The effects of nitrogen, phosphorus, potassium, sulfur, chloride, and their interactions, on the agronomic and quality characteristics of dryland small grains

by John Patrick Garvin

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOILS

Montana State University

Abstract:

The purposes of this experiment were to investigate the differences between KCl and K2S04 on dryland small grains, to study the differences between KCl and K2S04 on wheat quality, to study the effects of phosphorus fertilizer on wheat quality, and to locate any interactive effects of N, P, K, S, and Cl on small grains.

We used a 3x3x5 split plot design to meet our objectives. Nitrogen rates at 10, 31, and 100 kg N/ha were the main plots, and P rates of 0, 12, and 36 kg P/ha, combined with K rates of 0, 30, and 90 kg K/ha? as either KCl or K2S04, were the sub-plots. This design was implemented at 2 sites planted with barley in the spring of 1980? and 3 sites planted with winter wheat in the fall of 1980.

Potassium chloride significantly increased yield at 2 sites, but K2S04 only increased yield at one of these sites. The beneficial effect of Cl on disease resistance may have been responsible for the better yield response to KCl at these sites. There were no consistent differences between KCl and K2S04 on grain protein.

Potassium chloride decreased plant nitrate concentration an average of 25 and 15 % in the early tillering and boot stages? respectively. Total S was decreased by KCl an average of 7 and 12 % in the early and late stages, respectively. There was also a tendency for KCl to decrease total P and N. With the exception of total S, K2S04 did not influence any of the forementioned nutrients. Thirty-one kilograms N/ha decreased most of the quality parameters at site 3, and generally had no influence at site 4. Phosphorus significantly decreased flour protein, loaf volume, and the loaf grain and texture score at site 3, but had no significant effects at site 4. Farinograph absorption, farinograph peak? and bread volume were significantly decreased by both KCl and K2S04 at site 3? but neither source had any significant effects at site 4. Most of the quality characteristics affected by N, P, K, S, or Cl can be related to protein fluctuations.

Dryland root rot (Fusarium spp.) was analyzed at site 2. Both P and KCl significantly decreased the incidence of this pathogen. A significant NxK interaction was also found.

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Date 10/25/82

You, my friend - a citizen of the great and mighty and wise city of Athens - are you not ashamed of devoting yourself to acquiring the greatest amount of money and honour and reputation, and caring so little for wisdom and truth?

- Socrates -

THE EFFECTS OF NITROGEN, PHOSPHORUS, POTASSIUM, SULFUR, CHLORIDE, AND THEIR INTERACTIONS, ON THE AGRONOMIC AND QUALITY CHARACTERISTICS OF DRYLAND SMALL GRAINS

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of

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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INTRODUCTION

Two ways for the farmers in the northern Great Plains to increase income from small grain production are through increased grain yield and increased quality. In the past few years Montana farmers have become increasingly concerned about small grain quality. Quality is of particular concern in dryland cereal production because many farmers apply fertilizer at levels below those recommended from soil test results. The following research was undertaken due to the lack of information regarding the effects of P and K fertilizers on dryland small grain quality, and because little work has been done in the northern Great Plains addressing the problem of under-fertilization.

LITERATURE REVIEW

The research we have done over the past two years has involved material extensively covered by previous workers as well as some that has been covered very little, if at all. It would serve no purpose to cover topics such as the effect of N on yield, except briefly, in this literature review. The main purpose of this literature review will be to cover those areas that have been neglected, are vague, or are contradictory.

NITROGEN

Yield

Nitrogen is incorporated into plants as amino acids, chlorophyll, nucleic acids, and an abundance of other organic molecules. In general cereals contain between one and two percent N in the total dry matter, but N percent fluctuates with plant maturity. Plants with an N deficiency can be stunted and chlorotic depending on the severity of the deficiency.

Nitrogen fertilization can have a marked effect on wheat and barley grain yield. Response to N is usually similar to that described by Mitscherlich (1930). Several other response surfaces have been used to describe grain response to N. Fernandez and Laird (1959) found that logarithmic and parabolic functions best described wheat yield responses. In a five year, 81 site study on spring barley, Sparrows (1979) could find no single response surface that best described yield response to N fertilization. Many other workers have found similar results with both wheat and barley (Johnson et al. 1973; McGuire et al. 1979; Terman, 1979).

