8
Group means					
KCl		4292	4227	16.8	21.0
NaCl		4172	4584	16.7	24.1
LSD (P=0.05)		ns	ns	ns	ns
	0	2429	2875	10.4	14.4
	25	4696	4568	18.2	23.7
	50	5571	5773	21.6	29.6
LSD (P=0.05)		773	719	3.7	4.5

ANOVA	df	Pr > F			
Source (S)	1	0.70	0.22	0.95	0.09
Rate (R)	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
S*R	2	0.04 *	0.79	0.34	0.27
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.76	0.21	0.71	0.04 *
broadcast vs seedrow (25Cl,KCl)	1	0.35	0.05 *	0.45	0.09
all 0 vs 25 KCl	1	0.0001 **	0.004 **	0.002 **	0.006 **
all 0 vs 50 KCl	1	0.0001 **	0.0001 **	0.0008 **	0.0002 **
all 0 vs 25 NaCl	1	0.003 **	0.0001 **	0.009 **	0.0005 **
all 0 vs 50 NaCl	1	0.0001 **	0.0001 **	0.0001 **	0.0001 **
C.V. (%)		23.9	17.6	27.3	20.5

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Yields and Grain Quality at Maturity

Treatment did not have a significant effect on grain yield for Katepwa wheat in any of the four experiments conducted (Table 4.4). Results of studies conducted in South Dakota regarding the effect of soil Cl^- content on the frequency of yield responses of cereals to Cl^- fertilization (Fixen et al. 1986a,1987) would indicate that, based on soil Cl^- content, yield responses to the application of Cl^- fertilizers were likely in our field experiments. In our study, all sites contained less than the 66 kg Cl^- ha^{-1} to 60 cm

recommended by Fixen et al. (1987). In fact, all sites contained 33 kg Cl^- ha^{-1} or less to 60 cm. In studies by Fixen et al. (1987), a frequency of yield response in hard red spring wheat of 69% was observed on soils testing less than 33 kg Cl^- ha^{-1} to 60 cm. Fixen et al. (1986a) reported near maximum yields of spring wheat on soils testing greater than 43.5 kg Cl^- ha^{-1} to 60 cm or 75 kg Cl^- ha^{-1} to 120 cm. On the basis of soil Cl^- content to 60 cm or to 120 cm, all sites in our study would be considered responsive.

Table 4.4. Effect of chloride fertilizer on grain yield for Katepwa wheat in 1989 and 1990

Treatment		Grain yield (kg ha^{-1})			
		1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Anola	Darlingford	Anola	Darlingford
Treatment means					
KCl	0	3095	1668	2520	4034
KCl	25	3123	1896	2544	4257
KCl	50	3308	1612	2389	4306
NaCl	0	3077	1783	2476	4543
NaCl	25	3197	1525	2300	4351
NaCl	50	3344	1821	2267	4264
KCl (S)†	25	3223	2069	2459	4343
Group means					
KCl		3175	1725	2484	4199
NaCl		3206	1709	2348	4386
LSD (P=0.05)		ns	ns	ns	ns
	0	3086	1725	2498	4289
	25	3160	1716	2422	4304
	50	3326	1710	2328	4285
LSD (P=0.05)		ns	ns	ns	ns

ANOVA	df	Pr > F			
Source (S)	1	0.79	0.85	0.30	0.19
Rate (R)	1	0.24	0.99	0.57	0.99
S*R	2	0.95	0.02 *	0.82	0.25
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.69	0.42	0.23	0.89
broadcast vs seedrow (25Cl,KCl)	1	0.61	0.23	0.69	0.75
all 0 vs 25 KCl	1	0.83	0.17	0.80	0.89
all 0 vs 50 KCl	1	0.20	0.36	0.56	0.94
all 0 vs 25 NaCl	1	0.51	0.11	0.29	0.79
all 0 vs 50 NaCl	1	0.14	0.44	0.22	0.91
C.V. (%)		9.6	12.6	13.8	9.5

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Treatment did not have a significant effect on straw yield of Katepwa wheat in any of the four experiments conducted (Table E.1 in Appendix).

The addition of Cl^- did not have a consistent, significant effect on thousand kernel weight for Katepwa wheat in 1989 or in 1990 (Table 4.5). In contrast, in two of four common root rot experiments (Section 3.3.2), Cl^- applications as NaCl were found to significantly increase thousand kernel weight for Katepwa wheat over that of KCl, likely as a response by the plant to the deleterious effects of NaCl on plant emergence early in the season. However, in the chloride nutrition study, soil crusting in NaCl treatments and consequent reductions in plant stand were not apparent.

Table 4.5. Effect of chloride fertilizer on thousand kernel weight for Katepwa wheat in 1989 and 1990

Treatment		Thousand kernel weight (g per 1000 kernels)			
		1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Anola	Darlingford	Anola	Darlingford
Treatment means					
KCl	0	37.4	20.4	29.7	34.8
KCl	25	32.2	20.3	28.6	35.9
KCl	50	32.7	19.6	28.2	36.9
NaCl	0	32.0	19.9	29.1	36.0
NaCl	25	32.3	18.0	28.4	36.1
NaCl	50	32.5	20.2	28.4	36.4
KCl (S)†	25	32.9	21.1	29.4	35.7
Group means					
KCl		34.1	20.1	28.8	35.9
NaCl		32.3	19.4	28.6	36.2
LSD (P=0.05)		1.7	ns	ns	ns
	0	34.7	20.1	29.4	35.4
	25	32.2	19.1	28.5	36.0
	50	32.6	19.9	28.3	36.7
LSD (P=0.05)		~2.0‡	ns	ns	0.8

ANOVA	df	Pr > F			
Source (S)	1	0.04 *	0.21	0.70	0.32
Rate (R)	1	0.04 *	0.35	0.19	0.01 *
S*R	2	0.03 *	0.14	0.85	0.12
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.96	0.28	0.97	0.75
broadcast vs seedrow (25Cl,KCl)	1	0.71	0.45	0.32	0.82
all 0 vs 25 KCl	1	0.03 *	0.88	0.26	0.34
all 0 vs 50 KCl	1	0.08	0.56	0.11	0.004 **
all 0 vs 25 NaCl	1	0.04 *	0.03 *	0.17	0.16
all 0 vs 50 NaCl	1	0.06	0.93	0.16	0.04 *
C.V. (%)		6.1	8.4	4.5	2.3

† (S) indicates placement of chloride fertilizer in the seed row
‡ LSD for comparison between rates 0 and 25 is 2.1, 0 and 50 is 2.1 and 25 and 50 is 2.0.
*, ** Significant at the 0.05 and 0.01 levels respectively.

4.4 Summary and Conclusions

The concentration of Cl^- in plant tissue for Katepwa wheat was found to increase significantly with increasing rates of Cl^- fertilizer. Results of studies conducted in South Dakota (Fixen et al. 1986a, 1987) would indicate that, based on soil Cl^- content, yield responses to Cl^- fertilization were likely in our study. However, Cl^- applications did not result in a significant increase in grain yield or straw yield in any of the four experiments conducted. Very similar results were obtained in common root rot experiments with Katepwa wheat conducted in Manitoba in 1989 and 1990 (Section 3.3.2).

The lack of response observed in the Cl^- nutrition studies conducted at Anola and Darlingford may be due, in part, to the cultivar of wheat grown. Cultivar trials (Section 5) conducted in 1990 and 1991 have indicated than Katepwa tends to be less responsive to Cl^- than other wheat cultivars grown in Manitoba.

5. CULTIVAR STUDIES

5.1 Introduction

Cl^- fertilizer applications were found to have minimal effects on disease severity, grain yield and grain quality for Katepwa wheat and Bedford barley in field studies conducted in Manitoba in 1989 and 1990 (Sections 3 and 4). Based on the results of experiments conducted in North and South Dakota (Fixen et al. 1986a,b,1987; Goos et al. 1987a), responses to the application of Cl^--containing fertilizers had been anticipated in the Manitoba studies. The limited responses to Cl^- observed in Bedford barley and Katepwa wheat may have been due, in part, to the cultivars grown.

Information regarding the Cl^- responsiveness of wheat and barley cultivars commonly grown in Canada is limited. However, studies conducted in the United States have demonstrated differences among cultivars in the frequency and magnitude of positive responses to Cl^- fertilizer applications. In a study with spring wheat conducted in South Dakota, the application of Cl^- increased grain yield of Marshall by an average 470 kg ha^{-1} in three of three field experiments, but did not significantly increase grain yield of Guard in any of three field experiments (Cholick et al. 1986). American barley cultivars have also been shown to differ, although not significantly, in their responsiveness to Cl^- (Gelderman et al. 1988). In a study of five barley cultivars tested for two site-years, the application of KCl resulted in an average yield increase of 215 kg ha^{-1} for each of three cultivars tested, but had little effect on grain yield for the other two cultivars included in the study.

Characterization of Manitoba's recommended cultivars with respect to their responsiveness to Cl^- may help predict the occurrence of yield responses to the

application of Cl^--containing fertilizers. Field studies were conducted in 1990 and 1991 to investigate the effect of Cl^- fertilizer applications on nutrient concentrations in plant tissue, grain yield and grain quality for cultivars of barley and spring wheat commonly grown in Manitoba.

5.2 Materials and Methods

A factorial experiment consisting of four cultivars and three fertilizer treatments was conducted at a total of four sites for each of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). In 1990, the barley cultivar experiment was conducted at Portage adjacent to the site used for the 1990 common root rot experiment (Table 3.2); the wheat cultivar trial was conducted at Anola adjacent to the site used for the 1990 Cl^- nutrition study (Table 4.1). In 1991, wheat and barley experiments were conducted at Anola, Portage and Winnipeg (Table 5.1). At all sites, soil samples were taken in the spring prior to plot establishment and analyzed for extractable Cl^- using the mercuric thiocyanate procedure described by Fixen et al. (1988). The application of Cl^- fertilizer would be required according to current South Dakota soil test guidelines which recommend a total soil Cl^- content to 60 cm plus fertilizer Cl^- content of 66 kg Cl^- ha^{-1} (Fixen et al. 1987).

Fertilizer treatments included a control, 50 kg Cl^- ha^{-1} as broadcast KCl and 50 kg Cl^- ha^{-1} as broadcast NaCl. In 1991, the same fertilizer treatments were applied; however, $CaCl_2$ was used in place of NaCl. A randomized complete block design using six replications was employed at all sites. Subplots consisted of 6 drill rows 6 m in length with 18 cm spacings between rows. Alleys and border areas were seeded to wheat or barley in order to reduce edge effects.

Table 5.1. Physical and chemical characteristics of soils used in 1991 field studies

Characteristic†	Depth (cm)	Site		
		Anola	Portage	Winnipeg
Legal Location		NE23-10-6E	SE7-11-8W	-
Soil Name		Semple	Burnside	Riverdale
Texture		silty clay	clay loam	silty clay
pH	0 to 15	7.8	6.7	7.6
Organic C (%)	0 to 15	6.0	4.0	3.3
	15 to 30	3.9	3.1	3.2
Carbonates (% CO_3)	0 to 15	4.3	0.1	1.7
	15 to 30	10.9	0.4	2.9
NO_3^--N (mg kg^{-1})‡	0 to 60	8	8	13
	60 to 120	9	33	26
$NaHCO_3$-extr. P (mg kg^{-1})	0 to 15	7	11	80
	15 to 30	2	3	62
CH_3COONH_4-extr. K (mg kg^{-1})	0 to 15	408	196	441
	15 to 30	288	125	421
SO_4^{2-}-S (mg kg^{-1})‡	0 to 60	5	105	3
	60 to 120	30	1289	5
Cl^- (mg kg^{-1})	0 to 15	3.1	1.3	2.9
	15 to 30	4.4	1.1	2.6
	30 to 60	6.2	1.9	1.8
	60 to 90	2.6	23.0	2.0
	90 to 120	2.1	16.7	2.1
(Estimated kg ha^{-1})	0 to 60	40	12	18
	60 to 120	19	159	16
DTPA-extr. Cu (mg kg^{-1})	0 to 15	1.7	0.9	2.6
	15 to 30	2.3	1.0	2.8
DTPA-extr. Mn (mg kg^{-1})	0 to 15	9	22	19
	15 to 30	5	12	19
DTPA-extr. Zn (mg kg^{-1})	0 to 15	1.1	3.2	2.4
	15 to 30	0.4	2.7	2.4
DTPA-extr. Fe (mg kg^{-1})	0 to 15	20	35	25
	15 to 30	24	23	26

† Methods used for soil analysis are described in Appendix A.

‡ Concentrations of NO_3^--N and SO_4^{2-}-S in 0 to 60 cm depth established according to weighted average of concentrations in 0 to 15, 15 to 30 and 30 to 60 cm depths; concentrations in 60 to 120 cm depth established according to weighted average of 60 to 90 and 90 to 120 cm depths.

The cultivars Bedford, Brier, Heartland and Argyle were used in all barley cultivar experiments. All cultivars of barley grown were recommended for Manitoba in 1990 and 1991. Bedford, Brier and Heartland are 6-row feed cultivars. Argyle is a 6-row barley suitable for malting or feed purposes. The cultivars Katepwa, Roblin, Biggar and Marshall were used for all wheat cultivar experiments. Katepwa, Roblin and Biggar were recommended cultivars for Manitoba in 1990 and 1991. Katepwa and Roblin are high quality Canadian Western Red Spring wheat while Biggar is a red, medium quality Canadian Prairie Spring wheat. Marshall, which is not recommended in Manitoba, is an American semi-dwarf hard red spring wheat. Marshall was included because studies conducted in the Northern United States have demonstrated this cultivar to be responsive to Cl^- fertilizer applications.

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

Basal applications of macronutrients were made to meet or exceed recommendations of the Manitoba Provincial Soil Testing Laboratory. At Portage, 100 kg N ha^{-1} as anhydrous ammonia was applied by the producer in the fall of 1989 prior to establishment of the 1990 plot. At Anola in 1990, approximately 45 kg N ha^{-1} as urea was hand broadcast in the spring prior to seeding. At all 1991 sites, 100 kg N ha^{-1} as ammonium nitrate was hand broadcast in the spring prior to seeding. Fertilizer was incorporated prior to seeding except in 1991 at Anola and at Winnipeg where the crop was seeded directly without spring tillage. At all sites monoammonium phosphate was placed with the seed at time of seeding at a rate of 13 kg P ha^{-1} and 7 kg N ha^{-1}. At

Anola in 1991, an additional 25 kg N ha^{-1} as ammonium nitrate was hand broadcast approximately two weeks after seeding.

Herbicides were applied at recommended rates for the control of weeds.

Sites were sampled at midseason and maturity. The midseason harvest corresponded to approximately the boot to heading stage for all cultivars grown. At time of harvest, a measurement of crop advancement based on the physiological stage of the majority of plants within individual subplots was recorded using the Feekes scale.

In 1990, midseason harvest consisted of the shoot portion of plants from 3 m of one inside drill row; in 1991, midseason harvest consisted of the shoot portion of plants from 0.5 m of three drill rows collected from two areas within each subplot. Samples were oven dried at 68° C, weighed to determine dry matter yield and ground with a Wiley mill to pass a 2 mm sieve. Concentrations of Cl^-, NO_3^-, NH_4^+, K, Cu, and Mn in plant tissue were determined at midseason at all sites in 1990 and 1991. The concentration of Zn in plant tissue was determined in 1991 only. Cl^- was determined by $AgNO_3$ titration procedure (LaCroix et al. 1970). Plant tissue NO_3^- and NH_4^+ were extracted with 2 M KCl (Milham et al. 1970) and determined by steam distillation (Keeney and Nelson 1982). K, Cu, Mn, and Zn were determined by atomic absorption of a nitric perchloric digest (Isaac and Kerber 1971). (A complete description of procedures used for plant tissue analysis has been included in Appendix B.) Plant uptake of Cl^- was calculated as the product of midseason dry matter yield and Cl^- concentration in plant tissue.

After heading, cursory foliar disease ratings based on the height of disease lesions in the crop canopy and the severity of disease were conducted for selected treatments at selected sites. The rating system used was purely descriptive, not quantitative. Foliar diseases present were neither identified nor differentiated from one another. In 1991, all

wheat cultivars at Winnipeg and at Portage were rated. At Anola in 1990 and at Portage in 1991, only Katepwa and Marshall wheat were rated. In 1990, ratings of Bedford and Brier barley were conducted at Portage.

Final harvest consisted of the shoot portion of plants from 3 m of two inside drill rows from each subplot. Samples were cut by hand approximately 2.5 cm from the soil surface. Samples were air dried and threshed with a stationary thresher. Grain yield, straw yield, thousand kernel weight, hectolitre weight and barley kernel plumpness were determined. Hectolitre weight and kernel plumpness were determined according to methods outlined by the Canadian Grain Commission (1990). Thousand kernel weight was based on a random subsample of 200 kernels per subplot. In 1991 only, a subsample of grain was ground with a Wiley mill to pass a 2 mm sieve and total N concentration in grain samples determined by a conventional Kjeldahl procedure (Schuman et al. 1973).

Analysis of variance was conducted and LSD's calculated using the PROC GLM procedure (SAS Institute Inc. 1988). Single degree of freedom contrasts were used to further analyze treatment effects.

5.3 Results and Discussion

In 1990, the Anola and Portage sites received adequate precipitation during most of the growing season. Dry conditions later in the season may have limited grain fill. At Anola, uneven crop development occurred throughout most of the growing season due primarily to uneven germination caused by a poor seedbed. By final harvest, however, the unevenness in crop development evident at the Anola site during the growing season was minimal.

In 1991, at all field sites, high levels of precipitation occurred early in the growing season followed by drier weather during the grain fill period. High levels of disease and poor grain fill later in the season limited final grain yields. At Anola, excess moisture prior to midseason restricted crop growth and resulted in uneven crop development throughout the season.

5.3.1 Barley

Crop Maturity, Yields and Plant Tissue Nutrient Concentrations at Midseason

At Portage in 1990, a significant treatment effect and a significant cultivar × treatment interaction were observed in advancement in crop maturity for barley (Table 5.2). Contrasts indicated that Cl^- applications resulted in very small, statistically significant advancements in crop maturity for Bedford, Brier and Argyle but not for Heartland. In Brier and Argyle, the observed advancement in crop maturity with the application of Cl^- appeared to have been due largely to the effect of KCl. For Brier, the application of KCl resulted in a statistically significant advancement in crop maturity as compared to the NaCl treatment. The same trend was apparent for Argyle, but the effect was not statistically significant ($P=0.11$). In wheat, K fertilizer has been shown to advance time of anthesis (Haeder and Beringer 1981). In contrast to the 1990 data, in 1991, Cl^- applications did not have a significant effect on advancement in crop maturity for any of the cultivars at any of the sites. Cl^- applications tended to advance the maturity of Bedford at Portage in 1991 ($P=0.06$), but the effect was very small and not statistically significant. At all sites except Anola in 1991, very small but statistically significant differences in advancement in crop maturity were observed among cultivars.

The application of 50 kg Cl^- ha^{-1} did not have a significant effect on midseason

Table 5.2. Effect of chloride fertilizer on advancement in crop maturity for four barley cultivars

Treatment			Feekes rating			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	10.08	10.21	10.09	10.30
50	K	Bedford	10.13	10.22	10.13	10.33
50	Na or Ca	Bedford	10.18	10.19	10.12	10.30
0	-	Brier	10.12	10.19	10.09	10.27
50	K	Brier	10.25	10.19	10.09	10.27
50	Na or Ca	Brier	10.17	10.18	10.10	10.27
0	-	Argyle	10.05	10.18	10.08	10.25
50	K	Argyle	10.13	10.18	10.09	10.27
50	Na or Ca	Argyle	10.08	10.21	10.09	10.23
0	-	Heartland	10.08	10.19	10.11	10.40
50	K	Heartland	10.06	10.20	10.13	10.35
50	Na or Ca	Heartland	10.08	10.20	10.11	10.40
Group means						
0	-		10.08	10.19	10.09	10.30
50	K		10.14	10.20	10.11	10.30
50	Na or Ca		10.13	10.19	10.10	10.30
LSD (P=0.05)			0.03	ns	ns	ns
		Bedford	10.13	10.21	10.11	10.31
		Brier	10.18	10.19	10.09	10.27
		Argyle	10.09	10.19	10.09	10.25
		Heartland	10.07	10.20	10.12	10.38
LSD (P=0.05)			0.04	ns	0.02	0.03

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.38	0.01 **	0.0001
Treatment (T)		2	0.0008	0.89	0.11	0.93
C*T		6	0.007 **	0.59	0.76	0.21
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.18	0.22	0.64	0.20
	0 vs 50 Cl$^-$ (both	1	0.01 **	0.81	0.06	0.46
Brier	KCl vs NaCl or $CaCl_2$	1	0.0009	0.41	0.64	1.00
	0 vs 50 Cl$^-$ (both	1	0.001 **	0.63	0.79	1.00
Argyle	KCl vs NaCl or $CaCl_2$	1	0.11	0.22	1.00	0.20
	0 vs 50 Cl$^-$ (both	1	0.03 *	0.47	0.28	1.00
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.59	1.00	0.16	0.06
	0 vs 50 Cl$^-$ (both	1	0.53	0.63	0.42	0.27
C.V. (%)			0.05	0.34	0.30	0.44

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

dry matter yield at Portage in 1990 (Table 5.3). The overall significant effect of treatment at this site appeared to be the result of significantly higher midseason dry matter yields in KCl than in NaCl treatments for Argyle and Heartland. KCl also tended to result in higher midseason dry matter yields than NaCl for Brier, but the effect was not significant (P=0.09). It is likely that Na^+ adversely affected soil structure at the Portage site in 1990. Surface crusting and restricted plant emergence in NaCl treatments were apparent at Portage in 1990. In an adjoining experimental plot, plant density of barley were found to be significantly reduced by the addition of 50 kg Cl^- ha^{-1} as NaCl (Section 3.3.1). Due to the apparent deleterious effects of Na^+, $CaCl_2$ was used in place of NaCl in 1991. At Portage in 1990, the addition of 50 kg Cl^- ha^{-1} as KCl increased midseason dry matter yield over the control treatment for Brier, Argyle and Heartland. The Cl^- component of KCl may have been responsible for this effect; however, this cannot be confirmed since the other Cl^- source, NaCl, resulted in reductions in midseason dry matter yield due to the deleterious effects of Na^+. In 1991, the application of 50 kg Cl^- ha^{-1} as either KCl or $CaCl_2$ did not have a significant effect on midseason dry matter yield for any of the cultivars tested at any of the sites.

The addition of 50 kg Cl^- ha^{-1} significantly increased Cl^- concentration for all cultivars at all sites (Table 5.4). A significant cultivar × treatment interaction was evident at Portage in 1991; however, the reason for this effect was not readily apparent. In general, fertilizer source did not have a significant effect on concentration of Cl^- in plant tissue. With the exception of the Anola site in 1991, dramatic, significant differences in Cl^- concentration in plant tissue were noted among barley cultivars. The same trend was apparent at Anola in 1991, but the effect was not significant (P=0.14). In contrast, Goos et al. (1987a) found no difference between the Cl^- concentration of two cultivars of

Table 5.3. Effect of chloride fertilizer on midseason dry matter yield for four barley cultivars

Treatment			Midseason dry matter yield (kg ha^{-1})			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	3443	4965	5156	7115
50	K	Bedford	3106	4668	5009	6890
50	Na or Ca	Bedford	3237	4818	4856	6990
0	-	Brier	3244	4371	4649	7171
50	K	Brier	3656	4843	4671	7227
50	Na or Ca	Brier	3106	4553	4837	7449
0	-	Argyle	2597	4197	4490	6621
50	K	Argyle	3050	4200	4597	6262
50	Na or Ca	Argyle	2244	4499	4771	6805
0	-	Heartland	2240	4315	4509	6349
50	K	Heartland	2734	4034	4765	6421
50	Na or Ca	Heartland	2053	4465	4806	6321
Group means						
0	-		2881	4462	4701	6814
50	K		3136	4436	4760	6700
50	Na or Ca		2660	4584	4817	6891
LSD (P=0.05)			322	ns	ns	ns
		Bedford	3262	4817	5007	6998
		Brier	3335	4589	4719	7282
		Argyle	2630	4298	4619	6563
		Heartland	2342	4271	4693	6364
LSD (P=0.05)			372	367	ns	358

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.01 **	0.08	0.0001
Treatment (T)		2	0.02 *	0.61	0.69	0.47
C*T		6	0.37	0.52	0.72	0.78
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.68	0.64	0.57	0.75
	0 vs 50 Cl$^-$ (both	1	0.33	0.42	0.34	0.52
Brier	KCl vs NaCl or $CaCl_2$	1	0.09	0.36	0.54	0.48
	0 vs 50 Cl$^-$ (both	1	0.62	0.24	0.65	0.54
Argyle	KCl vs NaCl or $CaCl_2$	1	0.02 *	0.35	0.52	0.08
	0 vs 50 Cl$^-$ (both	1	0.86	0.58	0.41	0.75
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.04 *	0.18	0.88	0.75
	0 vs 50 Cl$^-$ (both	1	0.58	0.81	0.24	0.94
C.V. (%)			17.2	12.2	9.8	7.9

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.4. Effect of chloride fertilizer on plant tissue chloride concentration for four barley cultivars

Treatment			Plant tissue Cl^- concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	6121	1477	8219	882
50	K	Bedford	13788	6957	15349	8033
50	Na or Ca	Bedford	13457	7163	15503	7697
0	-	Brier	6547	1823	7992	850
50	K	Brier	15298	8644	17758	7637
50	Na or Ca	Brier	15215	7858	18616	7208
0	-	Argyle	7033	1238	8624	1025
50	K	Argyle	15881	7638	19018	9432
50	Na or Ca	Argyle	15436	9465	18207	8855
0	-	Heartland	5523	1631	8683	886
50	K	Heartland	15778	8819	15954	8609
50	Na or Ca	Heartland	14863	8477	16187	9362
Group means						
0	-		6306	1542	8380	911
50	K		15186	8014	17020	8428
50	Na or Ca		14743	8241	17128	8280
LSD (P=0.05)			929	881	929	770
		Bedford	11122	5199	13024	5537
		Brier	12353	6109	14789	5232
		Argyle	12783	6114	15283	6437
		Heartland	12054	6309	13608	6286
LSD (P=0.05)			1072	ns	1073	889

ANOVA		df	Pr > F			
Cultivar (C)		3	0.02 *	0.14	0.0003	0.02 *
Treatment (T)		2	0.0001	0.0001	0.0001	0.0001
C*T		6	0.61	0.25	0.05 *	0.43
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.72	0.82	0.87	0.66
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Brier	KCl vs NaCl or $CaCl_2$	1	0.93	0.38	0.36	0.58
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Argyle	KCl vs NaCl or $CaCl_2$	1	0.63	0.04 *	0.39	0.46
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.33	0.70	0.80	0.33
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
C.V. (%)			13.3	25.7	11.3	22.7

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

barley. Our study and Goos' study differed in that Goos et al. (1987a) collected plant tissue samples at the same stage of advancement for the two barley cultivars studied; in the our study, very small but significant differences in crop maturity occurred among cultivars at time of sampling at Portage in 1990 and 1991 and at Winnipeg in 1991 (Table 5.2). Differences among cultivars in the concentration of Cl^- in plant tissue may have been due, in part, to these differences in crop maturity at time of sampling. In spring wheat, Cl^- concentrations in plant tissue have been found to vary substantially during the growing season (Schumacher 1988). At Anola in 1991, cultivars tended to differ in concentration of Cl^- in plant tissue even though advancement in crop maturity at time of sampling was virtually the same for all cultivars.

Cl^- uptake for all cultivars at all sites was significantly increased by the application of 50 kg Cl^- ha^{-1} (Table 5.5). At Anola in 1990, Cl^- uptake from KCl treatments was significantly higher than from NaCl treatments in Argyle and Heartland. Observed differences in Cl^- uptake appeared to be due to reductions in midseason dry matter yield where NaCl had been applied (Table 5.3), not due to differences in the ability of the fertilizer sources to supply Cl^- to the plant (Table 5.4). For Argyle at Anola in 1991, plant uptake of Cl^- was significantly higher in $CaCl_2$ than in KCl treatments due to a higher Cl^- concentration in plant tissue (Table 5.4), not due to differences in dry matter yields (Table 5.3).

According to guidelines utilized by the Manitoba Provincial Soil Testing Lab, K concentrations in plant tissue were sufficient for all treatments at all sites (Table 5.6). In general, K concentrations in plant tissue did not differ with fertilizer treatment. These data indicated a low probability for a K response and lent further support to the claim that responses observed were due to the Cl^- component of the fertilizers applied.

Table 5.5. Effect of chloride fertilizer on midseason chloride uptake by four barley cultivars

Treatment			Cl^- uptake (kg ha^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	22.3	7.4	42.1	6.3
50	K	Bedford	43.9	32.9	76.2	55.5
50	Na or Ca	Bedford	43.8	35.1	75.1	54.0
0	-	Brier	21.2	8.0	36.9	6.1
50	K	Brier	56.0	42.0	82.7	55.3
50	Na or Ca	Brier	49.2	36.9	89.9	54.5
0	-	Argyle	18.7	5.2	38.5	6.8
50	K	Argyle	48.8	33.0	87.3	59.0
50	Na or Ca	Argyle	34.4	42.9	86.3	60.2
0	-	Heartland	12.9	7.1	39.1	5.6
50	K	Heartland	43.5	35.1	75.9	55.4
50	Na or Ca	Heartland	30.6	37.7	77.4	57.9
Group means						
0	-		18.8	6.9	39.1	6.2
50	K		48.0	35.8	80.5	56.3
50	Na or Ca		39.5	38.2	82.2	56.7
LSD (P=0.05)			5.2	4.9	5.2	5.6
		Bedford	36.7	25.2	64.5	38.6
		Brier	42.1	29.0	69.8	38.6
		Argyle	34.0	27.1	70.7	42.0
		Heartland	29.0	26.6	64.1	39.6
LSD (P=0.05)			6.0	5.7	6.0	6.4

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0006	0.62	0.06	0.69
Treatment (T)		2	0.0001	0.0001	0.0001	0.0001
C*T		6	0.28	0.46	0.12	0.99
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.99	0.65	0.83	0.79
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Brier	KCl vs NaCl or $CaCl_2$	1	0.19	0.31	0.17	0.89
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Argyle	KCl vs NaCl or $CaCl_2$	1	0.007 **	0.05 *	0.85	0.83
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.02 *	0.60	0.77	0.65
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
C.V. (%)			25.3	31.7	13.4	24.2

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.6. Effect of chloride fertilizer on plant tissue potassium concentration for four barley cultivars

Treatment			Plant tissue K concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	2.54	1.81	2.18	2.70
50	K	Bedford	2.51	1.67	2.20	2.66
50	Na or Ca	Bedford	2.49	1.66	2.10	2.86
0	-	Brier	2.56	1.77	2.41	2.80
50	K	Brier	2.75	1.90	2.36	2.98
50	Na or Ca	Brier	2.73	1.87	2.31	2.98
0	-	Argyle	2.77	1.93	2.38	2.91
50	K	Argyle	2.63	2.02	2.44	2.70
50	Na or Ca	Argyle	2.67	2.02	2.39	2.88
0	-	Heartland	2.81	1.73	2.33	2.83
50	K	Heartland	2.80	1.78	2.23	3.01
50	Na or Ca	Heartland	2.82	1.87	2.46	3.02
Group means						
0	-		2.67	1.81	2.33	2.81
50	K		2.67	1.84	2.31	2.84
50	Na or Ca		2.68	1.85	2.31	2.93
LSD (P=0.05)			ns	ns	ns	ns
		Bedford	2.51	1.71	2.16	2.74
		Brier	2.68	1.85	2.36	2.92
		Argyle	2.68	1.99	2.40	2.83
		Heartland	2.81	1.79	2.34	2.95
LSD (P=0.05)			0.13	0.10	0.12	ns

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0003	0.0001	0.0007	0.24
Treatment (T)		2	0.99	0.58	0.93	0.43
C*T		6	0.52	0.19	0.34	0.81
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.91	0.97	0.31	0.32
	0 vs 50 Cl^- (both	1	0.71	0.06	0.72	0.73
Brier	KCl vs NaCl or $CaCl_2$	1	0.87	0.72	0.63	0.99
	0 vs 50 Cl^- (both	1	0.07	0.14	0.38	0.31
Argyle	KCl vs NaCl or $CaCl_2$	1	0.73	0.92	0.68	0.38
	0 vs 50 Cl^- (both	1	0.21	0.24	0.71	0.46
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.84	0.34	0.04 *	0.93
	0 vs 50 Cl^- (both	1	0.99	0.20	0.90	0.28
C.V. (%)			7.3	8.3	7.7	11.8

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

An overall effect of fertilizer treatment on the concentration of Mn in plant tissue was evident at Portage in 1990 (P=0.0004), at Anola in 1991 (P=0.10) and at Winnipeg in 1991 (P=0.07) (Table 5.7). Observed effects of treatment were likely the result of reductions by Cl^- in Mn concentration in plant tissue for several cultivars. Contrasts indicated that the addition of 50 kg Cl^- ha^{-1} significantly reduced Mn concentration in plant tissue for Bedford at Portage in 1990, for Argyle at Portage in 1990 and at Anola in 1991 and for Brier at Winnipeg in 1991. The same trend was apparent in Brier (P=0.10) and Heartland (P=0.09) at Portage in 1990 and in Bedford at Portage in 1991 (P=0.07), but the effects were not significant. Cl^- applications were found to have negligible effects on midseason dry matter accumulations; thus, observed reductions in Mn concentrations in plant tissue cannot be attributed to a dilution effect. The reason for reductions in Mn concentrations with the addition of Cl^- is not known. According to guidelines utilized by the Manitoba Provincial Soil Testing Laboratory, concentrations of Mn in plant tissue were sufficient regardless of the effects of treatment.

The observed reductions in Mn concentration in plant tissue with the application of Cl^- contrasted with the suggestion by Beaton et al. (1988) that Cl^- may enhance the growth of cereals by increasing the availability of Mn to plants. Laboratory studies have shown that the addition of Cl^--containing solutions may increase extractable soil Mn (Westerman et al. 1971). This effect has been demonstrated primarily in acidic soils. The soils used for our study were neutral to alkaline (Tables 3.2, 4.1 and 5.1). A recent study by Khattak and Jarrell (1988) demonstrated that the addition of Cl^- increased extractable Mn of soils with a pH > 7. However, Cl^- concentrations used in the study by Khattak and Jarrell (1988) were substantially higher than those likely to be produced by the addition of a 50 kg Cl^- ha^{-1} rate of fertilizer. Field studies have yet to confirm that

Table 5.7. Effect of chloride fertilizer on midseason plant tissue manganese concentration for four barley cultivars

Treatment			Plant tissue Mn concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	22.1	17.6	25.7	44.5
50	K	Bedford	19.8	17.2	23.1	45.0
50	Na or Ca	Bedford	19.3	17.7	24.4	39.2
0	-	Brier	19.6	16.6	23.9	73.8
50	K	Brier	18.0	14.8	22.7	45.4
50	Na or Ca	Brier	18.0	16.8	23.7	56.9
0	-	Argyle	26.7	20.5	25.6	47.4
50	K	Argyle	24.1	18.2	26.3	43.7
50	Na or Ca	Argyle	24.7	18.1	25.8	42.5
0	-	Heartland	19.8	16.5	23.7	42.5
50	K	Heartland	18.5	15.3	23.4	37.4
50	Na or Ca	Heartland	17.8	15.7	23.1	39.8
Group means						
0	-		22.1	17.8	24.7	52.1
50	K		20.1	16.4	23.9	42.9
50	Na or Ca		19.9	17.1	24.2	44.6
LSD (P=0.05)			1.1	ns	ns	ns
		Bedford	20.4	17.5	24.4	42.9
		Brier	18.5	16.1	23.4	58.7
		Argyle	25.2	18.9	25.9	44.5
		Heartland	18.7	15.8	23.4	39.9
LSD (P=0.05)			1.3	1.5	1.5	9.5

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0003	0.003 **	0.001 **
Treatment (T)		2	0.0004	0.10	0.39	0.07
C*T		6	0.95	0.73	0.68	0.27
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.64	0.75	0.33	0.49
	0 vs 50 Cl^- (both	1	0.01 **	0.91	0.07	0.73
Brier	KCl vs NaCl or $CaCl_2$	1	0.99	0.13	0.41	0.17
	0 vs 50 Cl^- (both	1	0.10	0.52	0.52	0.003 **
Argyle	KCl vs NaCl or $CaCl_2$	1	0.62	0.95	0.72	0.88
	0 vs 50 Cl^- (both	1	0.02 *	0.04 *	0.71	0.55
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.51	0.75	0.82	0.77
	0 vs 50 Cl^- (both	1	0.09	0.35	0.71	0.59
C.V. (%)			9.2	13.1	9.0	30.7

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

typical rates of Cl^- applied in the field would enhance the availability of Mn to wheat and barley grown on neutral to alkaline soils.

In several cases, Cl^- applications were found to have a significant effect on concentrations of Cu in plant tissue (Table F.1 in Appendix). Effects were not consistent, however.

Concentration of Zn in plant tissue was determined in 1991 only. Cl^- applications did not have a significant effect on Zn concentration in plant tissue for any cultivar at any site (Table F.2 in Appendix).

In 1990, the addition of 50 kg Cl^- ha^{-1} as KCl or NaCl did not have a significant effect on NO_3^- concentration in plant tissue for any of the barley cultivars tested (Table 5.8). In 1991, Cl^- additions resulted in an overall significant decrease in NO_3^- concentration in plant tissue at Anola and Portage. The same trend was apparent at Winnipeg, but the effect was not significant ($P=0.12$). In 1991, the application of 50 kg Cl^- ha^{-1} as KCl or $CaCl_2$ significantly reduced NO_3^- concentrations in plant tissue for Bedford and Brier at all three field sites and for Argyle and Heartland at Portage only. Cl^- applications tended to decrease NO_3^- concentration in plant tissue for Heartland at Anola, but the effect was not statistically significant ($P=0.10$). Similarly, results of a study conducted in North Dakota by Goos et al. (1987a) showed that the addition of KCl fertilizer significantly reduced NO_3^- concentration in plant tissue for two barley cultivars at midseason. The magnitude of the reductions in NO_3^- concentration in plant tissue observed at Portage and Winnipeg in 1991 was substantially larger than that reported by Goos et al. (1987a) even though a higher rate of Cl^- had been applied in Goos' experiment. The large amount of variability in NO_3^- concentration in plant tissue evident in our experiment in 1990 may have masked, to some extent, the effects of Cl^-

Table 5.8. Effect of chloride fertilizer on midseason plant tissue nitrate concentration for four barley cultivars

Treatment			Plant tissue NO_3^- concentration (mg N kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	2514	1019	4712	5982
50	K	Bedford	2051	428	3247	4863
50	Na or Ca	Bedford	2572	641	3451	4647
0	-	Brier	2534	1310	6661	6946
50	K	Brier	2532	1035	5422	4939
50	Na or Ca	Brier	2621	758	5213	6240
0	-	Argyle	2634	787	6071	7839
50	K	Argyle	3148	471	4822	8559
50	Na or Ca	Argyle	2789	974	4832	8029
0	-	Heartland	3023	1164	5553	5942
50	K	Heartland	2620	961	4406	5668
50	Na or Ca	Heartland	2562	698	4378	6000
Group means						
0	-		2676	1070	5749	6677
50	K		2588	724	4474	6007
50	Na or Ca		2636	768	4468	6229
LSD (P=0.05)			ns	233	418	ns
		Bedford	2379	696	3803	5164
		Brier	2562	1035	5765	6042
		Argyle	2857	744	5242	8142
		Heartland	2735	941	4779	5870
LSD (P=0.05)			ns	270	483	758

ANOVA		df	Pr > F			
Cultivar (C)		3	0.27	0.05 *	0.0001	0.0001
Treatment (T)		2	0.92	0.008 **	0.0001	0.12
C*T		6	0.64	0.13	0.99	0.09
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.24	0.36	0.63	0.74
	0 vs 50 Cl^- (both	1	0.60	0.02 *	0.0004	0.04 *
Brier	KCl vs NaCl or $CaCl_2$	1	0.84	0.24	0.62	0.05 *
	0 vs 50 Cl^- (both	1	0.91	0.05 *	0.0005	0.02 *
Argyle	KCl vs NaCl or $CaCl_2$	1	0.42	0.04 *	0.98	0.42
	0 vs 50 Cl^- (both	1	0.39	0.75	0.001 **	0.43
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.90	0.26	0.95	0.61
	0 vs 50 Cl^- (both	1	0.26	0.10	0.002 **	0.85
C.V. (%)			29.1	47.3	14.7	18.0

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

fertilization on NO_3^- concentration in plant tissue. However, significant reductions in NO_3^- concentrations in plant tissue with the application of Cl^- were observed at the 1991 Anola site even though greater variability in NO_3^- concentration in plant tissue occurred at this site than at the 1990 Portage site.

Overall, the effect of fertilizer treatment on concentrations of NH_4^+ in plant tissue harvested at midseason was not significant (Table F.3 in Appendix).

In 1990, at the soft dough stage, a cursory assessment of foliar diseases was conducted for Bedford and Brier. Foliar diseases of barley were not rated in 1991. In 1990, the addition of 50 kg Cl^- ha^{-1} as KCl or NaCl did not have a consistent effect on foliar disease for Bedford or for Brier. In studies conducted in North Dakota, Timm et al. (1986) found the application of KCl to produce visible reductions in spot blotch on the flag leaves of barley at one of five sites. No visible reductions in foliar disease were observed for Bedford barley in spot blotch studies conducted in Manitoba in 1989 and 1990 (Section 3.3.1)

Yields and Grain Quality at Maturity

The addition of 50 kg Cl^- ha^{-1} as KCl or NaCl significantly increased grain yield for Heartland at Portage in 1990 only (Table 5.9). Aside from Heartland at Portage in 1990, no significant increases by Cl^- in grain yield were observed for any cultivar at any site. Cl^- applications resulted in a small increase in grain yield for Argyle at Anola in 1991, but the effect was not statistically significant ($P=0.06$). At Portage in 1991, the application of 50 kg Cl^- ha^{-1} as KCl or $CaCl_2$ significantly and substantially decreased grain yield for Bedford barley. This reduction in grain yield for Bedford contrasted with the results of common root rot and spot blotch studies conducted in Manitoba (Section

Table 5.9. Effect of chloride fertilizer on grain yield for four barley cultivars

Treatment			Grain yield (kg ha^{-1})			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	6036	2273	4582	3214
50	K	Bedford	5852	2178	3490	3395
50	Na or Ca	Bedford	5824	2300	3281	3321
0	-	Brier	6100	1997	3565	2930
50	K	Brier	6784	1872	3836	3095
50	Na or Ca	Brier	6348	1983	3657	2770
0	-	Argyle	5701	2062	4364	2661
50	K	Argyle	6196	2211	4196	3217
50	Na or Ca	Argyle	5742	2479	4839	2819
0	-	Heartland	4966	1597	4829	2670
50	K	Heartland	5666	1522	4652	3039
50	Na or Ca	Heartland	6075	1484	4238	3021
Group means						
0	-		5701	1982	4335	2869
50	K		6124	1946	4044	3186
50	Na or Ca		5997	2061	4004	2983
LSD (P=0.05)			ns	ns	ns	ns
		Bedford	5904	2250	3784	3310
		Brier	6411	1950	3686	2931
		Argyle	5879	2251	4466	2899
		Heartland	5569	1534	4573	2910
LSD (P=0.05)			443	193	416	ns

ANOVA		df	Pr > F			
Cultivar (C)		3	0.004 **	0.0001	0.0001	0.26
Treatment (T)		2	0.09	0.37	0.14	0.31
C*T		6	0.19	0.42	0.01 **	0.97
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.94	0.47	0.56	0.86
	0 vs 50 Cl$^-$ (both	1	0.55	0.81	0.0003	0.69
Brier	KCl vs NaCl or $CaCl_2$	1	0.26	0.51	0.62	0.44
	0 vs 50 Cl$^-$ (both	1	0.17	0.63	0.56	0.99
Argyle	KCl vs NaCl or $CaCl_2$	1	0.24	0.11	0.08	0.34
	0 vs 50 Cl$^-$ (both	1	0.42	0.06	0.62	0.32
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.29	0.82	0.25	0.97
	0 vs 50 Cl$^-$ (both	1	0.009 **	0.52	0.22	0.32
C.V. (%)			11.2	14.5	15.1	23.8

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

3.3.1) in which Cl^- significantly increased grain yield for Bedford in two of eight field experiments.

A significant cultivar × treatment interaction occurred at Portage in 1991, likely due to the significant decrease by Cl^- in grain yield of Bedford at this site. No other significant cultivar × treatment interactions were observed. In studies conducted in South Dakota, Gelderman et al. (1988) found that cultivars of barley differed in the magnitude of their yield response to Cl^-, but that the Cl^- × cultivar interaction was not significant (P=0.25).

Caution must be exercised in drawing specific conclusions from these data about the responsiveness or lack thereof for a particular barley cultivar. Firstly, the cultivar Bedford, which had been shown to respond to Cl^- in previous studies, did not respond at any of the four sites in the cultivar study. Secondly, results of the cultivar study appeared to suggest that the significant increase in grain yield observed in Heartland may have been related to the quality of seed planted more so than to characteristics of the cultivar itself. The seedlot of Heartland sown in 1990 was more weathered and had a substantially lower germination percentage than any other seedlot used for the barley cultivar trials. In a recent study conducted in Manitoba using Heartland barley, weathered seed was found to have a much higher infection level of *Fusarium* than unweathered seed (Wytinck et al. 1991). In a review of literature, Fixen (1987) stated that, in a study conducted in Montana, Cl^- fertilization decreased Fusarium root rot in barley. Possibly, in our study, Cl^- increased the yield of Heartland barley by reducing the deleterious effects of *Fusarium* infections, thereby improving seedling vigour and increasing grain yield.

Treatment was not found to have a consistent and significant effect on straw yield

for the barley cultivars tested (Table F.4 in Appendix).

At Winnipeg in 1991, $CaCl_2$ resulted in an overall reduction in thousand kernel weight as compared to the control treatments and the KCl treatments (Table 5.10). Cultivars tended to differ in their response to treatment, but the cultivar × treatment interaction was not significant (P=0.08) at this site. Contrasts indicated that $CaCl_2$ resulted in lower thousand kernel weights than KCl for Argyle (P=0.07) and Brier (P=0.08). The addition of 50 kg Cl^- ha^{-1} significantly decreased thousand kernel weight for Heartland and tended to decrease thousand kernel weight for Brier (P=0.06). Significant effects of treatment overall and cultivar × treatment interactions were not observed at any other sites. However, contrasts indicated that Cl^- applications tended to decrease thousand kernel weight for Heartland at Portage (P=0.15) and for Brier at Anola (P=0.13).

Fertilizer treatment had a significant overall effect on hectolitre weight at Portage in 1990 and at Anola in 1991 (Table 5.11). The same trend was apparent at Portage in 1991 (P=0.08) and at Winnipeg in 1991 (P=0.16), but the effects were not significant. At Anola and Portage in 1991, the application of Cl^- resulted in an overall reduction in hectolitre weight. At the Anola site in 1991, the application of 50 kg Cl^- ha^{-1} significantly decreased hectolitre weight for Bedford, Brier and Argyle. Similarly, at the Portage site in 1991, small, statistically insignificant decreases by Cl^- in hectolitre weight were observed for Bedford (P=0.19), Brier (P=0.19) and Argyle (P=0.12). Contrasts suggested that the overall treatment effect observed at Winnipeg in 1991 was due to a significantly lower hectolitre weight in $CaCl_2$ than in KCl treatments for Argyle and a similar trend for Brier (P=0.13). The reason for the significant overall effect of treatment at Portage in 1990 was not readily apparent.

Table 5.10. Effect of chloride fertilizer on thousand kernel weight for four barley cultivars

Treatment			Thousand kernel weight (g per 1000)			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	36.1	23.7	29.7	28.1
50	K	Bedford	36.5	23.8	29.7	28.3
50	Na or Ca	Bedford	36.1	24.7	29.5	28.1
0	-	Brier	39.2	25.6	27.8	30.3
50	K	Brier	38.5	24.5	28.4	29.1
50	Na or Ca	Brier	38.9	24.5	27.4	26.3
0	-	Argyle	36.2	24.3	30.4	24.3
50	K	Argyle	36.5	24.3	30.1	27.1
50	Na or Ca	Argyle	36.2	23.9	29.7	24.3
0	-	Heartland	37.6	25.4	30.1	33.2
50	K	Heartland	38.2	25.3	29.3	29.8
50	Na or Ca	Heartland	38.5	24.7	29.0	29.0
Group means						
0	-		37.3	24.7	29.5	29.0
50	K		37.4	24.5	29.3	28.6
50	Na or Ca		37.4	24.5	28.9	26.9
LSD (P=0.05)			ns	ns	ns	1.5
		Bedford	36.2	24.1	29.6	28.2
		Brier	38.9	24.8	27.9	28.6
		Argyle	36.3	24.2	30.1	25.2
		Heartland	38.1	25.1	29.5	30.7
LSD (P=0.05)			1.0	0.9	0.9	1.8

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.07	0.0001	0.0001
Treatment (T)		2	0.94	0.74	0.27	0.02 *
C*T		6	0.92	0.54	0.91	0.08
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.62	0.23	0.79	0.88
	0 vs 50 Cl^- (both	1	0.77	0.44	0.87	0.95
Brier	KCl vs NaCl or $CaCl_2$	1	0.62	0.96	0.22	0.08
	0 vs 50 Cl^- (both	1	0.51	0.13	0.89	0.06
Argyle	KCl vs NaCl or $CaCl_2$	1	0.73	0.66	0.66	0.07
	0 vs 50 Cl^- (both	1	0.86	0.85	0.43	0.29
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.73	0.46	0.71	0.63
	0 vs 50 Cl^- (both	1	0.37	0.56	0.15	0.006 **
C.V. (%)			4.0	5.7	4.6	9.4

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.11. Effect of chloride fertilizer on hectolitre weight for four barley cultivars

Treatment			Hectolitre weight (kg hL^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	68.8	58.8	60.6	56.3
50	K	Bedford	68.3	57.2	59.5	56.6
50	Na or Ca	Bedford	67.6	57.1	59.6	55.8
0	-	Brier	63.7	53.8	51.1	49.2
50	K	Brier	63.6	52.0	50.7	48.9
50	Na or Ca	Brier	62.9	51.4	49.6	45.8
0	-	Argyle	63.8	56.2	56.9	49.2
50	K	Argyle	63.7	55.2	56.1	52.4
50	Na or Ca	Argyle	62.7	54.0	55.4	48.2
0	-	Heartland	63.6	56.9	54.2	57.2
50	K	Heartland	63.6	56.5	54.6	53.3
50	Na or Ca	Heartland	62.4	55.8	54.2	55.1
Group means						
0	-		65.0	56.4	55.7	53.0
50	K		64.8	55.2	55.2	52.8
50	Na or Ca		63.9	54.6	54.7	51.2
LSD (P=0.05)			0.8	0.9	0.9	ns
		Bedford	68.2	57.7	59.9	56.2
		Brier	63.4	52.4	50.4	48.0
		Argyle	63.4	55.4	56.1	49.9
		Heartland	63.2	56.4	54.3	55.2
LSD (P=0.05)			0.9	1.0	1.0	2.3

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0001	0.0001	0.0001
Treatment (T)		2	0.02 *	0.0003	0.08	0.16
C*T		6	1.00	0.86	0.78	0.20
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.33	0.87	0.90	0.68
	0 vs 50 Cl^- (both	1	0.20	0.04 *	0.19	0.92
Brier	KCl vs NaCl or $CaCl_2$	1	0.40	0.52	0.21	0.13
	0 vs 50 Cl^- (both	1	0.54	0.007 **	0.19	0.28
Argyle	KCl vs NaCl or $CaCl_2$	1	0.23	0.15	0.44	0.04 *
	0 vs 50 Cl^- (both	1	0.39	0.04 *	0.12	0.53
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.11	0.42	0.61	0.36
	0 vs 50 Cl^- (both	1	0.40	0.31	0.77	0.09
C.V. (%)			2.1	2.7	2.7	6.4

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

At all sites in 1991, the application of 50 kg Cl^- ha^{-1} as KCl or $CaCl_2$ resulted in an overall reduction in the percentage of plump kernels (Table 5.12). Contrasts indicated that Cl^- applications significantly decreased the percentage of plump kernels for Brier and Argyle at Anola in 1991 and for Heartland at Portage and Winnipeg in 1991. Small, statistically insignificant reductions in the percentage of plump kernels were also observed in Brier at Portage (P=0.15) and Winnipeg (0.10) in 1991, in Heartland at Anola in 1991 (P=0.07) and in Bedford at Portage in 1990 (P=0.10). In contrast, Zubrinski et al (1970) found that the addition of KCl to soils with adequate levels of K significantly increased the percentage of plump kernels in malting barley.

A significant overall treatment effect on percentage of thin kernels and a significant cultivar × treatment interaction occurred at Winnipeg in 1991 (Table 5.13). Contrasts showed that the addition of 50 kg Cl^- ha^{-1} significantly increased the percentage of thin kernels for Brier and Heartland at this site. Also, at this site, $CaCl_2$ resulted in a higher percentage of thin kernels than KCl for Bedford and Argyle. Cl^- applications tended to increase the percentage of thin kernels for Bedford at Portage in 1990 (P=0.09) and for Brier (P=0.07) and Heartland (P=0.13) at Portage in 1991.

Total N concentration in grain was determined in 1991 only. At all sites, cultivars were found to differ significantly in total N concentration (Table F.5 in Appendix). For several cultivars, fertilizer treatment was found to have a significant effect on total N concentration. However, effects were not consistent for any cultivar across sites or years (Table F.5 in Appendix) despite significant reductions by Cl^- in the concentration of NO_3^- in plant tissue harvested at midseason (Table 5.8).