Walker (1975) found total soil nitrate-N to account for only 33% of the variability in barley yields. In dryland cereal production moisture supply is critical to yield (Day et al. 1978). Both Pushman and Bingham (1976) and Johnson et al. (1973) found significant varietal differences in winter wheat yields with respect to N fertilization. These data indicate that yield response to N fertilization is highly variable due to genetic and environmental variation.

Protein

Grain protein is important in determining the market value and end use of wheat and barley. Generally, good yeast leavened bread requires grain with at least 12% protein (Hlynka, 1964). High protein grain is desirable for feed barley but undesirable for malt barley. Nitrogen is a major constituent of all protein. Hence, an adequate supply of available soil or foliar N is required for efficient protein metabolism in plants. A major management tool to raise the protein content of small grains is to vary the amount of N fertilizer. Walker (1975) reported that total soil nitrate-N accounted for 50% of the variability in the total-N of barley plants. McGuire et al. (1979) found N fertilizer continued to increase barley grain protein even after it ceased to raise grain yield. Johnson et al. (1973) found N fertilizer had a significant linear affect on winter wheat grain protein. Low rates of N can sometimes decrease grain protein. Williams and Smith (1954) found that small amounts of N fertilizer decreased grain protein, presumably due to an N stimulation of vegetative growth which caused a decrease in the amount of N available for grain. Fernandez and Laird (1959) reported a similar decrease in protein percentage with the addition of 45 pounds N per acre to winter wheat, but higher rates increased grain protein. Soil N levels, prior to the addition of N fertilizer, may affect protein response. Walker (1975) found that when soil nitrate-N levels were less than 20 kg/ha, the addition of 34 and 64 kg N/ha had no effect on percent N in barley. However, when the soil nitrate-N levels were greater than 20 kg/ha, additions of 34 and 64 kg N/ha did increase N percent in the plant. These data demonstrate that the effect of N on grain protein percent depends on the amount of N used for dry matter production relative to the amount of residual N available for grain protein production.

As may be expected, environmental and genetic factors can and do influence protein response to N fertilizer. Both Miezan et al. (1977) and McGuire et al. (1979) found significant interactions between N fertilizer and environmental-varietal factors in wheat and barley protein. Pushman and Bingham (1976) reported that irrigation decreased grain protein in wheat. Such data indicate that grain protein production is largely a function of the amount of N in the soil in excess of that used for producing the maximum quantity of plant material. Grain yield however, can markedly benefit from increasing plant dry matter because of a subsequent increase in tillers, heads, and kernels per head. It is common to have a negative relation between yield and protein percent (Pushman and Bingham, 1976; Terman, 1979).

Nutrient Supply

Nitrogen fertilization exhibits a complex effect on nutrient uptake and concentration. Theoretically, the addition of N may influence the uptake and concentration of N and other elements by antagonism, synergism, dilution, and in other subtle, indirect ways. For this reason some reports of tissue nutrient concentrations seem contradictory. Day et al. (1978) found that N uptake decreased in barley under drought, with a corresponding decrease in growth, hence, the N tissue concentration increased. Several workers have reported an increase in N tissue concentration due to N fertilization (Spratt and Gasser, 1970; Gasser and Thornburn, 1972). The same authors indicated that low amounts of applied N may decrease tissue N content, probably due to dilution. This is in agreement with Walker (1975), Fernandez and Laird (1959), and Williams and Smith (1954).