Table 5.12. Effect of chloride fertilizer on percent plump kernels for four barley cultivars

Treatment			Plump kernels (%)			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	60.0	18.9	30.3	32.0
50	K	Bedford	55.9	17.4	29.7	30.1
50	Na or Ca	Bedford	50.4	17.4	31.6	27.9
0	-	Brier	55.2	17.0	22.9	39.0
50	K	Brier	56.8	13.5	19.9	32.0
50	Na or Ca	Brier	53.4	10.7	18.3	27.4
0	-	Argyle	69.7	31.7	47.7	33.9
50	K	Argyle	71.5	29.4	45.0	45.3
50	Na or Ca	Argyle	67.5	25.4	44.4	26.3
0	-	Heartland	55.8	24.7	38.1	58.2
50	K	Heartland	56.7	22.4	32.7	42.1
50	Na or Ca	Heartland	55.8	20.0	31.6	46.4
Group means						
0	-		60.1	23.1	34.8	40.8
50	K		60.2	20.7	31.8	37.4
50	Na or Ca		56.8	18.4	31.5	32.0
LSD (P=0.05)			ns	2.1	ns	6.4
		Bedford	55.4	17.9	30.5	30.0
		Brier	55.1	13.7	20.4	32.8
		Argyle	69.5	28.8	45.7	35.2
		Heartland	56.1	22.4	34.1	48.9
LSD (P=0.05)			5.3	2.5	3.4	7.4

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0001	0.0001	0.0001
Treatment (T)		2	0.24	0.0003	0.06	0.03 *
C*T		6	0.84	0.73	0.67	0.09
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.24	0.99	0.51	0.74
	0 vs 50 Cl$^-$ (both	1	0.10	0.40	0.89	0.59
Brier	KCl vs NaCl or $CaCl_2$	1	0.46	0.21	0.59	0.48
	0 vs 50 Cl$^-$ (both	1	0.98	0.01 **	0.15	0.10
Argyle	KCl vs NaCl or $CaCl_2$	1	0.39	0.07	0.84	0.005 **
	0 vs 50 Cl$^-$ (both	1	0.96	0.03 *	0.24	0.73
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.85	0.27	0.72	0.51
	0 vs 50 Cl$^-$ (both	1	0.91	0.07	0.02 *	0.01 **
C.V. (%)			13.5	17.9	15.6	30.2

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.13. Effect of chloride fertilizer on percent thin kernels for four barley cultivars

Treatment			Thin kernels (%)			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	34.8	47.8	55.9	52.1
50	K	Bedford	37.5	46.6	55.3	48.2
50	Na or Ca	Bedford	42.5	46.9	53.7	55.5
0	-	Brier	37.2	48.6	53.4	40.6
50	K	Brier	36.3	44.2	57.2	45.5
50	Na or Ca	Brier	37.8	46.0	55.3	46.8
0	-	Argyle	24.7	47.7	43.5	41.1
50	K	Argyle	23.3	49.0	45.1	40.5
50	Na or Ca	Argyle	25.5	50.0	45.3	46.6
0	-	Heartland	34.2	48.5	47.3	30.1
50	K	Heartland	33.1	49.3	49.5	40.6
50	Na or Ca	Heartland	32.4	47.9	49.8	38.4
Group means						
0	-		32.7	48.1	50.0	41.0
50	K		32.6	47.3	51.8	43.7
50	Na or Ca		34.5	47.7	51.0	46.8
LSD (P=0.05)			ns	ns	ns	2.8
		Bedford	38.2	47.1	55.0	51.9
		Brier	37.1	46.3	55.3	44.3
		Argyle	24.5	48.9	44.7	42.7
		Heartland	33.2	48.5	48.9	36.4
LSD (P=0.05)			4.0	1.9	2.1	3.3

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.02 *	0.0001	0.0001
Treatment (T)		2	0.46	0.58	0.15	0.0005
C*T		6	0.64	0.17	0.45	0.02 *
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.16	0.85	0.36	0.01 **
	0 vs 50 Cl$^-$ (both	1	0.09	0.48	0.36	0.91
Brier	KCl vs NaCl or $CaCl_2$	1	0.67	0.26	0.29	0.66
	0 vs 50 Cl$^-$ (both	1	0.96	0.02 *	0.07	0.03 *
Argyle	KCl vs NaCl or $CaCl_2$	1	0.54	0.56	0.91	0.04 *
	0 vs 50 Cl$^-$ (both	1	0.93	0.20	0.28	0.32
Heartlan	KCl vs NaCl or $CaCl_2$	1	0.83	0.39	0.88	0.44
	0 vs 50 Cl$^-$ (both	1	0.64	0.95	0.13	0.0003
C.V. (%)			18.1	5.9	6.1	11.1

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

5.3.2 Wheat

Crop Maturity, Yields and Plant Tissue Nutrient Concentrations at Midseason

A significant overall treatment effect on advancement in crop maturity and a significant cultivar × treatment interaction were observed at Anola in 1990 and at Portage in 1991 (Table 5.14). Caution must be exercised in the interpretation of 1990 data because advancement in crop maturity at this site was highly variable at time of sampling. Contrasts indicated that a significant advancement in crop maturity for Marshall may account for the significant treatment and cultivar × treatment effects apparent at Anola in 1990. The significant treatment effect and cultivar × treatment interaction observed at Portage in 1991 was likely the result of a very small, but statistically significant advancement in crop maturity for Biggar with the application of Cl^-. Also, in Biggar, the application of KCl resulted in a very small but significant advancement in crop maturity as compared to $CaCl_2$. Visible advancements in the maturity of Biggar and Marshall were noted at Portage and Winnipeg in 1991 but only corresponded to a statistically significant advancement in crop maturity according to the Feekes scale for Biggar at Portage. A rating scale more finely divided than the Feekes scale would likely have been more sensitive for recognizing the very small effects of treatment on crop maturity.

At Anola in 1990, the addition of 50 kg Cl^- ha^{-1} as KCl or NaCl resulted in an overall increase in midseason dry matter yield (Table 5.15). However, contrasts indicated a significant increase in dry matter yield at this site for only the cultivar Roblin. In contrast, Cl^- applications significantly decreased dry matter yields for Roblin at Portage and Anola in 1991. Chloride applications did not have a significant effect on midseason dry matter yield for Katepwa, Biggar or Marshall at any site.

The addition of 50 kg Cl^- ha^{-1} significantly increased the concentration of Cl^- in

Table 5.14. Effect of chloride fertilizer on advancement in crop maturity for four wheat cultivars

Treatment			Feekes rating			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	9.78	9.55	10.12	10.50
50	K	Katepwa	9.74	9.33	10.18	10.50
50	Na or Ca	Katepwa	9.91	9.81	10.21	10.50
0	-	Roblin	10.24	10.50	10.44	10.52
50	K	Roblin	10.28	10.48	10.45	10.52
50	Na or Ca	Roblin	10.31	10.50	10.45	10.52
0	-	Biggar	9.50	8.92	8.50	9.33
50	K	Biggar	9.86	9.50	9.33	9.35
50	Na or Ca	Biggar	9.67	9.08	9.00	9.50
0	-	Marshall	7.83	10.06	10.11	10.40
50	K	Marshall	9.42	10.13	10.23	10.44
50	Na or Ca	Marshall	9.42	10.48	10.23	10.43
Group means						
0	-		9.34	9.76	9.79	10.19
50	K		9.82	9.86	10.05	10.20
50	Na or Ca		9.83	9.97	9.97	10.24
LSD (P=0.05)			0.33	ns	0.16	ns
		Katepwa	9.81	9.56	10.17	10.50
		Roblin	10.28	10.49	10.45	10.52
		Biggar	9.68	9.17	8.94	9.39
		Marshall	8.89	10.22	10.19	10.43
LSD (P=0.05)			0.38	0.49	0.19	0.16

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0001	0.0001	0.0001
Treatment (T)		2	0.004 **	0.60	0.008 **	0.77
C*T		6	0.005 **	0.74	0.02 **	0.97
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.61	0.25	0.88	1.00
	0 vs 50 Cl$^-$ (both	1	0.86	0.96	0.57	1.00
Roblin	KCl vs NaCl or $CaCl_2$	1	0.92	0.95	1.00	1.00
	0 vs 50 Cl$^-$ (both	1	0.86	0.97	0.95	1.00
Biggar	KCl vs NaCl or $CaCl_2$	1	0.56	0.32	0.04 *	0.30
	0 vs 50 Cl$^-$ (both	1	0.35	0.31	0.0001	0.46
Marshall	KCl vs NaCl or $CaCl_2$	1	1.00	0.40	0.96	0.95
	0 vs 50 Cl$^-$ (both	1	0.0001	0.50	0.39	0.76
C.V. (%)			5.8	7.4	2.8	2.4

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.15. Effect of chloride fertilizer on midseason dry matter yield for four wheat cultivars

Treatment			Midseason dry matter yield (kg ha^{-1})			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	2125	2756	3968	5474
50	K	Katepwa	2246	2700	3915	5612
50	Na or Ca	Katepwa	2222	2719	4031	5552
0	-	Roblin	2150	3544	4815	6393
50	K	Roblin	2706	3118	4353	6090
50	Na or Ca	Roblin	2872	2781	4434	6412
0	-	Biggar	2244	2447	3234	4575
50	K	Biggar	2191	2747	3706	4709
50	Na or Ca	Biggar	2428	2428	3334	4531
0	-	Marshall	2147	2990	3803	4978
50	K	Marshall	2206	3128	3571	5406
50	Na or Ca	Marshall	2384	2968	3587	4971
Group means						
0	-		2166	2934	3955	5355
50	K		2337	2923	3886	5454
50	Na or Ca		2476	2724	3846	5367
LSD (P=0.05)			231	ns	ns	ns
		Katepwa	2198	2725	3971	5546
		Roblin	2576	3148	4534	6298
		Biggar	2287	2540	3425	4605
		Marshall	2246	3029	3654	5118
LSD (P=0.05)			267	357	282	284

ANOVA		df	Pr > F			
Cultivar (C)		3	0.03 *	0.005 **	0.0001	0.0001
Treatment (T)		2	0.03 *	0.32	0.67	0.68
C*T		6	0.42	0.49	0.21	0.39
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.91	0.95	0.64	0.81
	0 vs 50 Cl$^-$ (both	1	0.59	0.86	0.98	0.61
Roblin	KCl vs NaCl or $CaCl_2$	1	0.48	0.28	0.74	0.19
	0 vs 50 Cl$^-$ (both	1	0.002 **	0.03 *	0.05 *	0.51
Biggar	KCl vs NaCl or $CaCl_2$	1	0.31	0.31	0.13	0.47
	0 vs 50 Cl$^-$ (both	1	0.74	0.60	0.18	0.83
Marshall	KCl vs NaCl or $CaCl_2$	1	0.44	0.61	0.95	0.08
	0 vs 50 Cl$^-$ (both	1	0.46	0.83	0.29	0.33
C.V. (%)			17.2	18.7	10.8	7.9

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

plant tissue for all cultivars of wheat tested at all sites (Table 5.16). Despite significant increases by Cl^- in the Cl^- concentration in plant tissue for all cultivars, cultivar × treatment interactions were significant at all sites except Anola in 1991 where P=0.07.

Using data from studies conducted in South Dakota, Fixen et al. (1986a) established a critical Cl^- concentration in plant tissue for spring wheat at heading of 1500 μg Cl^- g^{-1} dry weight. In our study, Cl^- concentrations in plant tissue in control treatments from Anola in 1990 and from Winnipeg in 1991 were below this critical concentration of 1500 μg Cl^- g^{-1} dry weight; Cl^- concentrations in plant tissue in control treatments at the remaining sites were above this critical concentration. At all sites, soil Cl^- content was considered 'low', that is less than 66 kg Cl^- ha^{-1} to 60 cm. Regression models developed from South Dakota data to estimate the concentration of Cl^- in plant tissue for spring wheat using soil Cl^- contents (Fixen et al. 1986a) frequently underestimated the concentration of Cl^- in plant tissue for the wheat cultivars tested in our study. This regression model also consistently underestimated Cl^- concentrations in plant tissue in common root rot studies conducted with Katepwa wheat (Section 3.3.2). As noted previously, differences between our studies and South Dakota studies in cultivars grown, stage of crop development at sampling and environment may have influenced concentrations of Cl^- in plant tissue.

Dramatic, significant differences in the concentration of Cl^- in plant tissue harvested at midseason were noted among wheat cultivars (Table 5.16). The differences among cultivars may be due, in part, to differences in crop maturity among cultivars at time of sampling (Table 5.14). Schumacher (1988) found Cl^- concentrations in plant tissue for spring wheat to vary substantially during the growing season. In our study, Cl^- sources were generally equivalent in their ability to provide Cl^- to the plant. However, at

Table 5.16. Effect of chloride fertilizer on midseason plant tissue chloride concentration for four wheat cultivars

Treatment			Plant tissue Cl^- concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	2378	1122	3597	1003
50	K	Katepwa	8013	5890	10462	7434
50	Na or Ca	Katepwa	6871	5314	10459	8039
0	-	Roblin	2005	980	3077	781
50	K	Roblin	6016	4823	8214	5609
50	Na or Ca	Roblin	6050	4752	8619	5849
0	-	Biggar	2645	1022	5999	1082
50	K	Biggar	8916	7164	13366	9378
50	Na or Ca	Biggar	9448	7382	13561	10830
0	-	Marshall	2640	1301	5027	967
50	K	Marshall	9248	6332	12390	7698
50	Na or Ca	Marshall	8850	6994	12969	7747
Group means						
0	-		2417	1106	4425	958
50	K		8048	6052	11108	7530
50	Na or Ca		7805	6110	11402	8116
LSD (P=0.05)			505	657	445	630
		Katepwa	5754	4109	8173	5492
		Roblin	4690	3518	6637	4079
		Biggar	7003	5189	10975	7096
		Marshall	6913	4876	10129	5470
LSD (P=0.05)			583	758	514	728

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0002	0.0001	0.0001
Treatment (T)		2	0.0001	0.0001	0.0001	0.0001
C*T		6	0.0006	0.07	0.003 **	0.0003
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.03 *	0.38	0.99	0.34
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Roblin	KCl vs NaCl or $CaCl_2$	1	0.95	0.91	0.37	0.70
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Biggar	KCl vs NaCl or $CaCl_2$	1	0.30	0.74	0.66	0.02 *
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Marshall	KCl vs NaCl or $CaCl_2$	1	0.43	0.32	0.20	0.94
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
C.V. (%)			14.3	25.7	8.6	19.7

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Anola in 1990, the application of KCl resulted in a significantly higher Cl^- concentration for Katepwa than did the application of NaCl; at Winnipeg in 1991, $CaCl_2$ resulted in a significantly higher Cl^- concentration in plant tissue for Biggar than did KCl. Midseason dry matter yields for Katepwa and Biggar were the same regardless of Cl^- source and did not appear to account for the observed differences in Cl^- concentration.

The addition of 50 kg Cl^- ha^{-1} significantly increased Cl^- uptake for all cultivars of wheat at all sites (Table 5.17). Fertilizer source did not have a significant effect on Cl^- uptake for any of the cultivars tested. In all cultivars except Roblin, the effects of Cl^- applications on Cl^- uptake appeared to be due only to differences in Cl^- concentration (Table 5.16), not due to differences in midseason dry matter yield (Table 5.15). With the exception of Roblin, effects of Cl^- applications on midseason dry matter yields were negligible.

According to guidelines used by the Manitoba Provincial Soil Testing Laboratory, concentrations of K in plant tissue were adequate across all treatments (Table 5.18). Concentrations of K in plant tissue did not differ significantly among fertilizer treatments. These data indicated a low probability for a K response and lent further support to the claim that responses observed were due to the Cl^- component of the fertilizers applied.

The effects of Cl^- applications on Mn concentration in plant tissue harvested at midseason were inconsistent (Table 5.19). At Anola in 1991, the observed overall reduction by Cl^- in Mn concentration in plant tissue was likely due to significant reductions by Cl^- in Mn concentration in plant tissue for Biggar and Marshall, and a small, statistically insignificant reduction by Cl^- in the concentration of Mn in plant tissue for Katepwa ($P=0.12$). A significant cultivar $\times$ treatment interaction was observed at Portage in 1991. At this site, Cl^- applications significantly reduced Mn concentration in

Table 5.17. Effect of chloride fertilizer on midseason chloride uptake by four wheat cultivars

Treatment			Cl^- uptake (kg ha^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	5.1	3.0	14.3	5.4
50	K	Katepwa	18.2	16.1	40.9	41.4
50	Na or Ca	Katepwa	15.2	14.1	42.0	44.7
0	-	Roblin	4.0	3.5	14.6	5.0
50	K	Roblin	15.9	14.8	35.7	33.8
50	Na or Ca	Roblin	17.3	13.4	38.3	37.4
0	-	Biggar	6.0	2.7	19.6	5.0
50	K	Biggar	19.4	20.3	49.6	44.0
50	Na or Ca	Biggar	22.9	18.2	45.3	49.3
0	-	Marshall	5.7	4.0	19.3	4.8
50	K	Marshall	20.3	20.6	44.1	41.8
50	Na or Ca	Marshall	21.2	20.9	46.5	38.7
Group means						
0	-		5.2	3.3	16.9	5.0
50	K		18.5	18.0	42.6	40.2
50	Na or Ca		19.2	16.7	43.0	42.5
LSD (P=0.05)			2.0	2.9	2.5	3.3
		Katepwa	12.8	11.1	32.4	30.5
		Roblin	12.4	10.6	29.5	25.4
		Biggar	16.1	13.7	38.1	32.7
		Marshall	15.8	15.2	36.6	28.4
LSD (P=0.05)			2.3	3.3	2.8	3.9

ANOVA		df	Pr > F			
Cultivar (C)		3	0.002 **	0.02 *	0.0001	0.003 **
Treatment (T)		2	0.0001	0.0001	0.0001	0.0001
C*T		6	0.19	0.52	0.19	0.11
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.14	0.48	0.66	0.33
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Roblin	KCl vs NaCl or $CaCl_2$	1	0.48	0.63	0.31	0.29
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Biggar	KCl vs NaCl or $CaCl_2$	1	0.08	0.48	0.09	0.12
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
Marshall	KCl vs NaCl or $CaCl_2$	1	0.63	0.91	0.34	0.37
	0 vs 50 Cl^- (both	1	0.0001	0.0001	0.0001	0.0001
C.V. (%)			23.7	39.1	12.4	19.8

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.18. Effect of chloride fertilizer on midseason plant tissue potassium concentration for four wheat cultivars

Treatment			Plant tissue K concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	2.74	2.20	2.34	2.42
50	K	Katepwa	2.66	2.26	2.35	2.42
50	Na or Ca	Katepwa	2.66	2.23	2.22	2.52
0	-	Roblin	2.39	2.12	2.27	2.29
50	K	Roblin	2.51	2.25	2.21	2.29
50	Na or Ca	Roblin	2.59	2.21	2.07	2.22
0	-	Biggar	2.85	2.48	2.43	2.66
50	K	Biggar	2.67	2.35	2.23	2.62
50	Na or Ca	Biggar	2.69	2.29	2.30	2.43
0	-	Marshall	2.94	2.39	2.52	2.48
50	K	Marshall	2.92	2.38	2.41	2.51
50	Na or Ca	Marshall	2.86	2.42	2.30	2.49
Group means						
0	-		2.73	2.30	2.39	2.46
50	K		2.69	2.31	2.30	2.46
50	Na or Ca		2.70	2.29	2.22	2.41
LSD (P=0.05)			ns	ns	ns	ns
		Katepwa	2.69	2.23	2.30	2.45
		Roblin	2.50	2.19	2.19	2.27
		Biggar	2.74	2.37	2.32	2.57
		Marshall	2.91	2.40	2.41	2.49
LSD (P=0.05)			0.15	0.17	ns	0.13

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.05 *	0.28	0.0002
Treatment (T)		2	0.83	0.95	0.26	0.61
C*T		6	0.54	0.85	0.98	0.49
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	1.00	0.83	0.52	0.39
	0 vs 50 Cl^- (both	1	0.50	0.72	0.78	0.62
Roblin	KCl vs NaCl or $CaCl_2$	1	0.53	0.80	0.50	0.53
	0 vs 50 Cl^- (both	1	0.16	0.42	0.45	0.69
Biggar	KCl vs NaCl or $CaCl_2$	1	0.89	0.65	0.73	0.09
	0 vs 50 Cl^- (both	1	0.15	0.22	0.36	0.17
Marshall	KCl vs NaCl or $CaCl_2$	1	0.66	0.77	0.56	0.84
	0 vs 50 Cl^- (both	1	0.64	0.95	0.34	0.81
C.V. (%)			8.5	11.4	15.1	8.0

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table 5.19. Effect of chloride fertilizer on midseason plant tissue manganese concentration for four wheat cultivars

Treatment			Plant tissue Mn concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	24.5	18.7	40.9	42.1
50	K	Katepwa	25.5	17.6	35.4	49.0
50	Na or Ca	Katepwa	24.1	16.2	35.7	39.1
0	-	Roblin	19.8	15.2	26.1	34.8
50	K	Roblin	21.3	14.9	24.5	34.8
50	Na or Ca	Roblin	20.8	15.2	26.4	30.9
0	-	Biggar	28.0	26.4	35.0	51.4
50	K	Biggar	26.1	21.3	39.0	51.2
50	Na or Ca	Biggar	24.8	23.3	42.6	50.2
0	-	Marshall	32.0	27.0	39.5	54.4
50	K	Marshall	31.9	22.1	41.8	49.3
50	Na or Ca	Marshall	31.2	23.2	43.8	49.0
Group means						
0	-		26.1	21.8	35.4	45.7
50	K		26.2	19.0	35.2	46.1
50	Na or Ca		25.2	19.5	37.1	42.3
LSD (P=0.05)			ns	1.4	ns	ns
		Katepwa	24.7	17.5	37.3	43.4
		Roblin	20.6	15.1	25.7	33.5
		Biggar	26.3	23.7	38.9	50.9
		Marshall	31.7	24.1	41.7	50.9
LSD (P=0.05)			1.9	1.6	2.8	4.5

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0001	0.0001	0.0001
Treatment (T)		2	0.45	0.0002	0.24	0.11
C*T		6	0.68	0.09	0.02 *	0.42
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.41	0.32	0.93	0.01 **
	0 vs 50 Cl^- (both	1	0.85	0.12	0.01 **	0.56
Roblin	KCl vs NaCl or $CaCl_2$	1	0.77	0.78	0.45	0.32
	0 vs 50 Cl^- (both	1	0.38	0.91	0.76	0.56
Biggar	KCl vs NaCl or $CaCl_2$	1	0.42	0.15	0.15	0.81
	0 vs 50 Cl^- (both	1	0.08	0.001 **	0.009 **	0.82
Marshall	KCl vs NaCl or $CaCl_2$	1	0.68	0.44	0.41	0.92
	0 vs 50 Cl^- (both	1	0.74	0.0006	0.13	0.12
C.V. (%)			11.1	11.8	11.9	15.1

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

plant tissue for Katepwa, but significantly increased the concentration of Mn in plant tissue for Biggar and tended to increase Mn concentration in plant tissue for Marshall (P=0.13). The inconsistent effect of Cl^- on Mn concentration in plant tissue does not support the suggestion by Beaton et al. (1988) that Cl^- increases grain yield indirectly through effects on plant availability of Mn.

Fertilizer treatment did not have a significant effect on Cu concentration in plant tissue harvested at midseason for any of the cultivars tested (Table F.6 in Appendix).

Concentrations of Zn in plant tissue were determined in 1991 only (Table F.7 in Appendix). Cl^- applications did not have a consistent and significant effect on Zn concentrations in plant tissue for the wheat cultivars tested.

In 1990, Cl^- applications did not have a significant effect on NO_3^- concentration in plant tissue harvested at midseason for any of the cultivars tested (Table 5.20). However, in 1991, Cl^- applications resulted in an overall decrease in the concentration of NO_3^- in plant tissue at all sites. Contrasts showed that, in 1991, the application of 50 kg Cl^- ha^{-1} as either KCl or $CaCl_2$ significantly reduced NO_3^- concentrations in plant tissue for Roblin and Marshall at Anola, for Katepwa, Roblin, Biggar and Marshall at Portage and for Katepwa at Winnipeg. Cl^- applications also tended to decrease the concentration of NO_3^- in plant tissue for Roblin at Winnipeg (P=0.07) and for Biggar at Anola (P=0.07). Other researchers have also observed reductions in NO_3^- concentration in plant tissue for spring wheat with the addition of Cl^--containing fertilizers (Schumacher 1988; Wang 1987). Possibly, the large variability in NO_3^- concentration in plant tissue evident in experiments conducted at Anola in both 1990 and 1991 may have masked, to some extent, the effects of Cl^- fertilizers on NO_3^- concentration in plant tissue. The significant cultivar × treatment interaction observed at Portage in 1991 was likely due to the

Table 5.20. Effect of chloride fertilizer on midseason plant tissue nitrate concentration for four wheat cultivars

Treatment			Plant tissue NO_3^- concentration (mg N kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	1501	1621	4432	6970
50	K	Katepwa	1016	1536	2971	5100
50	Na or Ca	Katepwa	1295	1065	2629	5411
0	-	Roblin	1155	1993	2843	4770
50	K	Roblin	897	1189	2227	3699
50	Na or Ca	Roblin	1204	1057	2078	3417
0	-	Biggar	2211	2375	6045	7248
50	K	Biggar	1896	1410	5168	7453
50	Na or Ca	Biggar	2437	2045	4450	5300
0	-	Marshall	2236	2082	4718	4743
50	K	Marshall	1812	1111	3227	4533
50	Na or Ca	Marshall	1720	1206	3195	4627
Group means						
0	-		1776	2018	4509	5933
50	K		1405	1312	3398	5196
50	Na or Ca		1664	1343	3088	4689
LSD (P=0.05)			ns	405	267	756
		Katepwa	1271	1407	3344	5827
		Roblin	1085	1413	2383	3962
		Biggar	2181	1943	5221	6667
		Marshall	1923	1466	3713	4634
LSD (P=0.05)			456	ns	308	873

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.07	0.0001	0.0001
Treatment (T)		2	0.17	0.001 **	0.0001	0.007 **
C*T		6	0.88	0.46	0.05 *	0.16
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.48	0.25	0.21	0.68
	0 vs 50 Cl^- (both	1	0.32	0.36	0.0001	0.01 **
Roblin	KCl vs NaCl or $CaCl_2$	1	0.44	0.74	0.058	0.71
	0 vs 50 Cl^- (both	1	0.76	0.02 *	0.004 **	0.07
Biggar	KCl vs NaCl or $CaCl_2$	1	0.18	0.12	0.009 **	0.006 **
	0 vs 50 Cl^- (both	1	0.90	0.07	0.0001	0.19
Marshall	KCl vs NaCl or $CaCl_2$	1	0.82	0.81	0.91	0.90
	0 vs 50 Cl^- (both	1	0.17	0.01 **	0.0001	0.80
C.V. (%)			42.3	44.9	12.6	24.8

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

significantly lower concentrations of NO_3^- in plant tissue observed in $CaCl_2$ versus KCl treatments for Biggar.

The addition of 50 kg Cl^- ha^{-1} did not have a significant effect on concentrations of NH_4^+ in plant tissue for any of the wheat cultivars tested (Table F.8 in Appendix).

Shortly after the heading stage, a cursory assessment of foliar diseases was conducted on selected wheat cultivars at selected sites. At Anola in 1990, 50 kg Cl^- ha^{-1} as KCl or NaCl produced a visible reduction in foliar disease for Marshall in five of six replicates but no visible reductions in foliar disease for Katepwa. Cl^- applications did not appear to affect foliar disease severity at the Portage site in 1991. Possibly, the very high levels of foliar disease at the Portage site overcame the disease suppressive effects of Cl^-. At Winnipeg in 1991, the application of 50 kg Cl^- ha^{-1} as either KCl or $CaCl_2$ resulted in a visible reduction in the severity of foliar disease for Marshall in six of six replicates and for Roblin in four of six replicates. At this site, Cl^- applications did not result in a consistent, visible reduction in foliar disease for Katepwa or Biggar.

Various foliar diseases of wheat including tanspot, tanspot/septoria complexes, speckled leaf blotch, leaf rust and stripe rust have been shown to be reduced by the application of Cl^- (Lamond et al. 1990; Granade et al. 1989; Fixen et al. 1986a; Christensen et al. 1982). The effect of cultivar on the occurrence and magnitude of disease reductions by Cl^- is not well-documented for spring wheat. Granade et al. (1989) found a significant decrease in leaf rust by Cl^- in one of six winter wheat cultivars tested. Studies with winter wheat have also demonstrated reductions in the severity of stripe rust in both susceptible and resistant cultivars (Scheyer et al. 1987; Christensen et al. 1982). Although Scheyer et al. (1987) noted a more obvious reduction in stripe rust in a susceptible cultivar than a resistant cultivar, Christensen et al. (1982), in a study of 18

winter wheat cultivars differing in susceptibility to stripe rust, did not observe a significant cultivar × Cl^- interaction.