Other nutrients are also affected by N fertilization. Boatwright and Haas (1961) found N fertilization increased the early uptake and concentration of P, but had no affect on either uptake or concentration after maturity. These authors suggested that N either increased P availability, or increased its uptake by increasing the root area or density. Lal and Sharma (1974) found that both the grain and straw P concentrations of wheat decreased with increasing N, but that P uptake increased with applied N. However, the increase was not enough to compensate for the increase in dry matter. Singh et al. (1977) found that the N, P, and K content of wheat decreased with an initial application of 40 kg N/ha. This amount of N considerably increased the yield which caused a nutrient dilution. However, additional applications of N successively increased the N, P, and K content. Several authors have found a stimulatory effect of N on K uptake and concentration (Gasser and Thornburn, 1972; Nielson et al. 1967). Blevins et al. (1974) attributed this to an increase in nitrate uptake which caused an increase in K uptake as the counterion, and/or a greater capacity for the plant to accumulate K due to an increase in nondiffusible organic acids from an increase in nitrate reduction. Several researchers have found a mutual antagonism between nitrate and chloride. Lundegardh (1959) found that increasing nitrate levels decreased chloride absorption by wheat roots. James et al. (1970) found that N fertilizer sharply decreased the chloride content in potatoes. A clear explanation for this antagonism has not been presented but uptake competition is usually suggested. Nitrogen has been found to increase S. Rasmussen et al. (1975) reported N additions to have a stimulatory effect on S uptake. Rehm and Caldwell (1970) theorized that the S content of cereals may increase with increasing amounts of N because of a counteranion response of sulfate to an increase in ammonium absorption.

PHOSPHORUS

Phosphorus is necessary for both structural and biochemical plant processes. Structurally, P is a major constituent of membranes. Biochemically, P plays a major role in plant energy transfer reactions, being a constituent of ATP, NADP, and other high energy molecules. It is also a part of nucleic acids, and many enzymes. In general P comprises about 0.2% of small grain dry matter, but this is highly dependent on plant maturity.

Yield

Research on small grains has shown that under certain environmental conditions P fertilizer can increase grain yield (Nielson et al., 1967; Nutall et al., 1979; Osborn et al., 1977; Peterson et al., 1981; Sharma et al., 1977).

Factors affecting P fertilizer response include available soil P levels, levels of other nutrients, balance of other nutrients, environmental conditions, and method of P application. Stibbe and Kafkafi (1973) found winter wheat responded positivly and linearly to P fertilizer. Singh et al. (1973) reported a positive winter wheat response to 39 kg P/ha when soil tests for P were low, but a negative response to the same level when soil tests were medium. Other researchers have found soil P tests to be poor predictors of yield response even though P uptake is highly correlated with response (Stibbe and Kafkafi, 1973; Dalal and Hallsworth, 1976).

The reason for the unpredictability of P lies in its highly reactive chemical nature. The environment can affect P to a great degree. Blanchet et al. (1978) found that P diffusion was more severly limited by drought than N, K, or Ca. This agrees with Smith and Spence (1974) who reported a positive P yield response in all field trials except in those subjected to stress. One explanation for this is that most P lies in the upper surface horizon which is the first to dry out, so the diffusion of ions to the root surface would be most severly limited in this area.

NitrogenxP and PxK interactions have also been found to affect P yield response. MacLeod (1969) found that winter wheat response to fertilizer P was enhanced by additions of N fertilizer. Carlson and Grunes (1958) reported the same with barley. Chapman and Mason (1969) found almost no wheat grain response to P fertilizer alone, but a significant response when P was in combination with K. The strong PxK interaction doubled yield compared to the sum of the yields for P and K added individually.

Protein

Research indicates that P may affect the composition of amino acids in grain, and in some cases the total protein. The effects, however, are generally slight. Labananskas et al. (1978) found that increasing P, in a nutrient solution, decreased wheat grain total N by decreasing glutamic acid, proline, leucine, glycine, and serine. Nielson et al. (1967) reported that increasing the P rate from 50 to 200 lbs P2O5/acre decreased total grain N, and suggested that dilution was responsible since yields were also increased. Gately (1968) found the same to be true with barley and also attributed the N decrease to dilution. MacLeod and Carson (1973) found that the effect of P on total N and protein fractions of barley varied with the growth stage. Increasing P did not affect the total N when applied early in the season, but decreased total N and grain protein N when applied later. Other researchers have found no effect of P on protein (Mitchell et al., 1976).

Nutrient Supply

Phosphorous fertilization has been found to consistently increase P concentration in tissue (Stibbe and Kafkafi, 1973; MacLeod and Carson, 1973). Grain P concentration varies less than straw P concentration (Bishop and MacEachern, 1971).