Yields and Grain Quality at Maturity

The application of 50 kg Cl^- ha^{-1} resulted in a significant overall increase in grain yield for wheat at Anola in 1990 and 1991 (Table 5.21). Contrasts indicated that the application of 50 kg Cl^- ha^{-1} significantly increased grain yield for Roblin and Marshall at Anola in 1990 and for Biggar and Marshall at Anola in 1991. A significant increase by Cl^- in grain yield was also observed for Biggar at Portage in 1991. The same trend was evident for Katepwa at Winnipeg in 1991, but the effect was not statistically significant (P=0.15). Generally, the magnitude of yield responses observed was modest, ranging from approximately 260 to 490 kg ha^{-1}. Fixen et al. (1987) observed similarly moderate increases in yield for spring wheat in studies conducted in South Dakota. Significant cultivar × treatment interactions were observed at Anola and Portage in 1991. The significant interaction observed at Portage may be accounted for by the significant increase by Cl^- in grain yield for Biggar and the significant decrease by Cl^- in grain yield for Marshall. Also, at Portage in 1991, Cl^- applications tended to reduce grain yield for Katepwa, but the effect was not statistically significant (P=0.06). The reason for these decreases is not known. The significant cultivar × treatment interaction observed at Anola in 1991 may have been due to significant increases by Cl^- in grain yield for Biggar and Marshall, but not for Katepwa and Roblin.

The use of recommendations developed for South Dakota would suggest that, solely on the basis of soil Cl^- content, yield responses to the application of Cl^- fertilizers were likely at all sites at which wheat cultivar experiments were conducted. In our study,

Table 5.21. Effect of chloride fertilizer on grain yield for four wheat cultivars

Treatment			Grain yield (kg ha^{-1})			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	2684	1137	3542	1980
50	K	Katepwa	2762	1128	3204	2264
50	Na or Ca	Katepwa	2819	1084	3150	2205
0	-	Roblin	2690	1433	3325	2814
50	K	Roblin	3070	1434	2984	2947
50	Na or Ca	Roblin	3294	1505	3461	2919
0	-	Biggar	2595	1484	2528	1379
50	K	Biggar	2732	1648	2956	1192
50	Na or Ca	Biggar	2515	1847	2904	1377
0	-	Marshall	3195	1423	4140	2387
50	K	Marshall	3552	1669	3643	2665
50	Na or Ca	Marshall	3668	1797	3862	2361
Group means						
0	-		2791	1369	3384	2140
50	K		3029	1470	3197	2267
50	Na or Ca		3074	1558	3344	2215
LSD (P=0.05)			243	102	ns	ns
		Katepwa	2755	1116	3299	2149
		Roblin	3018	1457	3256	2893
		Biggar	2614	1660	2796	1316
		Marshall	3472	1629	3882	2471
LSD (P=0.05)			281	118	250	235

ANOVA		df	Pr > F			
Cultivar (C)		3	0.001 **	0.0001	0.0001	0.0001
Treatment (T)		2	0.05 *	0.002 **	0.20	0.46
C*T		6	0.51	0.05 *	0.03 *	0.55
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.81	0.67	0.80	0.77
	0 vs 50 Cl$^-$ (both	1	0.62	0.73	0.06	0.15
Roblin	KCl vs NaCl or $CaCl_2$	1	0.36	0.49	0.03 *	0.89
	0 vs 50 Cl$^-$ (both	1	0.02 *	0.68	0.59	0.50
Biggar	KCl vs NaCl or $CaCl_2$	1	0.38	0.06	0.81	0.37
	0 vs 50 Cl$^-$ (both	1	0.90	0.004 **	0.04 *	0.59
Marshall	KCl vs NaCl or $CaCl_2$	1	0.63	0.21	0.32	0.14
	0 vs 50 Cl$^-$ (both	1	0.05 *	0.0009	0.04 *	0.48
C.V. (%)			14.2	12.1	12.1	15.9

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

all sites tested less than 66 kg Cl^- ha^{-1} to 60 cm; three of four sites tested less than 33 kg Cl^- ha^{-1} to 60 cm. As stated previously, studies conducted in South Dakota by Fixen et al. (1987) demonstrated a frequency of yield response in hard red spring wheat of 31% on soils testing less than 66 kg Cl^- ha^{-1} to 60 cm and of 69% on soils testing less than 33 kg Cl^- ha^{-1} to 60 cm. Another study by Fixen et al. (1986a) demonstrated near maximum yield of spring wheat on soils testing greater than 43.5 kg Cl^- ha^{-1} to 60 cm or 75 kg Cl^- ha^{-1} to 120 cm. On the basis of soil Cl^- concentration to 60 cm, all sites in the our study would be considered responsive; on the basis of the 120 cm guideline, all sites except Portage in 1991 would be considered responsive.

Based on the critical concentration of Cl^- in plant tissue established by Fixen et al. (1986a) for spring wheat at heading, yield responses were likely at Anola and Winnipeg in 1991. However, significant yield increases by Cl^- were observed at all sites except Winnipeg in 1991. Possibly, due to differences between our study and South Dakota studies in terms of cultivar, stage of sampling and environment, the critical Cl^- concentration in plant tissue established for spring wheat in South Dakota may not be directly applicable to Manitoba.

Treatment was found to have significant effects on straw yield for several cultivars at several sites; however, effects were not consistent (Table F.9 in Appendix).

An overall increase in thousand kernel weight with the application of Cl^- was observed in 1991 at Anola and at Winnipeg (Table 5.22). At all sites except Winnipeg, cultivar × treatment interactions were significant; at Winnipeg in 1991 the cultivar × treatment interaction was nearly significant ($P=0.11$). Differences among cultivars with respect to the effect of Cl^- on thousand kernel weight were apparent from the contrasts conducted. Contrasts indicated that Cl^- applications significantly increased thousand

Table 5.22. Effect of chloride fertilizer on thousand kernel weight for four wheat cultivars

Treatment			Thousand kernel weight (g per 1000)			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	33.2	18.4	28.1	23.1
50	K	Katepwa	32.8	19.6	28.0	24.2
50	Na or Ca	Katepwa	32.5	18.0	29.0	24.6
0	-	Roblin	33.6	22.5	33.0	27.8
50	K	Roblin	35.4	23.1	32.8	29.4
50	Na or Ca	Roblin	35.7	23.3	32.5	29.5
0	-	Biggar	32.9	20.3	19.3	14.7
50	K	Biggar	33.4	21.7	21.8	13.6
50	Na or Ca	Biggar	32.1	22.5	21.8	14.4
0	-	Marshall	31.3	16.6	26.6	19.7
50	K	Marshall	31.9	19.6	26.1	22.5
50	Na or Ca	Marshall	32.3	21.2	25.9	22.8
Group means						
0	-		32.7	19.4	26.7	21.3
50	K		33.4	21.0	27.2	22.4
50	Na or Ca		33.2	21.2	27.3	22.8
LSD (P=0.05)			ns	1.0	ns	0.9
		Katepwa	32.8	18.7	28.3	24.0
		Roblin	34.9	23.0	32.8	28.9
		Biggar	32.8	21.5	20.9	14.2
		Marshall	31.8	19.1	26.2	21.7
LSD (P=0.05)			0.8	1.2	0.8	1.1

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0001	0.0001	0.0001
Treatment (T)		2	0.22	0.001 **	0.24	0.006 **
C*T		6	0.05 *	0.04 *	0.01 **	0.11
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.70	0.12	0.17	0.70
	0 vs 50 Cl^- (both	1	0.35	0.61	0.53	0.10
Roblin	KCl vs NaCl or $CaCl_2$	1	0.68	0.88	0.67	0.91
	0 vs 50 Cl^- (both	1	0.003 **	0.47	0.65	0.05 *
Biggar	KCl vs NaCl or $CaCl_2$	1	0.08	0.41	0.97	0.36
	0 vs 50 Cl^- (both	1	0.82	0.04 *	0.0001	0.37
Marshall	KCl vs NaCl or $CaCl_2$	1	0.59	0.13	0.84	0.76
	0 vs 50 Cl^- (both	1	0.19	0.0001	0.36	0.0006
C.V. (%)			3.8	8.6	4.5	7.3

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

kernel weight for Biggar and Marshall at Anola in 1991 and for Roblin and Marshall at Winnipeg in 1991. Significant increases by Cl^- were also observed for Roblin at Anola in 1990 and for Biggar at Portage in 1991. Cl^- applications did not significantly increase thousand kernel weight for Katepwa at any site. Similarly, in studies conducted in South Dakota, Schumacher (1990) observed increases in thousand kernel weight for only certain spring wheat cultivars. In our study, in four of the six cases in which Cl^- significantly increased thousand kernel weight, a significant increase in grain yield was also observed.

Cl^- applications resulted in an overall increase in hectolitre weight at Anola in 1991 likely due to significant increases by Cl^- in hectolitre weight for Biggar and Marshall at this site (Table 5.23). Significant cultivar × treatment interactions were observed at Anola in 1990 and at Portage in 1991. The significant interaction observed at Anola in 1990 was likely due to a significant increase by Cl^- in hectolitre weight for Roblin and a significantly lower hectolitre weight for Biggar in NaCl than in $CaCl_2$ treatments. The significant interaction observed at Portage in 1991 may be accounted for by the significant increase by Cl^- in hectolitre weight for Biggar and the significant decrease by Cl^- in hectolitre weight for Roblin. For Roblin at Anola in 1990, for Biggar at Anola and at Portage in 1991 and for Marshall at Anola in 1991, Cl^- applications resulted in small, statistically significant increases in hectolitre weight and significant increases in thousand kernel weight and grain yield. Significant increases in hectolitre weight were not found to be consistently associated with visible reductions in foliar disease. In contrast, Buchenau et al. (pers. comm.) found a significant increase in test weight of grain proportional to the level of disease suppression by Cl^-.

Total N concentration in grain was determined in 1991 only. Cl^- applications were found to result in an overall decrease in total N concentration in grain at Anola in 1991

Table 5.23. Effect of chloride fertilizer on hectolitre weight for four wheat cultivars

Treatment			Hectolitre weight (kg hL^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	79.8	74.1	75.3	71.3
50	K	Katepwa	79.7	73.8	74.7	72.0
50	Na or Ca	Katepwa	79.4	74.8	74.4	71.4
0	-	Roblin	77.7	73.4	75.1	73.3
50	K	Roblin	78.7	73.8	73.8	73.1
50	Na or Ca	Roblin	79.4	73.8	73.7	73.4
0	-	Biggar	75.3	71.7	64.3	59.6
50	K	Biggar	75.2	73.1	65.2	56.8
50	Na or Ca	Biggar	73.2	74.3	66.6	58.4
0	-	Marshall	77.7	70.0	74.0	69.3
50	K	Marshall	78.3	72.6	73.7	72.0
50	Na or Ca	Marshall	78.4	72.7	73.4	69.6
Group means						
0	-		77.6	72.3	72.2	68.4
50	K		78.0	73.3	71.9	68.5
50	Na or Ca		77.6	73.9	72.0	68.2
LSD (P=0.05)			ns	1.0	ns	ns
		Katepwa	79.6	74.3	74.8	71.6
		Roblin	78.6	73.7	74.2	73.3
		Biggar	74.6	73.0	65.4	58.3
		Marshall	78.2	71.8	73.7	70.3
LSD (P=0.05)			0.9	1.1	0.9	1.5

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001	0.0003	0.0001	0.0001
Treatment (T)		2	0.58	0.007 **	0.70	0.91
C*T		6	0.04 *	0.34	0.04 *	0.16
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.67	0.31	0.71	0.67
	0 vs 50 Cl^- (both	1	0.69	0.80	0.29	0.71
Roblin	KCl vs NaCl or $CaCl_2$	1	0.34	1.00	0.86	0.83
	0 vs 50 Cl^- (both	1	0.04 *	0.62	0.05 *	1.00
Biggar	KCl vs NaCl or $CaCl_2$	1	0.01 **	0.25	0.07	0.25
	0 vs 50 Cl^- (both	1	0.10	0.02 *	0.02 *	0.08
Marshall	KCl vs NaCl or $CaCl_2$	1	0.88	0.89	0.71	0.08
	0 vs 50 Cl^- (both	1	0.34	0.003 **	0.52	0.20
C.V. (%)			1.7	2.3	1.8	3.4

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

likely due to small, statistically insignificant reductions by Cl^- in total N concentration for Roblin (P=0.20), Biggar (P=0.17) and Marshall (P=0.06) (Table 5.24). The application of 50 kg Cl^- ha^{-1} also resulted in a small but significant reduction in total N concentration in grain for Biggar at Portage. A significant reduction in NO_3^- concentration in plant tissue harvested at midseason did not, in itself, consistently result in significant reductions in total N concentration in grain. For both Biggar at Portage and Marshall at Anola, in which Cl^- applications had significantly decreased NO_3^- concentration in plant tissue harvested at midseason and significantly increased grain yield, thousand kernel weight and hectolitre weight, Cl^- applications reduced total N concentration in grain. Results of this study indicated that the combined effects of a reduction in the concentration of NO_3^- in plant tissue and a dilution effect may have resulted in a significant reduction in total N concentration in grain.

None of the measurements taken during the course of this study consistently and conclusively predicted yield responsiveness for a particular wheat cultivar at a particular site. However, measurements taken did suggest possible mechanisms through which Cl^- may have operated to increase grain yield for the cultivars tested.

In several instances, Cl^- may have increased grain yield by reducing the concentration of NO_3^- in plant tissue, thereby reducing the severity of foliar disease. Increases in N content in plant tissue have often been associated with increases in plant disease (Huber and Watson 1974). In our study, however, significant reductions in NO_3^- concentration in plant tissue with the application of Cl^- did not consistently result in a visible reduction in foliar disease.

Fixen (1988) has suggested that differences among cultivars in their tendency to show yield responses to Cl^- may be due to differences in disease resistance. Results of

Table 5.24. Effect of chloride fertilizer on total nitrogen concentration in grain for four wheat cultivars

Treatment			Total N concentration (mg kg^{-1})		
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1991		
			Anola	Portage	Winnipeg
Treatment means					
0	-	Katepwa	2.35	2.06	2.43
50	K	Katepwa	2.32	2.06	2.38
50	Na or Ca	Katepwa	2.28	2.07	2.38
0	-	Roblin	2.44	2.26	2.52
50	K	Roblin	2.37	2.26	2.59
50	Na or Ca	Roblin	2.34	2.26	2.58
0	-	Biggar	2.13	2.34	2.20
50	K	Biggar	2.07	2.27	2.25
50	Na or Ca	Biggar	2.01	2.25	2.16
0	-	Marshall	2.30	2.25	2.12
50	K	Marshall	2.21	2.29	2.13
50	Na or Ca	Marshall	2.15	2.29	2.22
Group means					
0	-		2.30	2.23	2.31
50	K		2.24	2.22	2.33
50	Na or Ca		2.20	2.22	2.33
LSD (P=0.05)			0.07	ns	ns
		Katepwa	2.32	2.06	2.39
		Roblin	2.39	2.26	2.56
		Biggar	2.07	2.29	2.20
		Marshall	2.22	2.28	2.15
LSD (P=0.05)			0.08	0.04	0.05

ANOVA		df	Pr > F		
Cultivar (C)		3	0.0001	0.0001	0.0001
Treatment (T)		2	0.01 **	0.85	0.62
C*T		6	0.99	0.30	0.07
Contrasts					
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.53	0.68	0.92
	0 vs 50 Cl^- (both	1	0.40	0.89	0.25
Roblin	KCl vs NaCl or $CaCl_2$	1	0.68	0.73	0.86
	0 vs 50 Cl^- (both	1	0.20	0.85	0.10
Biggar	KCl vs NaCl or $CaCl_2$	1	0.37	0.57	0.07
	0 vs 50 Cl^- (both	1	0.17	0.02 *	0.96
Marshall	KCl vs NaCl or $CaCl_2$	1	0.43	0.95	0.06
	0 vs 50 Cl^- (both	1	0.06	0.28	0.16
C.V. (%)			5.5	3.0	3.5

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

our study indicated that foliar disease suppression by Cl^- might be a factor affecting cultivar responsiveness. Unfortunately, disease ratings from our cultivar studies did not provide adequate information to either confirm or reject Fixen's suggestion. Neither did information regarding the disease resistance of cultivars grown (DePauw et al. 1991; Campbell and Czarnecki 1987a,b; Busch et al. 1983) appear to clearly separate the yield-responsive from the non-responsive cultivars solely on the basis of their resistance to disease.

Results of our study suggested that observed increases in grain yield for Biggar and Marshall may have been due, in part, to an extended grain filling period. In South Dakota, Cl^- has been shown to hasten early season crop maturity and lengthen grain fill duration for Marshall wheat (Schumacher 1990). Under conditions conducive to high yield, resultant increases in kernel weight may produce higher grain yields. Data from our studies appeared to support this suggestion in the case of Marshall at Anola in 1990 and Biggar at Portage in 1991. In both cases, Cl^- visibly advanced crop developmental stage and increased grain yield. For Biggar at Portage in 1991, Cl^- significantly increased thousand kernel weight; for Marshall at Anola in 1990, thousand kernel weight increased slightly, but not significantly with the addition of Cl^-.

The mechanism by which Cl^- increased yield for Roblin is not readily apparent. Of all the cultivars in which an increase in grain yield was observed, a significant increase by Cl^- in midseason dry matter yield was observed only in the cultivar Roblin. This early season response might indicate that, at this site, Cl^- may have operated more effectively or earlier in the season in Roblin than in Marshall or Biggar. However, Cl^- applications did not consistently increase midseason dry matter yield for Roblin. Cl^- applications resulted in a significant reduction in midseason dry matter yield for Roblin at two of the

three sites at which Cl^- did not significantly increase grain yield. Application of Cl^- significantly increased thousand kernel weight and hectolitre weight for Roblin in 1990, indicating that Cl^- might have suppressed disease. No disease ratings were conducted to confirm this suggestion. However, Buchenau et al. (pers. comm.) found a significant increase in test weight of grain proportional to the level of disease suppression by Cl^-.

5.4 Summary and Conclusions

As observed in previous experiments, the application of Cl^-, regardless of source, consistently and significantly increased the concentration of Cl^- in plant tissue harvested at midseason for all cultivars at all sites. Based on regression models developed by Fixen et al. (1986a) for spring wheat, Cl^- concentrations in plant tissue for the wheat cultivars tested in our study were generally higher than would be estimated using soil Cl^- content. Cl^- applications had negligible or inconsistent effects on concentrations of K, Cu, Mn, Zn and NH_4^+ in plant tissue for spring wheat or barley. Significant reductions by Cl^- in the concentration of NO_3^- in plant tissue were observed for all cultivars at one or more experimental sites.

Differences among cultivars in responsiveness to Cl^- fertilization were observed in both barley and spring wheat. Similarly, studies with spring wheat conducted in South Dakota have also demonstrated differences among cultivars in Cl^- responsiveness (Cholick et al. 1986). In the barley cultivar study conducted in Manitoba (Section 5.3.1), of four barley cultivars, each tested at four experimental sites, a significant yield increase by Cl^- was observed only in Heartland at one site. Significant yield increases by Cl^- were more frequent in the wheat cultivars tested. Of the four wheat cultivars tested, yield increases

were observed in Roblin at one of four sites, in Biggar at two of four sites and in Marshall at two of four sites. The magnitude of yield increases for wheat was modest, ranging from approximately 260 to 490 kg ha^{-1}. Caution must be exercised in drawing specific conclusions from our study about the responsiveness of lack thereof for a particular cultivar, however.

The critical levels for soil Cl^- content and Cl^- concentration in plant tissue developed for spring wheat from studies conducted in South Dakota (Fixen et al. 1986a, 1987) did not reliably predict yield responses even in those cultivars which appeared to be Cl^--responsive. The literature suggested that the effect of Cl^- additions on certain measurements such as advancement in crop maturity, disease severity and concentrations of Cl^-, NO_3^- and Mn in plant tissue might give an indication of the responsiveness of various cultivars. However, none of the measurements taken during the course of this study clearly and conclusively distinguished the responsive from the non-responsive cultivars or indicated the mechanism through which Cl^- might have operated to produce yield increases. In several cases, Cl^- applications resulted in visible advancements in crop development and reductions in foliar disease; however, increases in grain yield did not always result. For wheat, an extension of the grain fill period or a reduction in disease severity appeared to be possible mechanisms through which Cl^- may have acted to increase grain yield. Results of the barley cultivar study suggested that the significant increase in grain yield observed in Heartland may have been related more to the very poor quality of the seedlot used rather than to characteristics of the cultivar itself.

In the wheat cultivar study, significant increases in thousand kernel weight and hectolitre weight most often occurred in conjunction with a significant increase in grain yield. Small reductions in total N concentrations in grain were found to occur where Cl^-

applications both significantly decreased the NO_3^- concentration in plant tissue harvested at midseason and significantly increased grain yield. In general, effects of Cl^- on grain quality of barley were negligible or deleterious; decreases in hectolitre weight and in the percentage of plump kernels were observed most frequently in the cultivars Brier and Heartland.

6. GROWTH CHAMBER STUDIES

6.1 Introduction

The application of Cl^- fertilizer had inconsistent effects on yield, common root rot severity and nutrient concentrations in plant tissue for Bedford barley in the 1989 field trials (Section 3.3.1). These inconsistencies may have resulted from variability in environmental conditions, disease pressure and concentrations of nutrients in the soil.

In order to determine the effect of Cl^- on Bedford barley under uniform conditions, two studies were undertaken in 1990 in a growth chamber. A nutritional study was conducted to determine the effect of five rates of soil-applied Cl^- on nutrient concentrations in plant tissue, plant growth and yield for Bedford barley grown on a soil testing very low in Cl^-. A common root rot study was conducted concurrently in the same growth chamber to determine the effect of common root rot inoculum and two rates of soil-applied Cl^- on nutrient concentrations in plant tissue, common root rot severity and yield for Bedford barley grown on a soil testing very low in Cl^-.

6.2 Materials and Methods

Two studies were conducted concurrently in the same growth chamber using barley (*Hordeum vulgare* cv. Bedford).

The Cl^- nutrition study consisted of a completely randomized design of 5 replications of 5 rates of Cl^- application. Cl^- application rates consisted of 0, 5, 10, 20 and 40 mg Cl^- kg^{-1} soil, applied as KCl.

A second study was conducted to determine the effect of Cl^- applications on the severity of common root rot incited by *Cochliobolus sativus* (Ito and Kurib.) Dreschsl. ex

Dastur. The common root rot experiment consisted of a completely randomized design of five replicates of treatments of 0 and 40 mg Cl^- kg^{-1} soil, with or without common root rot inoculum. In total, 10 pots of each treatment were prepared. This allowed for destructive sampling of plants in five pots per treatment at the soft dough stage. Plants in the remaining five pots were grown to maturity for yield determinations.

For both experiments, a very fine sand testing <0.40 mg Cl^- kg^{-1} was collected from the A horizon of a Stockton association near Holland, Manitoba (SE14-9-11W) (Table 6.1).

Table 6.1. Selected physical and chemical characteristics of soil used for growth chamber studies†

Legal location	SE14-9-11W
Soil name	Stockton
Texture	very fine sand
pH	7.4
Carbonates	none detected
NO_3^--N(mg kg^{-1})	4.0
$NaHCO_3$-extr. P (mg kg^{-1})	7.8
CH_3COONH_4-extr. K (mg kg^{-1})	87
SO_4^{2-}-S(mg kg^{-1})	0.6
Cl^- (mg kg^{-1})	<0.4

† Soil Cl^- concentration determined by ion chromatograph (Saskatchewan Soil Testing Lab); all other soil measurements were determined by the Manitoba Provincial Soil Testing Laboratory

Field-moist soil was passed through a 1 cm sieve before use. Nutrient concentrations other than Cl^- were balanced for all treatments. Each pot initially received 100 mg N kg^{-1}, 50 mg P kg^{-1}, 150 mg K kg^{-1}, 25 mg S kg^{-1}, 5 mg Cu kg^{-1} and 10 mg Zn kg^{-1} soil using combinations of $NH_4H_2PO_4$, $CuSO_4$, $ZnSO_4$, $(NH_4)_2SO_4$, NH_4NO_3,

and KCl and/or KNO_3, as described in Table G.1 in Appendix. All nutrient solutions were applied by pipette and thoroughly mixed into 1970 g field-moist soil. An additional 200 mg N kg^{-1} as NH_4NO_3 and 25 mg S kg^{-1} as K_2SO_4 were applied by pipette to the surface of the soil of each pot during the growing season.

In order to restrict contamination by Cl^- of soil and plant material in the growth chamber studies, plastic pots were rinsed twice with tap water then twice with distilled water prior to use. Prior to use, the interior of the growth chamber was washed with a 'Javex' bleach solution to remove plant pathogens, then rinsed with distilled water to remove Cl^-. Distilled water was used for watering. Plastic gloves were worn during handling of all soil and plant material.

Inoculum was applied as a spore suspension in aerosol form and mixed thoroughly with a mass of soil sufficient to supply soil for all inoculated treatments. A volume of 100 mL of *C. sativus* suspension was applied to 10 kg soil to produce a concentration of approximately 200 conidia g^{-1} soil.

The *C. sativus* spore suspension was prepared as follows. Sterile filter paper was aseptically placed on the surface of a potato dextrose agar (PDA) petri plate amended with antibiotics. An agar plug of *C. sativus* was placed on the surface of the filter paper. To increase conidia production, the plates were incubated under ultraviolet light for 10 to 20 days. Sterile water was added to the plates and the conidia were scraped from the colony surface. Conidia were added to sterile water and mixed. Conidia concentrations were determined with a haemocytometer.

A layer of 3880 g of untreated soil was placed in the bottom of each 5 kg plastic pot. Subsequently, 660 g treated soil was placed on top of the untreated soil. Sixteen Bedford barley seeds were placed on the surface of the treated soil and then covered with

an additional 1310 g of treated soil resulting in a 7.5 cm total depth of treated soil per pot - 2.5 cm below the seed and 5 cm above the seed. Thus, a total of 5850 g field-moist soil was used in each plastic container. At the three leaf stage, plants were thinned to 12 per pot.

In both experiments, the following measurements were taken. At approximately boot stage, the shoot portion of four plants per pot was harvested. At time of harvest, advancement in crop maturity of plants within each pot was recorded using the Feekes scale. Fresh weights were determined for these samples. Plant tissue was dried at 68°C, weighed and ground with a Wiley mill to pass a 2 mm sieve. The concentrations of Cl^-, NO_3^-, NH_4^+, Cu, Mn, Zn and total N were determined. The concentration of Cl^- in plant tissue was determined by $AgNO_3$ titration (LaCroix et al. 1970), NO_3^- and NH_4^+ were extracted with 2 M KCl (Milham et al. 1970) and determined by steam distillation (Keeney and Nelson 1982) and K, Cu, Mn and Zn were determined by atomic absorption of a nitric perchloric digest (Isaac and Kerber 1971). Total N concentration was determined by conventional Kjeldahl (Schuman et al. 1973).

At the soft dough stage, those pots designated for destructive sampling in the common root rot experiment were harvested. Fresh weights of the heads and of vegetative growth were determined. Samples were then dried at 68°C and reweighed for dry matter yield. Subcrown internodes were removed from the soil and rated for common root rot (Ledingham et al. 1973). A blind rating system was used so that individuals rating the samples were not aware of the treatments applied. All measurements taken at this harvest were based on 12 plants.

Final harvest samples consisted of the shoot portion of 8 plants per pot. Samples were oven dried at 68°C. Grain yield, straw yield and the number of heads per pot were

determined.

Analysis of variance and calculation of LSD's were conducted using the PROC GLM procedure. Regression analysis and correlation analysis were performed using the PROC REG and PROC CORR procedures, respectively (SAS Institute Inc. 1988).

6.3 Results and Discussion

During the course of the growth chamber experiments, the barley plants developed physiological leaf spotting. Prior to and at the boot stage, the effects of this leaf spotting were minimal and did not appear to have a significant effect on crop growth. During later stages of crop development, however, severe physiological leaf spotting occurred. The effects of this physiological problem on measurements taken during the later stages of barley development are not known, therefore only the results of the boot stage harvest are presented and discussed in the sections that follow. Measurements taken beyond the boot stage have been recorded in Tables G.2 and G.3 in the Appendix.

6.3.1 Chloride Nutrition Study

The concentration of Cl^- in plant tissue was significantly increased by increasing rates of soil applied Cl^- (Table 6.2). Under controlled environmental conditions, a very strong positive linear relationship was found to exist between Cl^- concentration in plant tissue for Bedford barley at boot stage and soil-applied Cl^- (r^2=0.993) (Figure 6.1). In field studies using Bedford barley, the relationship between Cl^- concentration in plant tissue and soil plus fertilizer Cl^- was somewhat poorer (Figure 7.1). Variability in soil Cl^- and NO_3^- concentrations, crop growth, severity of plant disease and environmental conditions within and among field sites likely contributed to the weaker relationship

Table 6.2. Effect of chloride fertilization on plant tissue nutrient concentrations for Bedford barley at boot stage

Treatment (mg Cl^- kg^{-1})	Midseason plant tissue nutrient concentration									
	mg kg^{-1}						%			
	Cl^-	NO_3^-	NH_4	Mn	Cu	Zn	Total N	K	Ca	Mg
0	201	6022	270	37.3	4.63	30.4	3.01	3.00	0.82	0.25
5	756	6912	317	40.3	4.76	31.3	3.19	2.91	0.89	0.25
10	1291	5774	320	38.3	4.65	29.7	2.95	3.01	0.87	0.26
20	2252	4572	311	34.5	4.10	26.0	2.85	2.91	0.85	0.25
40	4296	3604	333	34.4	3.94	25.3	2.66	2.78	0.80	0.24
Pr>F	0.0001 **	0.0001 **	0.96	0.15	0.09	0.0003 **	0.002 **	0.22	0.43	0.31
C.V.(%)	7.3	16.4	44.4	11.0	12.3	8.8	6.05	6.9	9.5	6.7

*,** Significant at the 0.05 and 0.01 levels respectively.

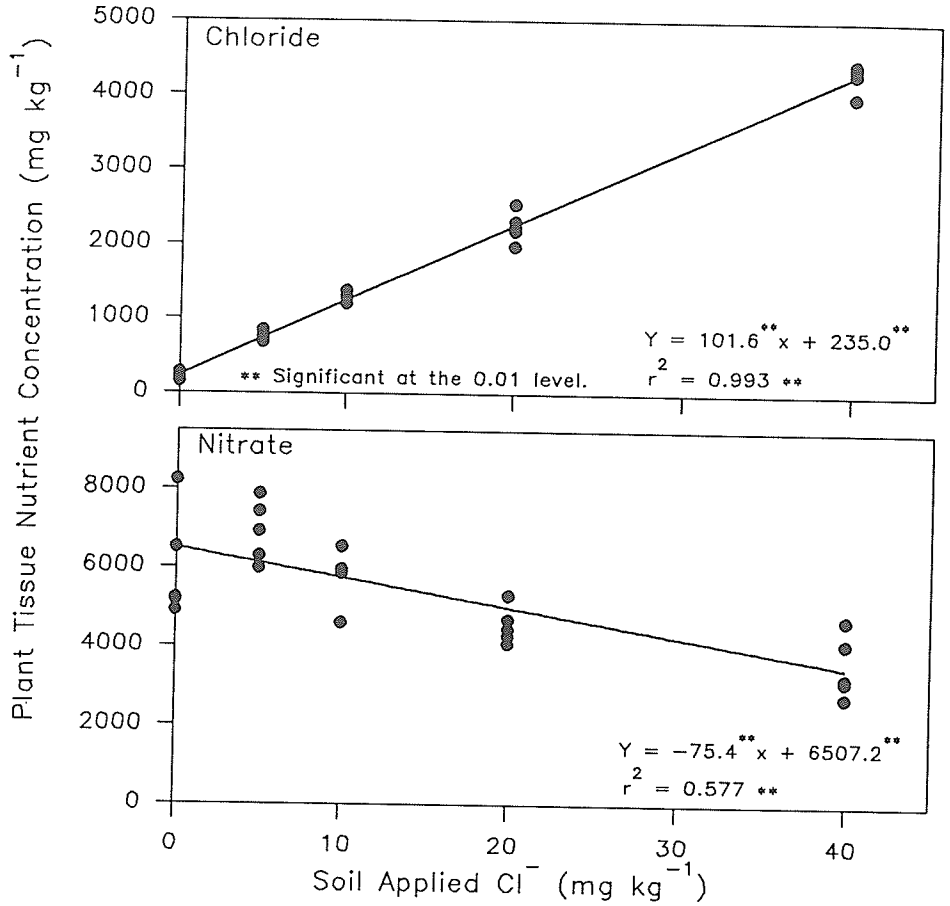

Figure 6.1. Effect of soil applied chloride on plant tissue chloride and nitrate concentrations for Bedford barley at boot stage as determined by linear regression

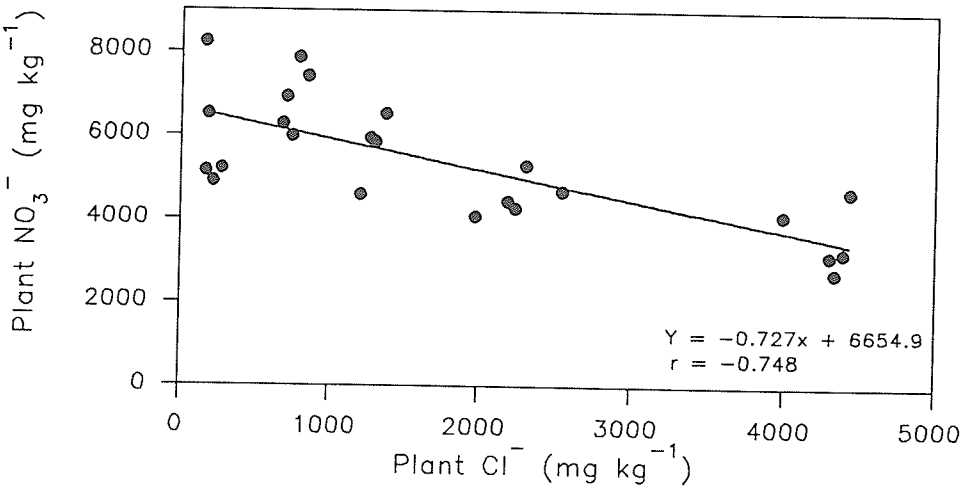

Figure 6.2. Correlation between plant tissue chloride and nitrate concentrations for Bedford barley at boot stage

observed between plant and soil Cl^- for field conditions.

The concentration of NO_3^- in plant tissue harvested at midseason was significantly decreased by the application of Cl^- (Table 6.2; Figure 6.1). A significant correlation ($r=-0.748^{**}$) between the concentration of Cl^- and NO_3^- in plant tissue at midseason was also apparent under growth chamber conditions (Figure 6.2). In the Manitoba field trials with Bedford barley (Sections 3.3.1 and 5.3.1) the relationship between concentrations of Cl^- in plant tissue or soil and the concentration of NO_3^- in plant tissue was poorer than that observed in the growth chamber study. Significant reductions by Cl^- in the concentration of NO_3^- in plant tissue for Bedford barley were observed in only four of twelve field experiments. This may have been because variability in plant tissue concentrations of NO_3^- and Cl^- was substantially higher in the field studies than in the growth chamber study. This variability may have masked, somewhat, the effects of Cl^- on concentrations of NO_3^- in plant tissue under field conditions. Inhibition by Cl^- of plant uptake of NO_3^- has been demonstrated previously with barley grown under field conditions, however (Goos et al. 1987a; Timm et al. 1986). In the growth chamber study, the 5 mg Cl^- kg^{-1} soil treatment resulted in a slightly higher NO_3^- concentration in plant tissue than the control treatment (Table 6.2). The reason for this effect was not clear.

The application of Cl^- significantly decreased total N concentration in plant tissue (Table 6.2; Figure 6.3). As was the case with NO_3^- concentration in plant tissue, the 5 mg Cl^- kg^{-1} soil treatment tended to result in a slightly higher total N concentration in plant tissue than the control treatment (Table 6.2). Results of this study suggested that the reductions by Cl^- in total N concentration in plant tissue may have been due to an inhibition of plant uptake of NO_3^-. The observed reductions in total N concentration in plant tissue may have important implications for grain protein content should this

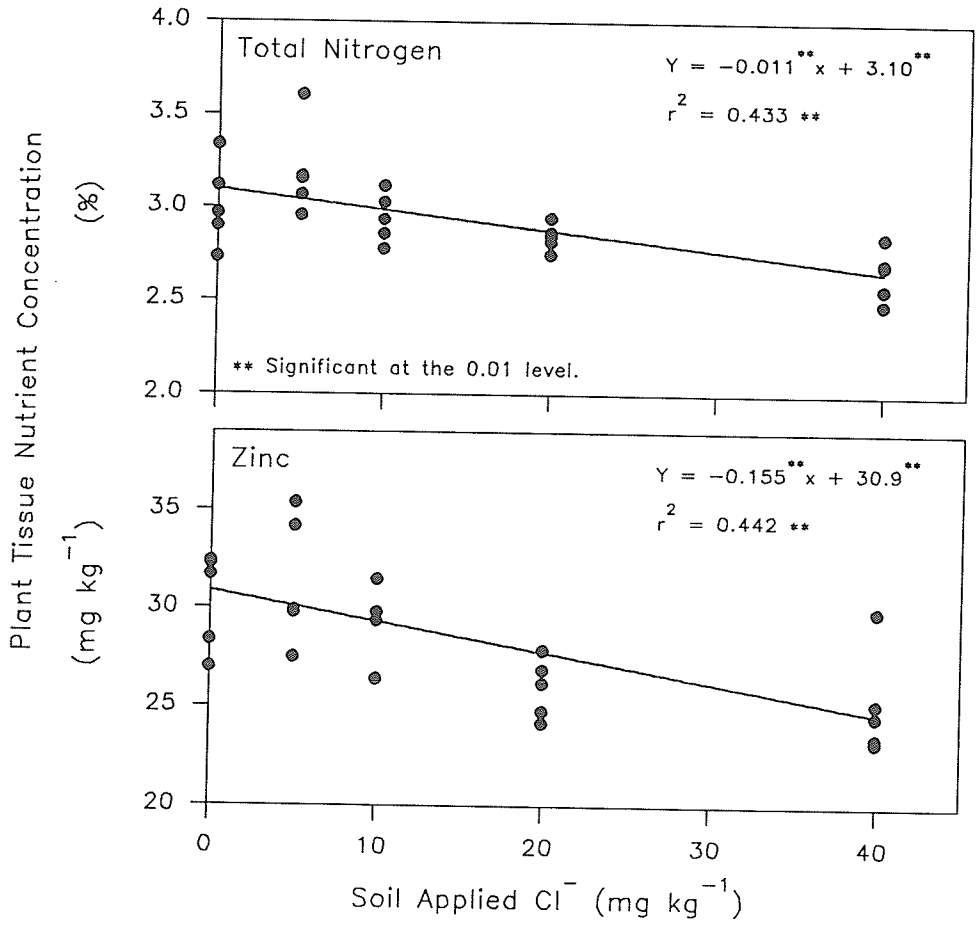

Figure 6.3. Effect of soil applied chloride on plant tissue total nitrogen and zinc concentrations for Bedford barley at boot stage as determined by linear regression

inhibition of NO_3^- uptake extend throughout the growing season. In common root rot and spot blotch experiments conducted with Bedford barley in Manitoba (Section 3.3.1), small, statistically insignificant reductions in the concentration of NO_3^- in plant tissue may have contributed to the small, statistically insignificant reductions in total N concentration in grain observed at two of four sites. In barley cultivar experiments conducted in Manitoba (Section 5.3.1), Cl^- did not result in a consistent and significant reduction in total N concentration in grain. In common root rot experiments conducted with Katepwa in Manitoba (Section 3.3.2), significant reductions by Cl^- in the concentration of NO_3^- in plant tissue appeared to contribute to small, but significant reductions in the total N concentration in grain at two of two sites; significant increases in grain yield did not occur at these sites. However, in wheat cultivar experiments conducted in Manitoba, significant reductions in total N concentration in grain were observed only where a significant reduction in NO_3^- concentration in plant tissue harvested at midseason occurred in combination with a significant increase in grain yield (Section 5.3.2).

Increasing rates of soil-applied Cl^- significantly decreased concentrations of Zn in plant tissue (Table 6.2; Figure 6.3). In contrast, in field trials conducted in Manitoba, the application of Cl^- fertilizers did not have a consistent and significant effect on Zn concentration in plant tissue for Bedford barley across sites and years (Section 3.3.1). Cl^- treatment did not have a significant effect on concentrations of NH_4^+, K, Mn, Cu, Ca or Mg in plant tissue (Table 6.2).

Cl^- treatment did not have a significant effect on fresh weight or oven dry weight of plants at the boot stage (Table 6.3). The addition of Cl^- tended to increase oven dry weight of plant tissue ($P=0.15$), but this effect was not statistically significant.

Table 6.3. Effect of chloride fertilization on yield and maturity for Bedford barley at boot stage

Treatment (mg Cl^- kg^{-1})	Midseason yield (g pot^{-1})†		Maturity (Feekes scale)
	Fresh weight	Oven dry	
0	119.2	21.0	10.0
5	121.8	20.4	10.0
10	124.4	20.6	10.02
20	132.6	23.2	10.04
40	131.8	24.4	10.06
Pr>F	0.70	0.15	0.11
C.V.(%)	14.4	13.4	0.40

† Mass based on shoot portion of eight plants.
*,** Significant at the 0.05 and 0.01 levels respectively.

Visible differences in the maturity of plants were apparent among treatments, but did not correspond to significant differences in plant maturity according to the Feekes scale. A slight, statistically insignificant (P=0.11) advancement in the maturity of barley with increasing rates of Cl^- may have been responsible, in part, for the slight increase in oven dry weight observed in this study. In the barley cultivar experiments (Section 5.3.1), the application of 50 kg Cl^- ha^{-1} significantly advanced or tended to advance crop maturity for Bedford barley at two of four field sites. Resultant significant increases by Cl^- in midseason dry matter yield did not occur in the field trials, however.

In the growth chamber study, when soil moisture was limiting, plants to which the highest rates of Cl^- had been applied appeared to be most turgid. Increases by Cl^- in turgour potential and leaf relative water content have also been observed in field studies conducted with wheat (Fixen et al. 1986a; Christensen et al. 1981).

6.3.2 Common Root Rot Study

The effect of Cl^- additions on the nutrient status of Bedford barley at boot stage

was consistent with the results of the Cl^- nutrition study described previously. The addition of 40 mg Cl^- kg^{-1} soil significantly and substantially increased the concentration of Cl^- in plant tissue (Table 6.4). The concentration of Cl^- in plant tissue was also increased significantly by the application of common root rot inoculum. The reason for this increase by inoculum is not clear; inoculum did not have a significant effect on dry matter yield.

The concentration of NO_3^- in plant tissue decreased significantly with the addition of 40 mg Cl^- kg^{-1} soil (Table 6.4) as was observed in the plant nutrition experiment. The addition of Cl^- resulted in a significant decrease in Zn concentration in plant tissue at boot stage (Table 6.4). As noted previously, this effect was not evident in the field studies.

Cl^- treatment did not have a significant effect on concentrations of NH_4^+, K, Mn, Cu, Mg or Ca in plant tissue (Table 6.4). The same results were observed for the chloride nutrition study conducted in the growth chamber.

Treatment did not have a significant effect on fresh weight or oven dry weight of plant tissue at boot stage (Table 6.5). In this study, the addition of 40 mg Cl^- kg^{-1} soil was found to significantly advance the maturity of Bedford barley at the boot stage (Table 6.5). As mentioned previously, similar trends had been observed in the chloride nutrition study conducted in the growth chamber as well as in field studies conducted in Manitoba.

6.4 Summary and Conclusions

Overall, the responses to Cl^- of Bedford barley grown under growth chamber conditions were similar to those observed under field conditions. The addition of Cl^- resulted in a significant increase in the concentration of Cl^- in plant tissue, a significant

Table 6.4. Effect of chloride fertilizer and *C. sativus* inoculum on plant tissue nutrient concentration for Bedford barley at boot stage

Treatment		Midseason plant tissue nutrient concentration								
mg Cl^- kg^{-1} soil	Disease inoculum applied	mg kg^{-1}						%		
		Cl^-	NO_3^-	NH_4^+	Mn	Cu	Zn	K	Ca	Mg
Treatment means										
0	-	201	6022	270	37.3	4.63	30.4	3.00	0.82	0.25
40	-	4296	3604	333	34.4	3.94	25.3	2.78	0.80	0.24
0	+	448	5536	238	39.5	4.30	30.8	3.01	0.91	0.26
40	+	4822	4335	363	40.1	4.61	28.1	3.08	0.86	0.25
Group means										
0		325	5779	254	38.4	4.47	30.6	3.01	0.87	0.25
40		4559	3969	348	37.3	4.27	26.7	2.93	0.83	0.24
LSD (P=0.05)		283	1324	ns	ns	ns	2.4	ns	ns	ns
	-	2248	4813	301	35.9	4.29	27.8	2.89	0.81	0.24
	+	2635	4935	300	39.8	4.46	29.5	3.04	0.88	0.26
LSD (P=0.05)		283	ns	ns	3.4	ns	ns	ns	ns	ns

ANOVA	df	Pr>F								
Rate (R)	1	0.0001 **	0.01 **	0.20	0.47	0.43	0.004 **	0.34	0.39	0.25
Inoculum (I)	1	0.01 **	0.85	0.99	0.02 *	0.49	0.18	0.07	0.08	0.13
R*I	1	0.31	0.34	0.66	0.29	0.05 *	0.31	0.07	0.75	0.92
C.V.(%)		12.2	28.6	51.5	9.4	12.3	9.0	5.9	10.4	8.4

*,** Significant at the 0.05 and 0.01 levels respectively.

Table 6.5. Effect of chloride fertilizer and *C. sativus* inoculum on yield and maturity for Bedford barley at boot stage

Treatment		Midseason yield (g pot^{-1})†		Maturity (Feekes scale)
mg Cl^- kg^{-1} soil	Disease inoculum applied	Fresh weight	Oven dry	
Treatment means				
0	-	119.2	21.0	10.00
40	-	131.8	24.4	10.06
0	+	134.4	22.0	10.02
40	+	128.8	22.8	10.08
Group means				
0		126.8	21.6	10.01
40		130.2	23.6	10.07
LSD (P=0.05)		ns	ns	0.04
	-	125.4	22.8	10.03
	+	131.6	22.4	10.05
LSD (P=0.05)		ns	ns	ns

ANOVA	df	Pr>F		
Rate (R)	1	0.71	0.24	0.006 **
Inoculum (I)	1	0.52	0.84	0.30
R*I	1	0.34	0.46	1.00
C.V.(%)		16.2	16.9	0.42

† Mass based on shoot portion of eight plants.
*,** Significant at the 0.05 and 0.01 levels respectively.

decrease in the concentration of NO_3^- in plant tissue and a visible advancement in crop maturity.

In addition, in the growth chamber study, a strong positive linear relationship was found to exist between soil-applied Cl^- and Cl^- concentration in plant tissue for Bedford barley at the boot stage. Increasing rates of Cl^- were found to result in significant reductions in concentrations of total N and Zn in plant tissue. The application of Cl^- did not have a significant effect on vegetative yield of barley at the boot stage although it had resulted in a visible advancement in crop maturity. As noted previously, due to the development of physiological leaf spotting, information regarding the effect of Cl^-

applications on crop growth after the boot stage has not been included.

7. SUMMARY AND CONCLUSIONS

In recent studies conducted in the northern Great Plains of the United States, the application of Cl^--containing fertilizers has been shown to increase grain yield, reduce the severity of foliar and root diseases and improve grain quality. Results of these studies have suggested several mechanisms through which Cl^- may act to produce beneficial effects. However, the fundamental mechanism through which Cl^- operates to enhance grain yield and quality has not been firmly established. Responses to the application of Cl^--containing fertilizers continue to be difficult to predict.

Information regarding the efficacy of Cl^- fertilization for Canadian wheat and barley cultivars commonly grown under Manitoba conditions is very limited. A series of experiments were conducted from 1989 to 1991 to determine the effect of Cl^- fertilization on wheat and barley grown under Manitoba conditions.

A total of 24 field experiments and two growth chamber studies were conducted from 1989 to 1991. Field studies were conducted at five sites in each of 1989 and 1990 to determine the effect of Cl^- fertilizer applications on the nutrient concentrations in plant tissue harvested at midseason, grain quality and yield for Katepwa wheat and Bedford barley. At several of these sites, the effect of Cl^- on common root rot for Katepwa wheat and Bedford barley and on spot blotch for Bedford barley was investigated. A low frequency of response to Cl^- in the aforementioned study prompted field studies at one site in 1990 and at three sites in 1991 to determine the effect of cultivar on crop response to Cl^- fertilization for wheat and barley. In addition, in 1990, a growth chamber study was conducted to determine the effect of Cl^- fertilization on nutrient concentrations in plant tissue, common root rot severity and yield for Bedford barley under controlled

environmental conditions.

Significant increases in the concentration of Cl^- in plant tissue with the application of Cl^--containing fertilizers were observed in all field and growth chamber studies conducted. In ten of ten field studies using wheat and in twelve of twelve field studies using barley, the application of Cl^- substantially and significantly increased Cl^- concentration in plant tissue of plants at the boot to heading stage. Neither source nor placement of Cl^- fertilizer was found to have a consistent overall effect on the concentration of Cl^- in plant tissue. Increases in Cl^- concentration were similar for applications of KCl and NaCl (Figure 7.1). Comparisons of broadcast KCl versus seedrow placed KCl indicated a significant difference in Cl^- concentration in plant tissue in only four of twenty-two contrasts.

A very strong, positive linear relationship between soil applied Cl^- and the concentration of Cl^- in plant tissue for Bedford barley at the boot stage was evident in the growth chamber study (Figure 6.1). Similarly, in the field studies, a strong positive linear relationship between Cl^- concentration in plant tissue and the total of soil Cl^- (to 60 cm) plus spring-applied fertilizer Cl^- was evident for both Katepwa wheat and Bedford barley (Figure 7.1).

Regression models developed using only control treatments from our field studies showed a linear relationship between soil Cl^- content and the concentration of Cl^- in plant tissue for Bedford barley and Katepwa wheat at heading (Figure 7.2). A stronger relationship was evident between the concentration of Cl^- in plant tissue and the 0 to 60 cm sampling depth than for the 0 to 30 or the 0 to 120 cm sampling depths. In our studies, barley tended to accumulate Cl^- to higher concentrations in plant tissue than did wheat (Figure 7.2). The regression models developed from South Dakota data to

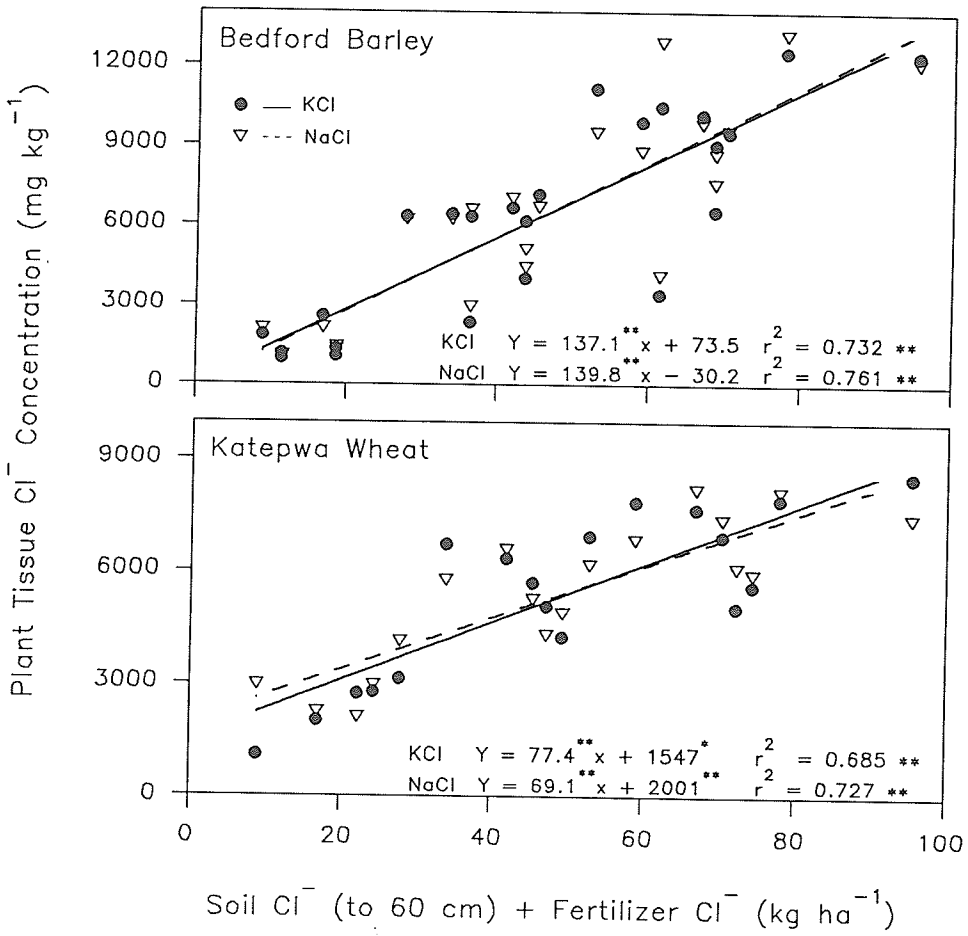

Figure 7.1. Effect of soil chloride and two sources of fertilizer chloride on plant tissue chloride concentration for Bedford barley and Katepwa wheat in 1989 and 1990 field studies as determined by linear regression†

*,** Significant at the 0.05 and 0.01 levels respectively.

† Data consists of non-inoculated treatments from the common root rot and spot blotch studies and the chloride nutrition study

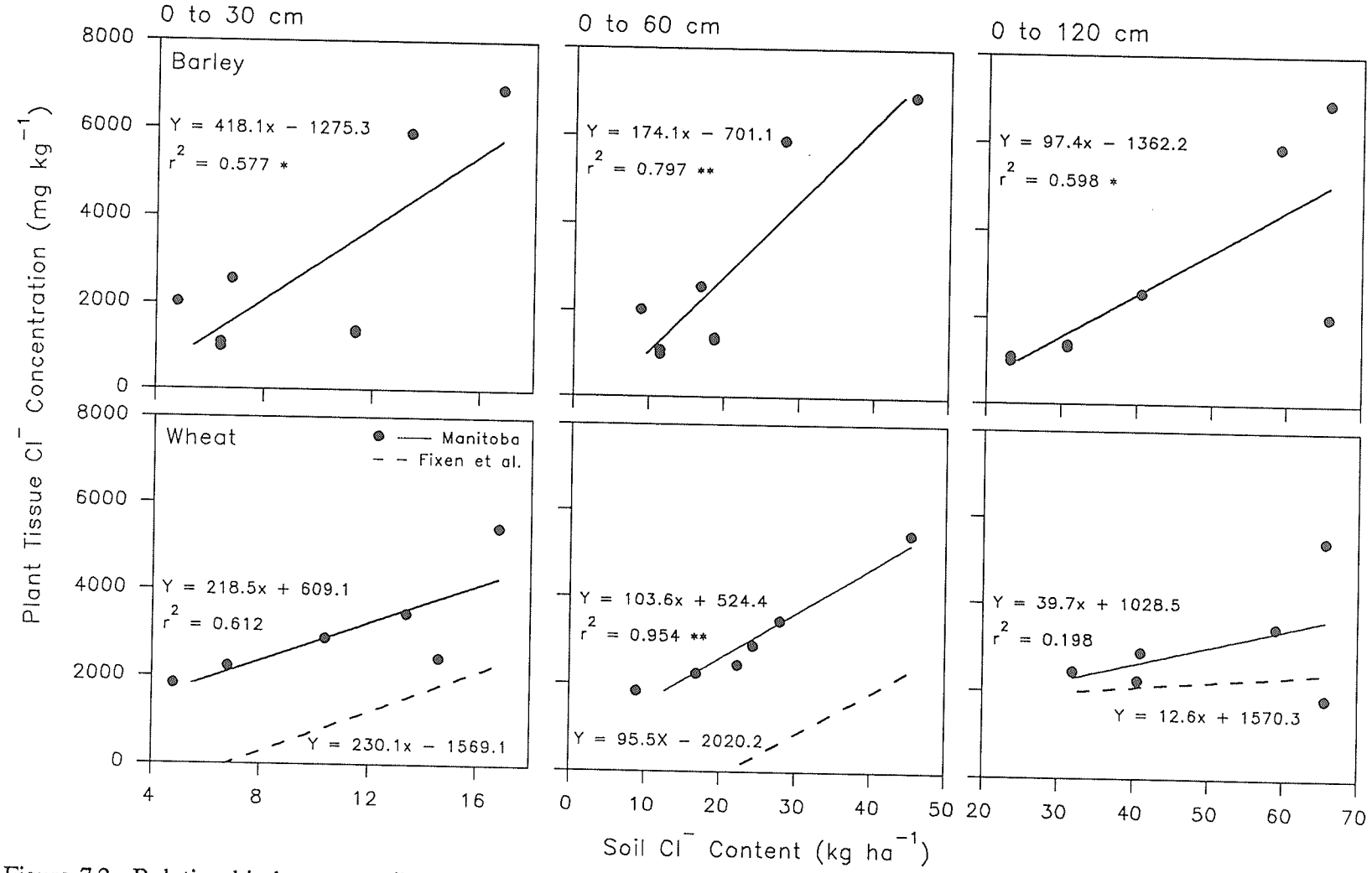

Figure 7.2. Relationship between soil chloride content and plant tissue chloride concentration for Bedford barley and Katepwa wheat as determined by linear regression†

*,** Significant at the 0.05 and 0.01 levels respectively.