Other nutrients are also affected by varying the amount of soil P. Phosphorus reportedly decreases the total N content in both the grain and straw of cereals (Gately, 1968; Nielson et al., 1967). Harper and Paulsen (1969) found that P increased the nitrate levels of wheat seedlings when added to a P deficient medium. Osborn et al. (1977) found P increased the amount of nitrate removed from the soil due to an increase in root volume. MacLeod and Carson (1973) reported that increasing rates of P increased the K content of barley. This is contradictory to the results of MacLeod (1969) who reported that P did not influence barley K concentration. Lundegardh (1959) reported a slight synergistic effect between P and chloride uptake in wheat. James et al. (1970) reported that increasing P application increased the chloride concentration of potatoes.

POTASSIUM

Potassium has been found to function in carbohydrate metabolism, protein synthesis, control and regulation of mineral activity, neutralization of organic acids, enzyme activation, meristematic tissue growth, stomatal regulation and water relations (Tisdale and Nelson, 1975). Plant dry matter generally ranges from 1 to 4% K, but this is highly dependent on the plant age.

Yield

Research indicates that under certain conditions K fertilizer can be beneficial to cereal yield. Koch and Mengel (1977) found K fertilization increased every major yield component of wheat. Numerous other reports indicate the importance of K in maintaining cereal yield (Bolton, 1977; MacLeod, 1969; Gately, 1968). Interactions may also be important. Chapman and Mason (1969) reported a strong PxK interaction in spring wheat. MacLeod (1969) found strong NxK and PxK interactions in barley. In general, the proper fertility balance is necessary for optimal fertilizer efficiency (Raychaudhuri, 1976). Environmental conditions have also been shown to greatly influence cereal response to K fertilizer. In Montana this is particularly true (Skogley, 1975; Skogley and Haby, 1981).

Protein

Potassium is essential for protein synthesis in plants. Mitchell et al. (1976) found K deficiency in sesame increased all of the free amino acids except cystine, and decreased the protein amino acids of the meal. Cummings and Teel (1965) found that increasing rates of K increased the protein amino acids and decreased the free amino acids in grasses. Research on the effect of K on cereal grain protein is contradictory. Arnon (1966), after reviewing the literature, concluded that increasing K tends to decrease grain protein slightly. Koch and Mengel (1977), however, found that high rates of K increased crude protein in spring wheat grain. These discrepancies are probably due to K fertilizer having varying effects on yield, thus a variance in the dilution of protein N. This is indicated by MacLeod and Carson (1973) who reported that increasing K fertilizer decreased barley grain protein percent, but increased protein per plant.

The redistribution and alteration of protein amino acids may be beneficial to the quality and baking characteristics of grain. Koch and Mengel (1977) found that K increased the proportion of prolamine and glutelin relative to globulin and albumin in spring wheat. Gluten is an important constituent of quality breads. Hojjati and Maleki (1972) found that K fertilization increased the lysine content of wheat.

Nutrient Supply

Potassium has been shown to affect the N balance of small grains. Blevins et al. (1978) found the roots and shoots of barley plants contained more nitrate when grown in KNO3 compared to Ca(NO3)2. Koch and Mengel (1977) found that nitrate uptake was substantially higher in wheat when K was applied. Other workers have also indicated the importance of K in the uptake and translocation of nitrate (MacLeod and Carson, 1973; Nielson et al., 1967; Harper and Paulsen, 1969). Some workers have found no effect or negative effects of K on nitrate concentration (Bhangoo, 1956; MacLeod, 1969; Gately, 1968). This reflects the complexity involved when working under a variety of environmental conditions.

The literature suggests that K slightly decreases or doesn't change plant P concentration (Bhangoo, 1956; Macleod and Carson, 1973). Potassium fertilizer has been shown to increase K content of wheat and barley (Bishop and MacEachern, 1971; Nielson et al., 1967; MacLeod, 1969). The fluctuation of P in the grain may be less than in the vegetative portion (Bolton, 1977).