† Data consists of control treatments from the common root rot and spot blotch studies and the chloride nutrition study

estimate the concentration of Cl^- in plant tissue for spring wheat at heading using soil Cl^- content (Fixen et al. 1986a; 1987) underestimated Cl^- concentration in plant tissue for wheat grown under Manitoba conditions (Figure 7.2). As mentioned previously, differences between our study and South Dakota studies with respect to the cultivars grown, stage of sampling and environmental conditions may have influenced the relationships observed between the concentration of Cl^- in plant tissue and soil Cl^- content. The higher accumulations of Cl^- observed for wheat in Manitoba as compared to South Dakota may account, in part, for the poor relationship between critical Cl^- contents in soil and plant tissue developed from South Dakota data and yield responses to Cl^- in our studies.

In spite of consistent and significant increases in Cl^- concentration in plant tissue with the addition of Cl^- fertilizers, Cl^- applications did not consistently and significantly influence any other parameter measured.

Cl^- applications frequently resulted in significant reductions in the concentration of NO_3^- in plant tissue for wheat and barley. The application of Cl^- resulted in a significant reduction in NO_3^- concentration in plant tissue for Bedford barley in four of twelve experiments and in a small, statistically insignificant reduction in NO_3^- concentration in plant tissue for Bedford barley in an additional four experiments. Similarly, in wheat, Cl^- applications resulted in significant reductions in the concentration of NO_3^- in plant tissue in six of eight experiments with Katepwa wheat. A significant reduction by Cl^- in NO_3^- concentration in plant tissue was observed for all cultivars grown on at least one, or more, experimental sites. Results of the barley cultivar study showed more frequent reductions by Cl^- in NO_3^- concentration in plant tissue for the cultivars Bedford and Brier than for Argyle and Heartland. Differences among cultivars were not noted for wheat.

The effects of Cl^- applications on concentrations of K, NH_4^+, Cu, Mn and Zn in plant tissue harvested at midseason were minimal or non-existent for wheat and barley; no consistent trends were apparent overall. Adequate to high concentrations of K in plant tissue and lack of a difference among KCl, NaCl and $CaCl_2$ treatments supported the claim that fertilizer responses observed were the result of the Cl^- component of the fertilizer used. The lack of an effect of Cl^- application on the concentration of Mn in plant tissue indicated that the effect of Cl^- applications on plant availability of Mn was not an important factor influencing responses to Cl^- under Manitoba conditions.

Small, statistically significant reductions by Cl^- in common root rot were observed in two of six experiments with Bedford barley and in one of four experiments with Katepwa wheat. However, consequent, significant increases in grain yield did not result from these reductions in common root rot severity at any site. In several instances, Cl^- applications resulted in visible reductions in foliar disease in the cultivar trials. Again, significant increases in grain yield were not generally associated with these reductions in disease. Increases in thousand kernel weight were occasionally observed, however.

In several instances, Cl^- applications produced significant increases in grain yield for wheat and barley (Tables 7.1 and 7.2). However, observed yield increases were generally modest in size.

Table 7.1. Effect of chloride fertilizer on yield response of Bedford barley and Katepwa wheat in Manitoba (1989-1990)†

Crop	Number of plots in which Cl^- significantly increased yield‡	Average yield response (kg ha^{-1}) at:	
		Responsive sites only	Across all sites
Bedford barley	2 of 8	393	187
Katepwa wheat	0 of 8	---	-10

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

Table 7.2. The effect of crop cultivar on yield response of wheat and barley to the application of chloride fertilizers in Manitoba (1990-1991)†

Crop	Cultivar	Number of sites in which Cl^- significantly increased yield‡	Average yield response (kg ha^{-1}) at:	
			Responsive sites only	Across all sites
Barley	Bedford	0 of 4 §	---	-257
	Brier	0 of 4	---	-44
	Argyle	0 of 4	---	55
	Heartland	1 of 4	905	239
Wheat	Katepwa	0 of 4	---	-16
	Roblin	1 of 4	492	137
	Biggar	2 of 4	333	150
	Marshall	2 of 4 ¶	363	116

† application rate was 50 kg Cl^- ha^{-1}
‡ $P \leq 0.05$
§ At 1 of 4 sites, a significant decrease in yield (~ 1200 kg ha^{-1}) was observed.
¶ At 1 of 4 sites, a significant decrease in yield (~ 390 kg ha^{-1}) was observed.

In two cases, Cl^- applications resulted in a significant reduction in grain yield. The reason for the observed yield reductions is not known.

The application of Cl^- rarely resulted in a significant increase in grain yield for the barley cultivars tested. Overall, yield responses to Cl^- were observed more frequently in the wheat cultivars tested. Cultivars tended to differ in Cl^- responsiveness, however. Yield increases by Cl^- were observed in two of four experiments for Biggar and Marshall and in one of four experiments for Roblin. Katepwa did not show a yield response to Cl^- in any of the four cultivar experiments conducted. Results of the wheat cultivar study suggested that the lack of response to Cl^- observed in Katepwa wheat in the common root rot and chloride nutrition studies may have been due, in part, to the non-responsive nature of this cultivar.

Results of field studies suggested that increases by Cl^- in grain yield may sometimes be due, in part, to reductions in foliar disease or to advancements in crop maturity and consequent increases in thousand kernel weight. Yield increases to Cl^-

tended to occur most frequently under high yield conditions. Similarly, in the wheat cultivar study, yield responses were observed most frequently in Marshall and Biggar which tend to have a higher yield potential than the other wheat cultivars tested.

As noted previously, neither soil Cl^- content (Figure 7.3) nor the concentration of Cl^- in plant tissue (Figure 7.4) reliably predicted yield responses to the application of Cl^-. None of the parameters measured in these studies consistently and conclusively separated responsive from non-responsive situations. As well, no single characteristic of the cultivars grown definitely separated the responsive from non-responsive cultivars.

Cl^- applications resulted in significant increases in thousand kernel weight and hectolitre weight in several cases. These improvements in grain quality were observed most frequently in conjunction with significant increases in grain yield for wheat. Generally, Cl^- applications had negligible or deleterious effects on thousand kernel weight, hectolitre weight and percent plump kernels for barley. Reductions by Cl^- in NO_3^- concentration in plant tissue harvested at midseason did not generally translate into significant reductions in total N concentration in grain. However, in wheat, significant reductions by Cl^- in total N concentration in grain were observed in two cases in which Cl^- had both significantly reduced the concentration of NO_3^- in plant tissue harvested at midseason and significantly increased grain yield.

In summary, Cl^- can, on occasion, provide a modest increase in grain yield for spring wheat and barley cultivars grown under Manitoba conditions. Additional benefits, including reductions in foliar and root diseases, advancements in crop maturity and improvements in grain quality, may also result from the application of Cl^--containing fertilizers. However, the reliable prediction of positive responses to Cl^- remains difficult.

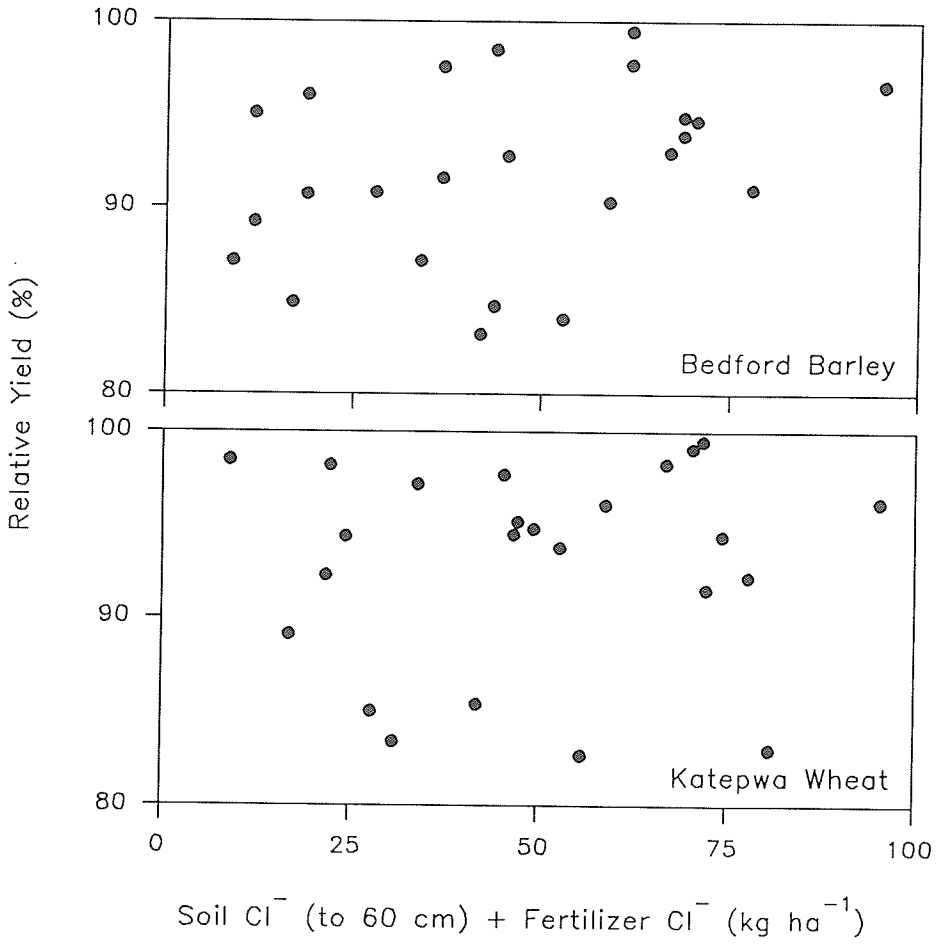

Figure 7.3. Effect of soil chloride and two sources of fertilizer chloride on relative yield of Bedford barley and Katepwa wheat in 1989 and 1990 field studies*

* Data consists of non-inoculated treatments from common root rot and spot blotch studies and the chloride nutrition study. Relative yield was calculated as percent of the highest treatment mean.

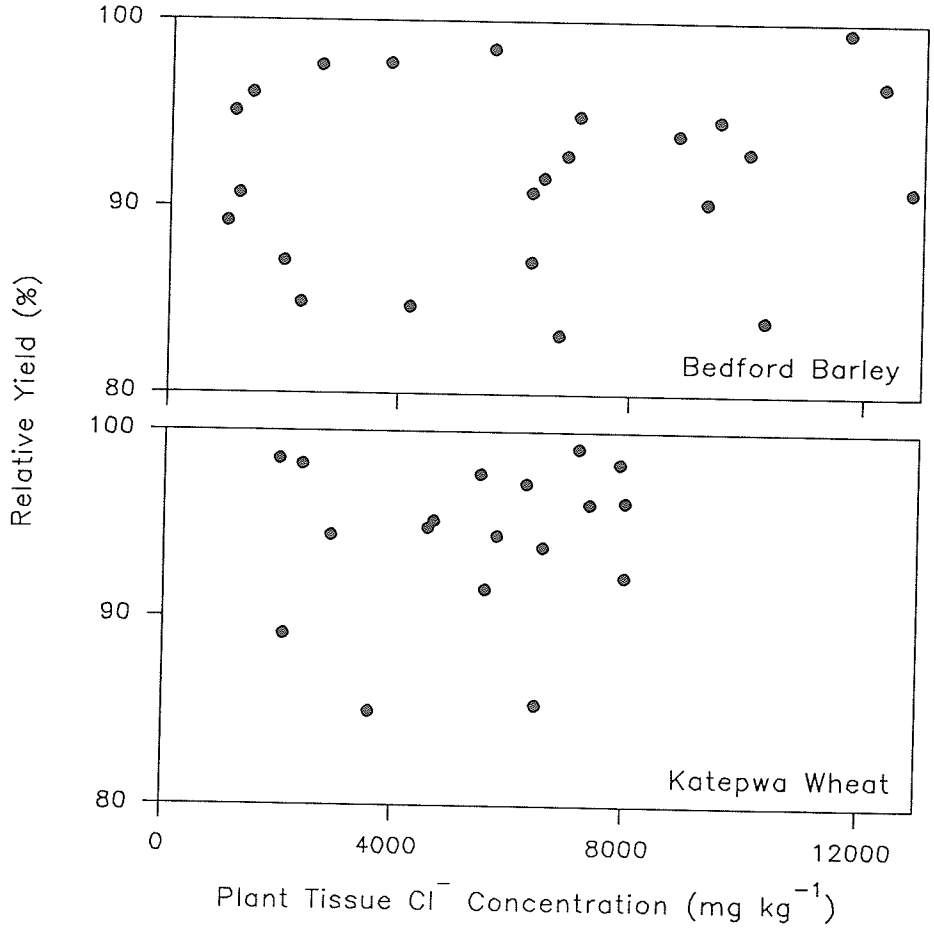

Figure 7.4. Relationship between plant tissue chloride concentration and relative yield of Bedford barley and Katepwa wheat in 1989 and 1990 field studies*

* Data consists of non-inoculated treatments from common root rot and spot blotch studies and the chloride nutrition study. Relative yield calculated as percent of the highest treatment mean.

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9. APPENDICES

Appendix A

Materials and Methods for Soil Analysis

A.1 Chloride

Extractable soil Cl^- was determined using the mercuric thiocyanate method described by Fixen et al. (1988) with several modifications. A 20 g sample of ground soil was shaken for 30 minutes with 0.01 M $Ca(NO_3)_2$ and 0.05 g $NaHCO_3$-washed charcoal. Immediately after shaking, the extract was filtered through Whatman #5 filter paper. (Immediately prior to filtering, funnels and filter papers were rinsed with deionized water to remove any Cl^- present). Two mL each of $Hg(SCN)_2$ and $Fe(NO_3)_3$ were added to a 5 mL aliquot of extractant and allowed to stand for 20 minutes to allow colour development. Absorbance was read at 460 nm.

A.2 Soil pH

The pH of soil samples was determined on a 1:1 water to soil paste using a glass-calomel electrode.

A.3 Organic Carbon

Organic C was determined using a modified Mebius procedure (Mebius 1960) as described by Yeomans and Bremner (1988). A 0.5 g sample of ground soil was digested with 5 mL 1 N $K_2Cr_2O_7$ and 7.5 mL H_2SO_4 for 30 minutes. The digested sample was brought up to a volume of 50 mL with distilled water and organic C determined by

titration with 0.2 N Mohr's salt.

A.4 Inorganic Carbon

Inorganic C was determined using the method described by Bundy and Bremner (1972). Twenty mL of 2 M HCl was added to 8 g or less of finely ground soil and 1 drop n-octyl alcohol in a stoppered French Square bottle and allowed to stand at room temperature for 16 to 24 hours. Five mL of 2 M KOH was used to collect CO_2. Inorganic C was determined by titration of KOH with 0.1 M HCl.

A.5 Nitrate

A 5.0 g soil sample was shaken with 100 mL 2M KCl for 30 minutes and filtered through Whatman #1 filter paper. Analysis was conducted using a copperized cadmium reduction method (Keeney and Nelson 1982) modified for use with a Tecator Nitrate Analyzer.

A.6 Phosphorus

A 5.0 g soil samples was shaken with 1.0 g $NaHCO_3$-washed charcoal and 100 mL 0.5 M $NaHCO_3$ (pH 8.5) for 30 minutes (Olsen and Sommers 1982). Extracts were filtered using Whatman #5 filter paper and phosphorus determined using the acid-molybdate-antimony method described by Murphy and Riley (1962).

A.7 Potassium

A 5 g soil sample was shaken with 100 mL 1 N NH_4OAc solution (pH 7.0) for 1 hour (Knudsen et al. 1982). K was determined by atomic absorption spectrophotometer

(Isaac and Kerber 1971).

A.8 Sulfate

A 25 g soil sample was shaken with 50 mL 0.001 M $CaCl_2$ for 30 minutes and SO_4^{2-} determined with an autoanalyzer using a method similar to that described by Hamm et al. (1973).

A.9 Copper, Manganese, and Zinc

A 20 g soil sample was shaken with 50 mL DTPA extracting solution (Lindsay and Norvell 1978) for 2 hours. The extract was filtered using Whatman #5 filter paper. Cu, Mn and Zn were determined by atomic absorption spectrophotometer (Isaac and Kerber 1971).

Appendix B

Materials and Methods for Plant Tissue Analysis

B.1 Chloride

A 1 g sample of finely ground oven-dried plant tissue was shaken with 50 mL 0.1 N nitric acid for 30 minutes. Immediately after shaking, the extract was filtered through Whatman #1 filter paper. (Immediately prior to filtering, funnels and filter papers were rinsed with deionized water to remove any Cl^- present). A 5, 10 or 20 mL aliquot of the filtered extract was brought up to a volume of approximately 70 mL with water and titrated with $AgNO_3$ in 0.1 N nitric acid to an endpoint equivalent to the millivolt reading of the extracting solution (LaCroix et al. 1970). During titration, the sample was stirred with a magnetic stirrer. A 50 mL biuret and Radiometer Titrator TTT2 were used. An Orion Model 96-17B Combination Chloride Electrode was used to determine the endpoint.

B.2 Nitrate and Ammonium

A 0.1 g sample of finely ground oven-dried plant tissue was shaken with 50 mL of 2 M KCl-PMA for a period of 1 hour (Milham et al. 1970). The extract was filtered through Whatman #5 filter paper and NO_3^- and NH_4^+ determined by steam distillation (Keeney and Nelson 1982).

B.3 Potassium, Copper, Manganese and Zinc

A wet ashing technique using nitric and perchloric acid followed by analysis by atomic absorption similar to that described by Isaac and Kerber (1971) was used. A 1 g

sample of finely ground oven-dried plant tissue was predigested at room temperature with 5 mL of concentrated HNO_3 and 2.5 mL of 70% $HClO_4$ for a minimum of 1 hour. The sample was then digested at 228°C using a Tecator Digestion System 40 - 1006 Heating Unit until the sample was clear. Samples were transferred to 25 mL volumetric flasks and brought up to volume with deionized distilled water. The concentration of Cu, Mn and Zn in this dilute digest was determined by atomic absorption. This solution was further diluted and K determined by atomic absorption. In 1989, a 10,000 time dilution was used. $LiNO_3$ acted as a swamping solution. In 1990 and 1991, a 20,000 time dilution factor was used. $LaCl_3$ was the swamping solution used.

B.4 Total Nitrogen

Total Nitrogen Concentration in Plant Tissue Harvested at Midseason

Total N excluding NO_3^- was determined by a micro-Kjeldahl method with a H_2O_2 pretreatment as described by Bowman et al. (1988). Total nitrogen concentration in midseason plant tissue consisted of the total of reduced N determined by the micro-Kjeldahl method described by Bowman et al. (1988) plus the NO_3^- concentration in plant tissue determined separately by the method described previously.

Total Nitrogen Concentration in Grain at Maturity

Total N was determined by a method similar to that described by Schuman et al. (1973) and in the Kjeltec Manual (Tecator 1987). A 0.5 g sample of finely ground grain plus 3.5 g prepared catalyst and 10 mL of concentrated H_2SO_4 was digested at 460°C for 1 hour and total N determined using a Tecator Kjeltec Auto Analyzer 1030.

Appendix C

Rating Systems for Plant Diseases

C.1 Common Root Rot

Common root rot severity was determined using the rating system described by Ledingham et al. (1973). Plants with sufficiently long subcrown internodes were placed in disease classes ranging from 1 to 4 based on the severity of common root rot lesions present on the subcrown internode of plants excavated from the field at the soft dough stage. The disease rating scale used was as follows: 1=clean, 2=slight, 3=moderate, 4=severe. The disease rating reported was calculated as a weighted average based on the proportion of plants in each disease class as follows:

a = number of plants in class 1
b = number of plants in class 2
c = number of plants in class 3
d = number of plants in class 4

$$\text{Reported disease rating} = \frac{a\times1 + b\times2 + c\times3 + d\times4}{a + b + c + d}$$

C.2 Spot Blotch

The rating system used to determine the severity of spot blotch was based on the height of disease in the canopy on a scale of 0 to 9 (Saari and Prescott 1975) and the severity of disease on a scale of 1 to 4. Height of disease in the canopy increased from 0 to 9 as follows: 0=no disease infection present, 5=disease infection present to half the height of the crop canopy, 9=disease infection present to the top of the canopy, including the spike. Disease severity rating was based on the occurrence of disease lesions on the uppermost leaves in the canopy. Disease severity increased from 1 to 4 as follows: 1=clean, 2=slight 3=moderate 4=severe.

Appendix D

Plant Tissue Nutrient Concentrations, Straw Yield and Grain Quality Measures from Common Root Rot and Spot Blotch Studies

Table D.1. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue zinc concentration for Bedford barley in 1989

Treatment			Plant tissue Zn concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	16.5	21.2	18.1	19.9
KCl	25	-	16.8	18.9	18.3	19.2
KCl	50	-	16.5	19.6	18.5	19.8
NaCl	0	-	16.3	20.3	18.7	19.2
NaCl	25	-	16.2	21.7	18.4	20.1
NaCl	50	-	17.2	22.7	19.5	19.3
KCl	0	+	17.9	20.6	19.8	19.7
KCl	25	+	16.8	21.4	18.8	19.6
KCl	50	+	16.7	22.3	18.7	19.8
NaCl	0	+	17.7	23.9	19.7	20.3
NaCl	25	+	16.4	21.7	19.3	19.2
NaCl	50	+	15.1	22.4	19.5	21.5
KCl (S)‡	25	-	17.1	23.0	17.4	-
KCl (S)	25	+	17.3	22.2	19.3	-
Group means						
KCl			16.9	20.7	18.7	19.7
NaCl			16.6	22.2	19.2	20.0
LSD (P=0.05)			ns	1.1	ns	ns
	0		17.1	21.6	19.1	19.8
	25		16.5	21.0	18.7	19.6
	50		16.4	21.7	19.1	20.1
LSD (P=0.05)			ns	ns	ns	ns
		-	16.6	20.8	18.6	19.6
		+	16.9	22.1	19.3	20.0
LSD (P=0.05)			ns	1.1	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.66	0.03 *	0.10	0.24
Source (S)	1	0.64	0.01 **	0.25	0.45
Rate (R)	2	0.58	0.56	0.75	0.45
S*R	2	0.99	0.97	0.80	0.73
I*R	2	0.27	0.98	0.56	0.33
S*I	1	0.61	0.69	0.86	0.35
I*S*R	2	0.77	0.03 *	0.89	0.14
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.66	0.08	0.27	0.31
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.65	0.04	0.63	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.72	0.62	0.65	-
all 0 vs 25 KCl	1	0.61	0.24	0.45	0.52
all 0 vs 50 KCl	1	0.51	0.50	0.50	0.96
all 0 vs 25 NaCl	1	0.33	0.92	0.78	0.88
all 0 vs 50 NaCl	1	0.37	0.36	0.51	0.23
C.V. (%)		13.5	13.1	10.5	7.8

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.2. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue zinc concentration for Bedford barley in 1990

Treatment			Plant tissue Zn concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	13.5	15.1	17.6	20.4
KCl	25	-	13.8	13.6	17.3	20.2
KCl	50	-	12.9	14.7	19.1	22.6
NaCl	0	-	14.5	13.9	16.9	18.2
NaCl	25	-	13.6	14.2	18.0	20.8
NaCl	50	-	13.0	14.6	18.0	20.0
KCl	0	+	13.6	14.2	18.5	21.4
KCl	25	+	14.7	15.5	15.8	17.5
KCl	50	+	13.1	14.4	18.5	20.6
NaCl	0	+	14.3	13.6	17.9	19.6
NaCl	25	+	13.5	14.6	17.2	19.4
NaCl	50	+	13.2	15.6	18.0	19.8
KCl (S)‡	25	-	13.3	13.8	15.3	-
KCl (S)	25	+	13.3	15.2	15.8	-
Group means						
KCl			13.6	14.6	15.1	20.4
NaCl			13.7	14.4	15.7	19.6
LSD (P=0.05)			ns	ns	ns	ns
	0		14.0	14.2	15.5	19.9
	25		13.9	14.5	14.7	19.5
	50		13.0	14.8	16.0	20.7
LSD (P=0.05)			0.6	ns	ns	ns
		-	13.6	14.3	15.3	20.4
		+	13.7	14.6	15.5	19.7
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	P > F			
Inoculum (I)	1	0.56	0.57	0.73	0.30
Source (S)	1	0.73	0.77	0.04 *	0.20
Rate (R)	2	0.006 **	0.62	0.009 **	0.26
S*R	2	0.07	0.57	0.92	0.07
I*R	2	0.77	0.43	0.41	0.09
S*I	1	0.37	0.89	0.97	0.35
I*S*R	2	0.77	0.53	0.97	0.88
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.36	0.77	0.83	0.77
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.36	0.87	0.20	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.03 *	0.85	0.99	-
all 0 vs 25 KCl	1	0.45	0.69	0.16	0.26
all 0 vs 50 KCl	1	0.01 **	0.64	0.19	0.08
all 0 vs 25 NaCl	1	0.30	0.81	0.90	0.83
all 0 vs 50 NaCl	1	0.02 *	0.27	0.69	0.97
C.V. (%)		7.8	15.6	18.2	13.1

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.3. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue ammonium concentration for Bedford barley in 1989

Treatment			Plant tissue NH_4^+ concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	341	1356	320	350
KCl	25	-	335	1050	386	427
KCl	50	-	408	1460	522	381
NaCl	0	-	390	872	367	339
NaCl	25	-	344	908	375	345
NaCl	50	-	363	1349	423	422
KCl	0	+	337	1531	301	337
KCl	25	+	314	1389	453	367
KCl	50	+	346	1528	405	392
NaCl	0	+	353	1276	312	363
NaCl	25	+	442	1088	353	370
NaCl	50	+	404	1279	326	433
KCl (S)‡	25	-	328	1341	336	-
KCl (S)	25	+	355	992	369	-
Group means						
KCl			347	1395	398	376
NaCl			382	1136	359	379
LSD (P=0.05)			ns	218	ns	ns
	0		355	1268	323	347
	25		358	1116	392	377
	50		381	1404	419	407
LSD (P=0.05)			ns	ns	ns	ns
		-	364	1178	400	377
		+	365	1348	358	377
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.97	0.19	0.11	0.99
Source (S)	1	0.18	0.02 *	0.11	0.91
Rate (R)	2	0.80	0.14	0.007 **	0.23
S*R	2	0.76	0.87	0.15	0.50
I*R	2	0.64	0.63	0.10	0.91
S*I	1	0.20	0.92	0.50	0.47
I*S*R	2	0.40	0.89	0.66	0.82
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.23	0.11	0.01 **	0.98
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.82	0.50	0.33	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.51	0.15	0.21	-
all 0 vs 25 KCl	1	0.50	0.93	0.008 **	0.24
all 0 vs 50 KCl	1	0.73	0.22	0.0002 **	0.36
all 0 vs 25 NaCl	1	0.33	0.10	0.25	0.82
all 0 vs 50 NaCl	1	0.48	0.86	0.15	0.06
C.V. (%)		29.9	37.9	26.5	31.7

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.4. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue ammonium concentration for Bedford barley in 1990

Treatment			Plant tissue NH_4^+ concentration (mg kg^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	349	277	407	1189
KCl	25	-	418	200	444	828
KCl	50	-	443	362	481	857
NaCl	0	-	411	340	456	668
NaCl	25	-	644	242	719	760
NaCl	50	-	546	485	495	795
KCl	0	+	538	306	384	489
KCl	25	+	362	261	367	848
KCl	50	+	398	299	388	818
NaCl	0	+	648	407	466	698
NaCl	25	+	346	215	483	1104
NaCl	50	+	442	292	456	666
KCl (S)‡	25	-	549	208	474	-
KCl (S)	25	+	459	375	547	-
Group means						
KCl			418	284	412	838
NaCl			506	330	512	782
LSD (P=0.05)			ns	ns	92	ns
	0		486	333	428	761
	25		443	229	503	885
	50		457	359	455	784
LSD (P=0.05)			ns	111	ns	ns
		-	468	318	500	849
		+	455	297	424	770
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.82	0.65	0.10	0.53
Source (S)	1	0.13	0.31	0.03 *	0.66
Rate (R)	2	0.81	0.05 *	0.41	0.69
S*R	2	0.97	0.74	0.34	0.69
I*R	2	0.02 *	0.24	0.41	0.25
S*I	1	0.46	0.51	0.79	0.21
I*S*R	2	0.58	0.73	0.58	0.42
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.19	0.61	0.03 *	0.97
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.33	0.94	0.78	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.47	0.30	0.10	-
all 0 vs 25 KCl	1	0.24	0.13	0.73	0.68
all 0 vs 50 KCl	1	0.42	0.98	0.93	0.69
all 0 vs 25 NaCl	1	0.92	0.12	0.01 **	0.37
all 0 vs 50 NaCl	1	0.93	0.40	0.48	0.87
C.V. (%)		49.5	61.7	39.9	65.7

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.5. Effect of chloride fertilizer on midseason plant tissue total nitrogen concentration for Bedford barley in 1990

Treatment			Plant tissue total N concentration (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
-	0	-	2.61	2.74	2.33	2.22
KCl	50	-	2.60	2.54	2.40	2.16
NaCl	50	-	2.65	3.00	2.41	2.10

ANOVA	df	Pr > F			
Treatment	2	0.95	0.007 **	0.76	0.13
Contrasts					
0 vs 50 Cl^- as KCl or NaCl	1	0.92	0.79	0.48	0.09
0 vs 50 Cl^- as KCl	1	0.95	0.10	0.55	0.33
0 vs 50 Cl^- as NaCl	1	0.82	0.05 *	0.52	0.05 *
KCl vs NaCl	1	0.77	0.002 **	0.96	0.25
C.V. (%)		11.7	7.0	8.5	4.4

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.6. Effect of chloride fertilizer and *C. sativus* inoculum on straw yield for Bedford barley in 1989

Treatment			Straw yield (kg ha^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	2919	4533	5224	4784
KCl	25	-	3016	3864	4943	4643
KCl	50	-	3263	4619	4992	4510
NaCl	0	-	3110	4330	5002	4912
NaCl	25	-	3132	4452	5208	4450
NaCl	50	-	2728	4827	4753	4904
KCl	0	+	2829	4214	4714	4907
KCl	25	+	2851	4065	5231	4601
KCl	50	+	3044	4387	5035	4834
NaCl	0	+	2788	4330	5106	4505
NaCl	25	+	2901	4053	5018	4445
NaCl	50	+	2825	4621	4847	4588
KCl (S)‡	25	-	2901	4169	5806	-
KCl (S)	25	+	3042	3739	5195	-
Group means						
KCl			2984	4280	5023	4713
NaCl			2913	4436	4989	4634
LSD (P=0.05)			ns	ns	ns	ns
	0		2911	4352	5012	4777
	25		2966	4108	5100	4535
	50		2965	4614	4907	4709
LSD (P=0.05)			ns	349	ns	ns
		-	3025	4437	5020	4713
		+	2870	4278	4992	4634
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.20	0.27	0.80	0.54
Source (S)	1	0.62	0.28	0.75	0.37
Rate (R)	2	0.80	0.02 *	0.35	0.07
S*R	2	0.19	0.61	0.50	0.46
I*R	2	0.70	0.94	0.53	0.77
S*I	1	0.75	0.77	0.77	0.04 *
I*S*R	2	0.28	0.41	0.13	0.25
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.36	0.14	0.61	0.64
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.77	0.37	0.02 *	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.35	0.35	0.92	-
all 0 vs 25 KCl	1	0.98	0.07	0.74	0.24
all 0 vs 50 KCl	1	0.10	0.47	0.99	0.43
all 0 vs 25 NaCl	1	0.55	0.64	0.65	0.02 *
all 0 vs 50 NaCl	1	0.63	0.08	0.35	0.81
C.V. (%)		12.0	13.8	12.6	7.9

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.7. Effect of chloride fertilizer and *C. sativus* inoculum on straw yield for Bedford barley in 1990

Treatment			Straw yield (kg ha^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	5021	3930	5274	5550
KCl	25	-	4619	4238	5201	5757
KCl	50	-	4636	4175	5021	6055
NaCl	0	-	4822	3930	5488	5503
NaCl	25	-	4555	3987	5465	5894
NaCl	50	-	5155	4200	5845	5805
KCl	0	+	5128	4555	4952	5485
KCl	25	+	4856	3783	5421	5728
KCl	50	+	4692	3794	5258	5718
NaCl	0	+	4959	3783	4981	5855
NaCl	25	+	4386	3947	5069	5888
NaCl	50	+	4430	3675	5311	6022
KCl (S)‡	25	-	4629	4326	5490	-
KCl (S)	25	+	4923	3848	4947	-
Group means						
KCl			4825	4079	5188	5715
NaCl			4718	3920	5360	5828
LSD (P=0.05)			ns	ns	ns	ns
	0		4982	4049	5174	5598
	25		4604	3989	5289	5817
	50		4728	3961	5359	5900
LSD (P=0.05)			291	ns	ns	223
		-	4801	4077	5382	5760
		+	4742	3923	5165	5783
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.62	0.16	0.10	0.81
Source (S)	1	0.37	0.15	0.19	0.22
Rate (R)	2	0.04 *	0.79	0.51	0.03
S*R	2	0.36	0.34	0.32	0.80
I*R	2	0.26	0.04 *	0.56	0.63
S*I	1	0.11	0.45	0.05 *	0.07
I*S*R	2	0.38	0.09	0.64	0.47
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.63	0.73	0.24	0.43
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.97	0.74	0.39	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.81	0.81	0.16	-
all 0 vs 25 KCl	1	0.17	0.81	0.50	0.29
all 0 vs 50 KCl	1	0.08	0.69	0.86	0.04 *
all 0 vs 25 NaCl	1	0.005 **	0.61	0.65	0.04 *
all 0 vs 50 NaCl	1	0.28	0.49	0.05 *	0.02 *
C.V. (%)		10.4	11.5	10.9	6.7

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.8. Effect of chloride fertilizer and *C. sativus* inoculum on hectolitre weight for Bedford barly in 1989

Treatment			Hectolitre weight (kg hL^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	61.5	59.9	65.3	63.8
KCl	25	-	60.8	59.4	63.7	62.7
KCl	50	-	63.1	58.8	63.2	64.5
NaCl	0	-	63.1	60.1	64.2	64.5
NaCl	25	-	61.8	59.4	63.5	62.3
NaCl	50	-	60.6	60.5	64.8	63.6
KCl	0	+	61.1	59.2	64.3	63.1
KCl	25	+	61.7	60.3	62.5	64.0
KCl	50	+	61.5	59.8	64.1	64.6
NaCl	0	+	60.4	58.8	64.4	64.4
NaCl	25	+	59.7	59.0	63.5	63.0
NaCl	50	+	61.2	59.1	62.7	63.3
KCl (S)‡	25	-	60.5	59.8	61.6	-
KCl (S)	25	+	60.8	59.1	62.9	-
Group means						
KCl			61.6	59.6	63.9	63.8
NaCl			61.1	59.5	63.8	63.5
LSD (P=0.05)			ns	ns	ns	ns
	0		61.5	59.5	64.5	63.9
	25		61.0	59.5	63.3	63.0
	50		61.6	59.5	63.7	64.0
LSD (P=0.05)			ns	ns	0.8	0.7
		-	61.8	59.7	64.1	63.6
		+	60.9	59.4	63.6	63.7
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.06	0.47	0.09	0.53
Source (S)	1	0.34	0.95	0.96	0.37
Rate (R)	2	0.83	0.97	0.008 **	0.01 **
S*R	2	0.62	0.61	0.54	0.01 **
I*R	2	0.59	0.44	0.95	0.11
S*I	1	0.32	0.13	0.79	0.84
I*S*R	2	0.11	0.66	0.01 **	0.68
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.22	0.94	0.56	0.01 **
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.60	0.64	0.007 **	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.52	0.24	0.66	-
all 0 vs 25 KCl	1	0.87	0.53	0.003 **	0.19
all 0 vs 50 KCl	1	0.27	0.83	0.06	0.18
all 0 vs 25 NaCl	1	0.67	0.78	0.03 *	0.004 **
all 0 vs 50 NaCl	1	0.73	0.56	0.09	0.27
C.V. (%)		3.7	2.9	2.1	1.9

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.9. Effect of chloride fertilizer and *C. sativus* inoculum on hectolitre weight for Bedford barley in 1990

Treatment			Hectolitre weight (kg hL^{-1})			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	68.9	68.3	72.9	73.0
KCl	25	-	68.9	67.9	73.2	72.1
KCl	50	-	65.9	67.6	73.1	72.5
NaCl	0	-	67.6	67.7	73.7	73.6
NaCl	25	-	67.1	68.4	73.1	72.1
NaCl	50	-	67.2	68.2	73.7	72.4
KCl	0	+	68.2	68.3	73.2	73.0
KCl	25	+	69.7	68.5	72.4	72.5
KCl	50	+	67.5	67.3	72.7	72.7
NaCl	0	+	69.7	67.8	73.4	73.4
NaCl	25	+	68.9	68.2	72.7	72.5
NaCl	50	+	67.6	67.4	72.9	72.4
KCl (S)‡	25	-	69.4	69.2	72.6	-
KCl (S)	25	+	68.1	68.6	71.6	-
Group means						
KCl			68.2	68.0	72.9	72.6
NaCl			68.0	68.0	73.2	72.7
LSD (P=0.05)			ns	ns	0.3	ns
	0		68.6	68.0	73.3	73.2
	25		68.7	68.2	72.8	72.3
	50		67.1	67.6	73.1	72.5
LSD (P=0.05)			1.4	ns	0.3	0.3
		-	67.6	68.0	73.3	72.6
		+	68.6	67.9	72.9	72.7
LSD (P=0.05)			ns	ns	0.3	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.08	0.72	0.006 **	0.32
Source (S)	1	0.79	0.88	0.02 *	0.38
Rate (R)	2	0.03 *	0.09	0.03 *	0.0001 **
S*R	2	0.33	0.35	0.42	0.10
I*R	2	0.91	0.41	0.15	0.34
S*I	1	0.46	0.36	0.50	0.63
I*S*R	2	0.34	0.66	0.24	0.91
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.66	0.47	0.23	0.66
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.73	0.02 *	0.07	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.22	0.84	0.03 *	-
all 0 vs 25 KCl	1	0.38	0.61	0.03 *	0.0001 **
all 0 vs 50 KCl	1	0.02 *	0.10	0.08	0.004 **
all 0 vs 25 NaCl	1	0.47	0.41	0.06	0.0001 **
all 0 vs 50 NaCl	1	0.14	0.44	0.87	0.0002 **
C.V. (%)		3.3	1.4	0.87	0.81

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.10. Effect of chloride fertilizer and *C. sativus* inoculum on percent thin kernels for Bedford barley in 1989

Treatment			Thin kernels (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	22.7	22.3	5.1	6.8
KCl	25	-	26.3	23.9	6.5	7.3
KCl	50	-	21.8	24.2	7.3	6.3
NaCl	0	-	22.9	19.9	5.5	5.7
NaCl	25	-	25.3	21.8	6.7	8.5
NaCl	50	-	25.9	18.9	6.5	6.6
KCl	0	+	23.5	24.3	6.1	7.2
KCl	25	+	21.4	19.3	7.3	6.5
KCl	50	+	23.0	21.6	6.1	6.3
NaCl	0	+	26.6	22.4	5.7	5.6
NaCl	25	+	25.5	25.0	7.2	8.5
NaCl	50	+	21.2	25.7	8.4	7.5
KCl (S)‡	25	-	23.8	21.4	8.8	-
KCl (S)	25	+	23.3	21.7	7.5	-
Group means						
KCl			23.0	22.5	6.4	6.7
NaCl			24.7	22.2	6.7	7.1
LSD (P=0.05)			ns	ns	ns	ns
	0		23.8	22.2	5.6	6.3
	25		24.5	22.4	6.9	7.7
	50		23.2	22.6	7.1	6.7
LSD (P=0.05)			ns	ns	1.1	0.9
		-	24.1	21.8	6.3	6.9
		+	23.6	22.9	6.8	6.9
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.94	0.43	0.25	0.86
Source (S)	1	0.49	0.77	0.53	0.37
Rate (R)	2	0.86	0.98	0.01 **	0.01 **
S*R	2	0.92	0.56	0.75	0.007 **
I*R	2	0.62	0.59	0.97	0.61
S*I	1	0.83	0.06	0.47	0.65
I*S*R	2	0.45	0.41	0.16	0.67
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.75	0.75	0.45	0.01 **
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.81	0.45	0.03 *	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.71	0.48	0.87	-
all 0 vs 25 KCl	1	0.70	0.73	0.04 *	0.30
all 0 vs 50 KCl	1	0.60	0.77	0.08	0.97
all 0 vs 25 NaCl	1	0.93	0.66	0.03 *	0.0003 **
all 0 vs 50 NaCl	1	0.66	0.99	0.005 **	0.19
C.V. (%)		36.9	25.8	26.4	23.4

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.11. Effect of chloride fertilizer and *C. sativus* inoculum on percent thin kernels for Bedford barley in 1990

Treatment			Thin kernels (%)			
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Winnipeg (CRR)†	Winnipeg (SB)†
Treatment means						
KCl	0	-	52.2	41.6	23.5	26.7
KCl	25	-	51.3	37.3	21.9	26.8
KCl	50	-	54.3	38.9	24.2	26.7
NaCl	0	-	50.5	40.2	23.3	26.6
NaCl	25	-	56.0	34.8	22.8	25.7
NaCl	50	-	54.1	35.4	19.0	24.3
KCl	0	+	53.3	36.6	29.3	28.9
KCl	25	+	47.3	37.9	26.6	26.6
KCl	50	+	55.3	37.6	27.1	27.2
NaCl	0	+	50.4	37.3	27.3	29.2
NaCl	25	+	50.3	38.1	27.1	28.0
NaCl	50	+	55.9	38.3	24.8	26.1
KCl (S)‡	25	-	50.8	31.3	26.0	-
KCl (S)	25	+	53.9	35.1	34.6	-
Group means						
KCl			52.3	38.3	25.4	27.1
NaCl			52.8	37.4	24.0	26.7
LSD (P=0.05)			ns	ns	ns	ns
	0		51.6	38.9	25.9	27.9
	25		51.2	37.0	24.6	26.8
	50		54.9	37.6	23.8	26.1
LSD (P=0.05)			ns	ns	ns	ns
		-	53.1	38.0	22.4	26.1
		+	52.0	37.6	27.0	27.7
LSD (P=0.05)			ns	ns	1.8	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.54	0.76	0.0001 **	0.09
Source (S)	1	0.69	0.47	0.13	0.59
Rate (R)	2	0.11	0.48	0.18	0.27
S*R	2	0.26	0.94	0.14	0.62
I*R	2	0.21	0.17	0.97	0.79
S*I	1	0.84	0.25	0.93	0.45
I*S*R	2	0.93	0.95	0.55	0.89
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.28	0.40	0.22	0.48
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.90	0.05 *	0.10	-
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.08	0.37	0.002 **	-
all 0 vs 25 KCl	1	0.31	0.47	0.29	0.40
all 0 vs 50 KCl	1	0.16	0.72	0.90	0.50
all 0 vs 25 NaCl	1	0.50	0.19	0.55	0.47
all 0 vs 50 NaCl	1	0.15	0.26	0.01 **	0.05 *
C.V. (%)		12.3	14.1	16.8	14.2

† CRR indicates the common root rot experiment at Winnipeg; SB, the spot blotch experiment at Winnipeg.
‡ (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.12. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue copper concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue Cu concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	4.95	4.41	3.71	6.29
KCl	25	-	4.37	3.87	3.48	5.92
KCl	50	-	5.16	4.86	3.96	6.63
NaCl	0	-	4.46	4.53	4.36	6.74
NaCl	25	-	5.75	4.69	3.52	6.54
NaCl	50	-	4.25	3.45	4.09	6.30
KCl	0	+	4.37	4.08	3.75	7.20
KCl	25	+	5.03	3.72	3.58	6.46
KCl	50	+	5.27	4.24	3.36	6.50
NaCl	0	+	6.50	3.63	3.27	6.58
NaCl	25	+	5.41	4.14	3.53	6.16
NaCl	50	+	5.07	4.23	3.74	6.57
KCl (S)†	25	-	5.25	4.86	3.52	6.17
KCl (S)	25	+	4.91	3.93	3.52	5.91
Group means						
KCl			4.85	4.20	3.64	6.50
NaCl			5.24	4.11	3.75	6.48
LSD (P=0.05)			ns	ns	ns	ns
	0		5.07	4.16	3.77	6.70
	25		5.14	4.11	3.53	6.27
	50		4.93	4.19	3.79	6.50
LSD (P=0.05)			ns	ns	ns	ns
		-	4.82	4.30	3.85	6.40
		+	5.28	4.01	3.54	6.58
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.12	0.43	0.07	0.40
Source (S)	1	0.29	0.82	0.50	0.93
Rate (R)	2	0.94	0.98	0.39	0.23
S*R	2	0.08	0.34	0.83	0.82
I*R	2	0.74	0.74	0.32	0.78
S*I	1	0.28	0.84	0.35	0.20
I*S*R	2	0.07	0.48	0.25	0.28
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.80	0.91	0.53	0.96
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.25	0.26	0.91	0.69
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.88	0.81	0.89	0.38
all 0 vs 25 KCl	1	0.43	0.49	0.32	0.18
all 0 vs 50 KCl	1	0.58	0.47	0.65	0.71
all 0 vs 25 NaCl	1	0.28	0.64	0..34	0.36
all 0 vs 50 NaCl	1	0.38	0.54	0.57	0.49
C.V. (%)		26.1	36.0	19.1	16.8

† (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.13. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue zinc concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue Zn concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	21.0	23.4	14.2	16.8
KCl	25	-	19.8	20.9	14.8	15.6
KCl	50	-	19.0	23.2	14.4	15.8
NaCl	0	-	23.2	22.0	14.1	16.6
NaCl	25	-	19.9	22.6	14.3	15.7
NaCl	50	-	22.0	23.6	13.5	17.4
KCl	0	+	19.0	24.5	14.4	17.5
KCl	25	+	21.0	23.6	13.8	17.3
KCl	50	+	20.6	22.0	13.7	16.9
NaCl	0	+	19.2	24.6	15.3	18.3
NaCl	25	+	21.3	21.6	14.4	17.1
NaCl	50	+	21.1	22.6	14.8	15.9
KCl (S)†	25	-	22.4	22.9	14.6	16.5
KCl (S)	25	+	20.4	23.9	14.6	16.6
Group Means						
KCl			20.1	22.9	14.3	16.7
NaCl			21.1	22.8	14.4	16.9
LSD (P=0.05)			ns	ns	ns	ns
	0		20.6	23.6	14.5	17.3
	25		20.5	22.2	14.3	16.5
	50		20.6	22.9	14.1	16.5
LSD (P=0.05)			ns	ns	ns	ns
		-	20.8	22.6	14.2	16.3
		+	20.4	23.2	14.4	17.2
LSD (P=0.05)			ns	ns	ns	0.8

ANOVA	df	Pr > F			
Inoculum (I)	1	0.58	0.34	0.63	0.03 *
Source (S)	1	0.24	0.88	0.57	0.64
Rate (R)	2	0.99	0.13	0.55	0.13
S*R	2	0.75	0.73	0.85	0.90
I*R	2	0.15	0.10	0.32	0.14
S*I	1	0.49	0.53	0.03	0.42
I*S*R	2	0.84	0.14	0.74	0.16
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.33	0.80	0.89	0.78
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.27	0.16	0.68	0.33
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.80	0.85	0.27	0.40
all 0 vs 25 KCl	1	0.87	0.12	0.69	0.14
all 0 vs 50 KCl	1	0.44	0.26	0.30	0.09
all 0 vs 25 NaCl	1	0.99	0.09	0.65	0.11
all 0 vs 50 NaCl	1	0.50	0.57	0.43	0.26
C.V. (%)		18.1	10.7	8.4	9.3

† (S) indicates placement of chloride fertilizer in the seed row.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.14. Effect of chloride fertilizer and *C. sativus* inoculum on midseason plant tissue ammonium concentration for Katepwa wheat in 1989 and 1990

Treatment			Plant tissue NH_4^+ concentration (mg kg^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	672	958	420	290
KCl	25	-	699	1030	267	285
KCl	50	-	626	713	356	246
NaCl	0	-	572	1036	407	283
NaCl	25	-	608	1045	332	313
NaCl	50	-	696	1044	308	270
KCl	0	+	627	1101	327	346
KCl	25	+	713	924	312	322
KCl	50	+	624	887	278	335
NaCl	0	+	573	1081	313	356
NaCl	25	+	577	789	299	285
NaCl	50	+	719	1005	348	354
KCl (S)†	25	-	657	1083	382	310
KCl (S)	25	+	846	1034	417	344
Group means						
KCl			660	935	327	304
NaCl			624	1000	334	310
LSD (P=0.05)			ns	ns	ns	ns
	0		611	1044	367	319
	25		649	947	302	301
	50		666	912	322	301
LSD (P=0.05)			ns	ns	ns	ns
		-	646	971	348	281
		+	639	964	313	333
LSD (P=0.05)			ns	ns	ns	33

ANOVA	df	Pr > F			
Inoculum (I)	1	0.86	0.90	0.33	0.003 **
Source (S)	1	0.37	0.23	0.83	0.72
Rate (R)	2	0.51	0.12	0.34	0.62
S*R	2	0.11	0.09	0.90	0.81
I*R	2	0.94	0.07	0.51	0.13
S*I	1	0.91	0.15	0.85	0.60
I*S*R	2	0.89	0.91	0.54	0.59
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.75	0.22	0.67	0.69
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.67	0.69	0.18	0.55
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.18	0.41	0.22	0.60
all 0 vs 25 KCl	1	0.12	0.42	0.14	0.55
all 0 vs 50 KCl	1	0.82	0.004 **	0.34	0.28
all 0 vs 25 NaCl	1	0.76	0.13	0.33	0.45
all 0 vs 50 NaCl	1	0.11	0.81	0.46	0.79
C.V. (%)		25.7	23.8	43.5	23.6

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.15. Effect of chloride fertilizer on midseason plant tissue total nitrogen concentration for Katepwa wheat in 1990

Treatment			Plant tissue total N concentration (%)	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage
Treatment Means				
KCl	0	-	2.65	2.55
KCl	50	-	2.56	2.39
NaCl	50	-	2.55	2.49

ANOVA	df	Pr > F	
Treatment	1	0.53	0.29
Contrasts			
0 vs 50 Cl^- as KCl or NaCl	1	0.28	0.23
0 vs 50 Cl^- as KCl	1	0.39	0.13
0 vs 50 Cl^- as NaCl	1	0.30	0.58
KCl vs NaCl	1	0.86	0.30
C.V. (%)		6.1	6.8

*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.16. Effect of chloride fertilizer and *C. sativus* inoculum on straw yield for Katepwa wheat in 1989 and 1990

Treatment			Straw Yield (kg ha^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	3253	4128	3805	5829
KCl	25	-	3097	4064	3472	5670
KCl	50	-	3067	4201	3601	5531
NaCl	0	-	3089	3797	3719	5829
NaCl	25	-	3572	3470	3914	6043
NaCl	50	-	3047	4412	3574	5875
KCl	0	+	2134	3881	3317	6065
KCl	25	+	2478	3917	3174	5580
KCl	50	+	2508	3413	3667	5035
NaCl	0	+	2682	3404	3917	5562
NaCl	25	+	2392	3881	3346	5647
NaCl	50	+	2239	3441	2976	4992
KCl (S)†	25	-	3211	4058	3946	3830
KCl (S)	25	+	2523	3910	3932	3516
Group means						
KCl			2756	3934	3506	5618
NaCl			2837	3734	3574	5658
LSD (P=0.05)			ns	ns	ns	ns
	0		2789	3803	3689	5821
	25		2885	3833	3476	5735
	50		2715	3867	3455	5358
LSD (P=0.05)			ns	ns	ns	327
		-	3187	4012	3681	5796
		+	2405	3656	3400	5480
LSD (P=0.05)			212	ns	ns	267

ANOVA	df	Pr > F			
Inoculum (I)	1	0.0001 **	0.07	0.15	0.02 *
Source (S)	1	0.45	0.30	0.73	0.77
Rate (R)	2	0.43	0.96	0.55	0.01 **
S*R	2	0.33	0.48	0.30	0.30
I*R	2	0.70	0.10	0.83	0.12
S*I	1	0.88	0.84	0.83	0.14
I*S*R	2	0.04 *	0.67	0.35	0.96
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.84	0.68	0.91	0.26
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.65	0.99	0.30	0.0001 **
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.86	0.99	0.10	0.0001 **
all 0 vs 25 KCl	1	0.99	0.51	0.19	0.33
all 0 vs 50 KCl	1	0.99	0.99	0.84	0.009 **
all 0 vs 25 NaCl	1	0.21	0.66	0.83	0.90
all 0 vs 50 NaCl	1	0.34	0.66	0.14	0.05 *
C.V. (%)		15.5	20.9	22.0	10.5

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table D.17. Effect of chloride fertilizer and *C. sativus* inoculum on hectolitre weight for Katepwa wheat in 1989 and 1990

Treatment			Hectolitre weight (kg hL^{-1})			
			1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Disease inoculum applied	Carman	Portage	Carman	Portage
Treatment means						
KCl	0	-	75.2	78.9	82.7	83.4
KCl	25	-	73.6	80.0	81.4	83.2
KCl	50	-	76.8	79.8	81.2	82.5
NaCl	0	-	73.1	78.6	82.4	83.6
NaCl	25	-	74.9	79.7	81.9	83.2
NaCl	50	-	73.6	79.5	82.3	82.8
KCl	0	+	74.7	79.6	82.5	83.4
KCl	25	+	73.9	79.4	81.7	83.1
KCl	50	+	73.1	79.2	81.2	82.9
NaCl	0	+	76.3	79.1	81.3	83.2
NaCl	25	+	75.5	79.9	82.0	83.1
NaCl	50	+	76.3	79.0	81.6	82.8
KCl (S)†	25	-	72.8	79.0	81.6	83.3
KCl (S)	25	+	78.4	78.9	81.9	83.3
Group means						
KCl			74.5	79.5	81.8	83.1
NaCl			74.9	79.3	81.9	83.1
LSD (P=0.05)			ns	ns	ns	ns
	0		74.8	79.0	82.2	83.4
	25		74.5	79.7	81.8	83.2
	50		74.9	79.5	81.6	82.7
LSD (P=0.05)			ns	0.5	ns	0.3
		-	74.5	79.4	82.0	83.1
		+	74.9	79.4	81.7	83.1
LSD (P=0.05)			ns	ns	ns	ns

ANOVA	df	Pr > F			
Inoculum (I)	1	0.69	0.73	0.37	0.81
Source (S)	1	0.69	0.38	0.65	0.98
Rate (R)	2	0.92	0.05 *	0.18	0.0001 **
S*R	2	0.75	0.66	0.09	0.94
I*R	2	0.75	0.09	0.49	0.32
S*I	1	0.09	0.76	0.29	0.21
I*S*R	2	0.46	0.72	0.87	0.73
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.54	0.65	0.10	0.84
b'cast vs seedrow (25Cl,KCl,-inoc)	1	0.75	0.07	0.78	0.55
b'cast vs seedrow (25Cl,KCl,+inoc)	1	0.06	0.43	0.74	0.60
all 0 vs 25 KCl	1	0.47	0.07	0.13	0.16
all 0 vs 50 KCl	1	0.92	0.13	0.02 *	0.0001 **
all 0 vs 25 NaCl	1	0.79	0.06	0.55	0.16
all 0 vs 50 NaCl	1	0.93	0.52	0.54	0.0002 **
C.V. (%)		5.5	1.1	1.5	0.5

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Appendix E

Straw Yield for Nutrition Study

Table E.1. Effect of chloride fertilizer on straw yield of Katepwa wheat in 1989 and 1990

Treatment		Straw yield (kg ha^{-1})			
		1989		1990	
Cl^- source	kg ha^{-1} Cl^- applied	Anola	Darlingford	Anola	Darlingford
Treatment Means					
KCl	0	6334	3012	3981	6021
KCl	25	5935	3380	4076	6123
KCl	50	6294	2910	3854	6155
NaCl	0	6073	3123	4167	6376
NaCl	25	6017	3113	3761	6007
NaCl	50	6065	3159	3714	6027
KCl (S)†	25	6043	3605	3896	6133
Group Means					
KCl		6188	3101	3970	6100
NaCl		6052	3132	3881	6137
LSD (P=0.05)		ns	ns	ns	ns
	0	6204	3068	4074	6199
	25	5976	3247	3918	6065
	50	6180	3034	3784	6091
LSD (P=0.05)		ns	ns	ns	ns

ANOVA	df	Pr > F			
Source (S)	1	0.47	0.81	0.63	0.86
Rate (R)	1	0.55	0.37	0.45	0.86
S*R	2	0.71	0.26	0.54	0.56
Contrasts					
KCl vs NaCl at 25 and 50 Cl	1	0.74	0.95	0.32	0.63
broadcast vs seedrow (25Cl,KCl)	1	0.73	0.30	0.58	0.98
all 0 vs 25 KCl	1	0.33	0.10	0.99	0.80
all 0 vs 50 KCl	1	0.74	0.40	0.43	0.89
all 0 vs 25 NaCl	1	0.49	0.81	0.27	0.53
all 0 vs 50 NaCl	1	0.61	0.62	0.20	0.58
C.V. (%)		8.0	10.5	12.8	9.0

† (S) indicates placement of chloride fertilizer in the seed row
*, ** Significant at the 0.05 and 0.01 levels respectively.

Appendix F

Plant Tissue Nutrient Concentrations and Straw Yield for Cultivar Studies

Table F.1. Effect of chloride fertilizer on midseason plant tissue copper concentration for four barley cultivars

Treatment			Plant tissue Cu concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	6.95	4.56	5.97	6.21
50	K	Bedford	6.50	3.69	5.94	6.93
50	Na or Ca	Bedford	6.12	3.73	5.59	7.06
0	-	Brier	6.06	3.40	5.55	7.09
50	K	Brier	6.13	3.95	6.06	6.61
50	Na or Ca	Brier	6.74	3.68	6.11	7.11
0	-	Argyle	9.89	4.55	7.10	7.71
50	K	Argyle	8.37	4.28	6.59	7.98
50	Na or Ca	Argyle	8.18	4.59	6.19	7.41
0	-	Heartland	7.46	3.66	5.21	6.42
50	K	Heartland	6.53	4.12	5.30	6.48
50	Na or Ca	Heartland	6.86	4.07	5.39	6.58
Group means						
0	-		7.59	4.04	5.96	6.86
50	K		6.88	4.01	5.97	7.00
50	Na or Ca		6.97	4.02	5.82	7.04
LSD (P=0.05)			ns	ns	ns	ns
		Bedford	6.52	3.99	5.83	6.73
		Brier	6.31	3.68	5.91	6.94
		Argyle	8.81	4.47	6.62	7.70
		Heartland	6.95	3.95	5.30	6.49
LSD (P=0.05)			0.73	0.52	0.86	0.51

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001 **	0.03 *	0.03 *	0.0001 **
Treatment (T)		2	0.06	0.99	0.90	0.69
C*T		6	0.24	0.25	0.88	0.33
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.55	0.92	0.65	0.75
	0 vs 50 Cl^- (both sources)	1	0.24	0.03 *	0.75	0.04 *
Brier	KCl vs NaCl or $CaCl_2$	1	0.34	0.54	0.95	0.27
	0 vs 50 Cl^- (both sources)	1	0.50	0.30	0.41	0.54
Argyle	KCl vs NaCl or $CaCl_2$	1	0.76	0.49	0.59	0.20
	0 vs 50 Cl^- (both sources)	1	0.005 **	0.77	0.28	0.96
Heartland	KCl vs NaCl or $CaCl_2$	1	0.60	0.91	0.91	0.83
	0 vs 50 Cl^- (both sources)	1	0.17	0.27	0.84	0.78
C.V. (%)			15.3	19.3	21.7	10.9

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.2. Effect of chloride fertilizers on midseason plant tissue zinc concentration for four barley cultivars

Treatment			Plant tissue Zn concentration (mg kg^{-1})		
kg ha^{-1} Cl^- applied	Cl^- salt	Cultivar	1991		
			Anola	Portage	Winnipeg
Treatment means					
0	-	Bedford	10.0	20.5	24.8
50	K	Bedford	8.5	18.9	25.6
50	Ca	Bedford	9.2	21.2	24.1
0	-	Brier	9.3	19.9	29.4
50	K	Brier	9.6	20.8	29.3
50	Ca	Brier	8.9	19.6	27.5
0	-	Argyle	10.9	21.7	28.6
50	K	Argyle	10.3	19.9	31.6
50	Ca	Argyle	12.9	22.6	27.4
0	-	Heartland	11.8	23.1	27.4
50	K	Heartland	11.8	21.5	25.7
50	Ca	Heartland	11.1	23.1	26.7
Group means					
0	-		10.5	21.3	27.5
50	K		10.1	20.3	28.0
50	Ca		10.5	21.6	26.4
LSD (P=0.05)			ns	ns	ns
		Bedford	9.2	20.2	24.8
		Brier	9.3	20.1	28.7
		Argyle	11.3	21.4	29.2
		Heartland	11.6	22.6	26.6
LSD (P=0.05)			1.7	2.0	2.8

ANOVA		df	Pr > F		
Cultivar (C)		3	0.007 **	0.05 *	0.01 **
Treatment (T)		2	0.77	0.27	0.39
C*T		6	0.61	0.75	0.81
Contrasts					
Bedford	KCl vs $CaCl_2$	1	0.63	0.18	0.53
	0 vs 50 Cl^- (both sources)	1	0.39	0.78	0.98
Brier	KCl vs $CaCl_2$	1	0.62	0.48	0.46
	0 vs 50 Cl^- (both sources)	1	0.96	0.87	0.63
Argyle	KCl vs $CaCl_2$	1	0.08	0.12	0.09
	0 vs 50 Cl^- (both sources)	1	0.58	0.79	0.69
Heartland	KCl vs $CaCl_2$	1	0.64	0.36	0.68
	0 vs 50 Cl^- (both sources)	1	0.78	0.61	0.59
C.V. (%)			24.7	13.9	15.3

*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.3. Effect of chloride fertilizer on midseason plant tissue ammonium concentration for four barley cultivars

Treatment			Plant tissue NH_4^+ concentreation (mg N kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	807	298	2158	1020
50	K	Bedford	559	226	2031	1203
50	Na or Ca	Bedford	776	243	2620	954
0	-	Brier	873	345	2790	1732
50	K	Brier	1070	472	3459	1533
50	Na or Ca	Brier	934	328	2738	1837
0	-	Argyle	992	382	2574	1634
50	K	Argyle	1231	431	2892	2036
50	Na or Ca	Argyle	1019	465	4018	1649
0	-	Heartland	1210	371	3098	1418
50	K	Heartland	1253	411	3395	1411
50	Na or Ca	Heartland	1353	541	3248	1919
Group means						
0	-		971	349	2655	1451
50	K		1028	385	2944	1546
50	Na or Ca		1020	394	3156	1590
LSD (P=0.05)			ns	ns	ns	ns
		Bedford	714	256	2270	1059
		Brier	959	381	2995	1701
		Argyle	1080	426	3161	1773
		Heartland	1272	441	3247	1582
LSD (P=0.05)			185	82	674	375

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001 **	0.0001 **	0.02 *	0.001 **
Treatment (T)		2	0.74	0.41	0.23	0.69
C*T		6	0.31	0.09	0.33	0.44
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.18	0.82	0.32	0.44
	0 vs 50 Cl^- (both sources)	1	0.32	0.31	0.74	0.84
Brier	KCl vs NaCl or $CaCl_2$	1	0.40	0.05 *	0.22	0.35
	0 vs 50 Cl^- (both sources)	1	0.36	0.37	0.54	0.87
Argyle	KCl vs NaCl or $CaCl_2$	1	0.19	0.63	0.06	0.24
	0 vs 50 Cl^- (both sources)	1	0.34	0.29	0.09	0.46
Heartland	KCl vs NaCl or $CaCl_2$	1	0.54	0.07	0.80	0.12
	0 vs 50 Cl^- (both sources)	1	0.50	0.09	0.66	0.38
C.V. (%)			27.5	32.8	34.6	36.7

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.4. Effect of chloride fertilizer on straw yield for four barley cultivars

Treatment			Straw Yield (kg ha^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Portage	Anola	Portage	Winnipeg
Treatment means						
0	-	Bedford	4146	4988	5679	6187
50	K	Bedford	4005	4987	5092	6060
50	Na or Ca	Bedford	4371	4967	4762	6184
0	-	Brier	4565	4767	5689	7579
50	K	Brier	5137	4551	5553	7098
50	Na or Ca	Brier	4905	4346	5965	7269
0	-	Argyle	5230	4517	6018	6096
50	K	Argyle	5319	4509	5448	6295
50	Na or Ca	Argyle	5088	5360	6510	6360
0	-	Heartland	4014	5032	5476	5868
50	K	Heartland	3985	4631	5624	6310
50	Na or Ca	Heartland	3925	4724	4996	6566
Group means						
0	-		4489	4826	5715	6433
50	K		4612	4669	5429	6441
50	Na or Ca		4572	4849	5558	6595
LSD (P=0.05)			ns	ns	ns	ns
		Bedford	4174	4981	5178	6144
		Brier	4869	4555	5735	7315
		Argyle	5212	4795	5992	6250
		Heartland	3974	4796	5366	6248
LSD (P=0.05)			417	ns	416	496

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001 **	0.09	0.001 **	0.0001 **
Treatment (T)		2	0.79	0.39	0.29	0.70
C*T		6	0.73	0.04 *	0.01 **	0.70
Contrasts						
Bedford	KCl vs NaCl or $CaCl_2$	1	0.32	0.94	0.36	0.78
	0 vs 50 Cl^- (both sources)	1	0.89	0.96	0.02 *	0.86
Brier	KCl vs NaCl or $CaCl_2$	1	0.52	0.47	0.26	0.69
	0 vs 50 Cl^- (both sources)	1	0.15	0.20	0.82	0.29
Argyle	KCl vs NaCl or $CaCl_2$	1	0.52	0.004 **	0.005 **	0.88
	0 vs 50 Cl^- (both sources)	1	0.93	0.09	0.90	0.54
Heartland	KCl vs NaCl or $CaCl_2$	1	0.86	0.74	0.09	0.55
	0 vs 50 Cl^- (both sources)	1	0.85	0.15	0.60	0.13
C.V. (%)			13.7	10.3	11.2	11.4

† NaCl was applied at Portage in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.5. Effect of chloride fertilizers on total nitrogen concentration in grain for four barley cultivars

Treatment			Total N concentration (%)		
kg ha^{-1} Cl^- applied	Cl^- salt	Cultivar	1991		
			Anola	Portage	Winnipeg
Treatment means					
0	-	Bedford	2.05	1.85	2.36
50	K	Bedford	1.93	1.84	2.30
50	Ca	Bedford	1.94	1.89	2.32
0	-	Brier	1.96	2.01	2.45
50	K	Brier	2.00	1.88	2.36
50	Ca	Brier	1.92	1.98	2.44
0	-	Argyle	1.93	1.93	2.14
50	K	Argyle	1.91	1.93	2.00
50	Ca	Argyle	2.01	1.94	2.19
0	-	Heartland	2.39	1.81	2.51
50	K	Heartland	2.36	1.83	2.41
50	Ca	Heartland	2.34	1.87	2.42
Group means					
0	-		2.08	1.90	2.36
50	K		2.05	1.87	2.27
50	Ca		2.05	1.92	2.34
LSD (P=0.05)			ns	ns	ns
		Bedford	1.98	1.86	2.32
		Brier	1.96	1.96	2.41
		Argyle	1.95	1.93	2.11
		Heartland	2.36	1.84	2.45
LSD (P=0.05)			0.06	0.05	0.12

ANOVA		df	Pr > F		
Cultivar (C)		3	0.0001 **	0.0001 **	0.0001 **
Treatment (T)		2	0.37	0.06	0.16
C*T		6	0.10	0.29	0.91
Contrasts					
Bedford	KCl vs $CaCl_2$	1	0.92	0.22	0.82
	0 vs 50 Cl^- (both sources)	1	0.02 *	0.68	0.59
Brier	KCl vs $CaCl_2$	1	0.18	0.02 *	0.43
	0 vs 50 Cl^- (both sources)	1	0.96	0.04 *	0.59
Argyle	KCl vs $CaCl_2$	1	0.05 *	0.70	0.07
	0 vs 50 Cl^- (both sources)	1	0.51	0.79	0.64
Heartland	KCl vs $CaCl_2$	1	0.75	0.46	0.93
	0 vs 50 Cl^- (both sources)	1	0.33	0.36	0.32
C.V. (%)			4.5	4.0	7.9

*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.6. Effect of chloride fertilizer on midseason plant tissue copper concentration for four wheat cultivars

Treatment			Plant tissue Cu concentration (mg kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	7.00	3.92	4.88	5.70
50	K	Katepwa	7.07	3.56	4.97	5.86
50	Na or Ca	Katepwa	6.65	3.43	4.23	5.92
0	-	Roblin	5.79	3.25	3.70	4.06
50	K	Roblin	5.70	3.14	3.84	4.54
50	Na or Ca	Roblin	5.70	3.05	3.74	4.11
0	-	Biggar	7.71	4.65	6.58	6.39
50	K	Biggar	7.33	3.97	6.17	7.17
50	Na or Ca	Biggar	7.25	4.20	5.81	6.48
0	-	Marshall	6.93	3.88	4.75	5.08
50	K	Marshall	6.93	3.54	4.54	5.75
50	Na or Ca	Marshall	6.81	3.39	5.07	5.62
Group means						
0	-		6.86	3.93	4.98	5.31
50	K		6.75	3.55	4.88	5.83
50	Na or Ca		6.60	3.52	4.71	5.53
LSD (P=0.05)			ns	0.35	ns	0.40
		Katepwa	6.90	3.64	4.69	5.83
		Roblin	5.73	3.14	3.76	4.24
		Biggar	7.43	4.28	6.19	6.68
		Marshall	6.89	3.60	4.79	5.48
LSD (P=0.05)			0.42	0.40	0.56	0.46

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001 **	0.0001 **	0.0001 **	0.0001 **
Treatment (T)		2	0.38	0.04 *	0.54	0.04 *
C*T		6	0.95	0.94	0.51	0.82
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.25	0.72	0.13	0.88
	0 vs 50 Cl^- (both sources)	1	0.64	0.17	0.51	0.57
Roblin	KCl vs NaCl or $CaCl_2$	1	1.00	0.80	0.83	0.29
	0 vs 50 Cl^- (both sources)	1	0.79	0.61	0.84	0.44
Biggar	KCl vs NaCl or $CaCl_2$	1	0.84	0.51	0.46	0.09
	0 vs 50 Cl^- (both sources)	1	0.18	0.07	0.17	0.22
Marshall	KCl vs NaCl or $CaCl_2$	1	0.76	0.66	0.29	0.76
	0 vs 50 Cl^- (both sources)	1	0.85	0.17	0.90	0.09
C.V. (%)			9.4	16.5	17.3	12.4

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.7. Effect of chloride fertilizer on midseason plant tissue zinc concentration for four wheat cultivars

Treatment			Plant tissue Zn concentration (mg kg^{-1})		
kg ha^{-1} Cl^- applied	Cl^- salt	Cultivar	1991		
			Anola	Portage	Winnipeg
Treatment means					
0	-	Katepwa	11.1	25.0	26.5
50	K	Katepwa	11.2	24.1	23.9
50	Ca	Katepwa	10.2	22.7	25.7
0	-	Roblin	10.2	18.9	18.9
50	K	Roblin	10.4	17.8	17.9
50	Ca	Roblin	9.9	18.0	18.1
0	-	Biggar	13.9	30.3	33.9
50	K	Biggar	12.8	29.0	37.6
50	Ca	Biggar	12.6	28.8	33.9
0	-	Marshall	12.3	24.5	26.1
50	K	Marshall	11.8	23.9	26.8
50	Ca	Marshall	11.0	23.2	24.9
Group means.					
0	-		11.9	24.7	26.4
50	K		11.5	23.7	26.5
50	Ca		10.9	23.2	25.7
LSD (P=0.05)			0.5	1.2	ns
		Katepwa	10.8	23.9	25.4
		Roblin	10.1	18.2	18.3
		Biggar	13.1	29.4	35.1
		Marshall	11.7	23.8	25.9
LSD (P=0.05)			0.6	1.4	1.7

ANOVA		df	Pr > F		
Cultivar (C)		3	0.0001 **	0.0001 **	0.0001 **
Treatment (T)		2	0.002 **	0.05 *	0.47
C*T		6	0.43	0.98	0.08
Contrasts					
Katepwa	KCl vs $CaCl_2$	1	0.04 *	0.27	0.22
	0 vs 50 Cl^- (both sources)	1	0.37	0.15	0.19
Roblin	KCl vs $CaCl_2$	1	0.34	0.89	0.88
	0 vs 50 Cl^- (both sources)	1	0.94	0.32	0.49
Biggar	KCl vs $CaCl_2$	1	0.74	0.86	0.02 *
	0 vs 50 Cl^- (both sources)	1	0.009 **	0.18	0.16
Marshall	KCl vs $CaCl_2$	1	0.12	0.55	0.20
	0 vs 50 Cl^- (both sources)	1	0.03 *	0.38	0.86
C.V. (%)			7.7	9.0	10.0

*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.8. Effect of chloride fertilizer on midseason plant tissue ammonium concentration for four wheat cultivars

Treatment			Plant tissue NH_4^+ concentration (mg N kg^{-1})			
kg ha^{-1} Cl^- applied	Cl^- salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	930	460	1967	1082
50	K	Katepwa	836	561	1948	912
50	Na or Ca	Katepwa	830	285	1891	1147
0	-	Roblin	464	292	909	525
50	K	Roblin	508	221	1103	463
50	Na or Ca	Roblin	657	243	1094	516
0	-	Biggar	2207	1056	4467	3085
50	K	Biggar	2549	1075	4152	3763
50	Na or Ca	Biggar	2504	979	4089	3237
0	-	Marshall	1579	717	2913	1514
50	K	Marshall	2067	570	2389	1265
50	Na or Ca	Marshall	1777	522	2587	1309
Group means						
0	-		1295	631	2564	1551
50	K		1490	607	2398	1601
50	Na or Ca		1442	507	2415	1552
LSD (P=0.05)			ns	ns	ns	ns
		Katepwa	865	435	1935	1047
		Roblin	543	252	1035	501
		Biggar	2420	1037	4236	3362
		Marshall	1808	603	2630	1362
LSD (P=0.05)			363	160	407	370

ANOVA		df	Pr > F			
Cultivar (C)		3	0.0001 **	0.0001 **	0.0001 **	0.0001 **
Treatment (T)		2	0.44	0.17	0.59	0.94
C*T		6	0.84	0.75	0.81	0.42
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.99	0.05 *	0.87	0.47
	0 vs 50 Cl^- (both sources)	1	0.72	0.76	0.88	0.85
Roblin	KCl vs NaCl or $CaCl_2$	1	0.64	0.87	0.98	0.87
	0 vs 50 Cl^- (both sources)	1	0.66	0.62	0.54	0.90
Biggar	KCl vs NaCl or $CaCl_2$	1	0.88	0.49	0.86	0.11
	0 vs 50 Cl^- (both sources)	1	0.24	0.81	0.26	0.14
Marshall	KCl vs NaCl or $CaCl_2$	1	0.36	0.73	0.58	0.89
	0 vs 50 Cl^- (both sources)	1	0.21	0.16	0.17	0.42
C.V. (%)			38.6	41.1	24.8	35.4

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Table F.9. Effect of chloride fertilizer on straw yield for four wheat cultivars

Treatment			Straw yield (kg ha^{-1})			
kg ha^{-1} Cl$^-$ applied	Cl$^-$ salt†	Cultivar	1990	1991		
			Anola	Anola	Portage	Winnipeg
Treatment means						
0	-	Katepwa	4264	4084	6407	7020
50	K	Katepwa	4308	3917	5726	6509
50	Na or Ca	Katepwa	4508	3698	5818	6624
0	-	Roblin	3574	4624	6209	6782
50	K	Roblin	4161	4060	5448	6707
50	Na or Ca	Roblin	4443	4010	5867	6785
0	-	Biggar	4267	3904	6944	6531
50	K	Biggar	4000	4083	6757	6763
50	Na or Ca	Biggar	4406	4354	6290	6519
0	-	Marshall	4060	4471	6640	6695
50	K	Marshall	4357	4424	6016	6990
50	Na or Ca	Marshall	4532	4506	6199	6923
Group means						
0	-		4041	4271	6550	6757
50	K		4206	4121	5987	6742
50	Na or Ca		4472	4142	6043	6713
LSD (P=0.05)			347	ns	282	ns
		Katepwa	4360	3900	5984	6717
		Roblin	4059	4232	5841	6758
		Biggar	4224	4114	6664	6604
		Marshall	4316	4467	6285	6869
LSD (P=0.05)			ns	339	326	ns

ANOVA		df	Pr > F			
Cultivar (C)		3	0.45	0.01 **	0.0001 **	0.27
Treatment (T)		2	0.05 *	0.54	0.0002 **	0.93
C*T		6	0.66	0.23	0.46	0.22
Contrasts						
Katepwa	KCl vs NaCl or $CaCl_2$	1	0.56	0.46	0.74	0.62
	0 vs 50 Cl$^-$ (both sources)	1	0.63	0.28	0.01 **	0.03 *
Roblin	KCl vs NaCl or $CaCl_2$	1	0.42	0.87	0.14	0.74
	0 vs 50 Cl$^-$ (both sources)	1	0.02 *	0.02 *	0.03 *	0.86
Biggar	KCl vs NaCl or $CaCl_2$	1	0.25	0.36	0.10	0.29
	0 vs 50 Cl$^-$ (both sources)	1	0.83	0.22	0.09	0.58
Marshall	KCl vs NaCl or $CaCl_2$	1	0.61	0.78	0.52	0.77
	0 vs 50 Cl$^-$ (both sources)	1	0.21	0.98	0.03 *	0.20
C.V. (%)			14.1	12.1	7.9	5.9

† NaCl was applied at Anola in 1990; $CaCl_2$ was applied at all sites in 1991.
*, ** Significant at the 0.05 and 0.01 levels respectively.

Appendix G

Measurements at Soft Dough and Maturity for Growth Chamber Studies

Table G.1. Basal fertilizer applied for growth chamber study

Chemical	Application rate (mg chemical kg^{-1} oven dry soil)				
Cl^- application rate (mg Cl^- kg^{-1} oven dried soil)	0	5	10	20	40
KCl	0	11	21	42	84
$KN0_3$	388	374	360	331	274
$NH_4H_2PO_4$	186	186	186	186	186
$CuSO_4$	20	20	20	20	20
$ZnSO_4$	44	44	44	44	44
$(NH_4)_2SO_4$	72	72	72	72	72
NH_4NO_3	24	29	35	46	69

Table G.2. Effect of chloride fertilizer on yield for Bedford barley at maturity

Treatment (mg Cl^- kg^{-1})	Yield (g pot^{-1})†	
	Grain	Straw
0	30.3	41.0
5	33.2	37.3
10	33.3	39.4
20	32.7	39.9
40	31.2	42.7
Pr>F	0.35	0.07
C.V.(%)	8.6	7.1

† Mass based on eight plants.

Table G.3. Effect of chloride fertilizer and *C. sativus* inoculum on common root rot disease severity and yield for Bedford barley at soft dough stage and maturity

Treatment		Soft dough stage					Maturity		
mg Cl^- kg^{-1} soil	Disease inoculum applied	Yield (g pot^{-1})†				Disease rating‡	Yield (g pot^{-1})†		Heads pot^{-1}
		Vegetative		Heads			Grain	Straw	
		Fresh	Oven dry	Fresh	Oven dry				
Treatment means									
0	-	44.0	18.3	75.5	27.5	2.50	30.3	41.0	24.4
40	-	52.1	23.5	73.7	27.8	2.43	31.2	42.7	27.8
0	+	48.0	21.5	74.5	27.8	2.66	32.8	39.9	24.0
40	+	46.7	21.2	82.5	31.0	2.49	34.8	45.1	28.4
Group means									
0		46.0	19.9	75.0	27.6	2.58	31.5	40.5	24.2
40		49.4	22.3	78.1	29.4	2.46	33.0	43.9	28.1
LSD (P=0.05)		ns	1.9	ns	ns	ns	ns	2.2	2.1
	-	48.1	20.9	74.6	27.6	2.46	30.7	41.9	26.1
	+	47.4	21.3	78.5	29.4	2.58	33.8	42.5	26.2
LSD (P=0.05)		ns	ns	ns	ns	ns	2.6	ns	ns

ANOVA	df	Pr>F							
Rate (R)	1	0.14	0.02 *	0.60	0.14	0.56	0.24	0.005 **	0.001 **
Inoculum (I)	1	0.76	0.61	0.52	0.14	0.59	0.02 *	0.57	0.92
R*I	1	0.05 *	0.007 **	0.41	0.23	0.82	0.62	0.11	0.63
C.V.(%)		10.1	9.4	17.1	9.0	18.5	8.5	5.5	8.6

† Mass based on 8 plant for harvests at soft dough and at maturity.
‡ Disease classes based on severity of lesions on subcrown internode: 1=clean 2=slight 3=moderate 4=severe (Ledingham et al. 1973)
*,** Significant at the 0.05 and 0.01 levels respectively.