Literature on the effect of K on S or chloride could not be found.

SULFUR

The major plant requirement for S is in the production of S amino acids. Sulfur is also a constituent of coenzyme A, glutathione, and some vitamins. It also maintains the structural integrity of proteins, and activates certain proteolytic enzymes (Tisdale and Nelson, 1975).

Yield

Sulfur is not used as extensively as N, P, or K as a fertilizer because of its widespread availability in nature. Many soils have the inherent capacity to supply the plant's demand for S. If not, the addition of S can greatly enhance yield (Lipsett and Williams, 1971; Beaton, 1966). Nitrogen fertilization increases the plant demand for S. Several researchers have reported a strong NxS yield interaction (Eppendorfer, 1968; O'Connor and Vartha, 1969). Nitrogen fertilization can induce a S deficiency when soils contain only marginal amounts of soil S (Eppendorfer, 1968).

Protein

Sulfur is a constituent of the amino acids cystine, cysteine, and methionine. The nutritional value of wheat and barley is largely limited by the disproportionately small amounts of S amino acids they contain. Eppendorfer (1968) reported that S fertilization increased the S amino acids in barley between 10 and 40%, depending on the N rate used. Byers and Bolton (1979) demonstrated that N fertilization can decrease the amounts of S amino acids if the soil S is inadaquate. In general, however, S fertilization does not influence the total amount of grain protein. It causes a redistribution of amino acids (Byers and Bolton, 1979; Reisenauer and Dickson, 1961).

Nutrient Supply

Sulfur deficiencies have been shown to influence the

N fraction in cereals. Bolton (1977) found that wheat grown on S deficient soil was high in non-protein N. Goh et al. (1979) found that increasing S increased the nitrate content of perennial grass. The most consistent and dramatic effect of S fertilization has been to increase the plant S concentration. Roberts and Koelen (1965) reported that S, in excess of that required for grain protein formation, accumulated in the vegetative tissue. Furthermore, they found that S was highly variable in the vegetative tissue but quite stable in the grain. Not much has been reported on the effect of S on other nutrients. Goh et al. (1979) reported that increasing S rates increased K, sulfate, and chloride, had no affect on H2PO4, and decreased nitrate. Rominger et al. (1976) reported that increasing K2SO4 increased chloride in alfalfa herbage, and attributed this to impurities in the fertilizer. Lundegardh (1959), using a solution technique, found a slight synergistic effect of S on chloride in wheat. Hayward and Long (1943), however, found that sulfate decreased the chloride concentration in tomatoes.

CHLORIDE

The essentiality of chloride was first suggested by

Broyer et al. (1954). Later Izawa et al. (1969) pinpointed the site of chloride activity at the oxidizing side of photosystem 2. The actual function of chloride has not yet been discovered. Chloride deficiencies are very rare in nature due to its abundance in the atmosphere and in rainwater. Ericksson (1952) found rainfall commonly deposited 12 to 35 lbs Cl/A/yr in most soils. Since crops generally require 5 lbs Cl/A/yr, rainfall can more than adequately supply most crops with chloride (Stout and Johnson, 1957). Deficiencies of chloride are manifest as chlorosis of newly emerged leaves, a prolonged tubular form of the leaves, and at times necrosis (Eaton, 1966).

Chloride excesses have been more of a problem than chloride deficiencies. Excessive amounts of chloride occur particularly in low lying, poorly drained land, near coastal areas. Irrigating with salty water may also cause chloride toxicity (LaCroix, 1969). Crops vary in tolerance to excessive amounts of chloride. Tobacco, avocado, peach, and legumes are sensitive. Yield and quality reductions occur when tissue levels range from 0.5 to 2% of the plant dry weight. Barley, corn, beets, cotton, and flax can tolerate levels of chloride in excess of 4% in the plant dry weight without any detrimental effects (Eaton, 1966).

In general cereals and grasses seem to be tolerant to high levels of chloride (Hoagland and Martin, 1923; Cordukes and Parups, 1971).

Yield

Research indicates that high levels of chloride may reduce the yields of several agricultural crops. Younts and Musgrave (1958) reported that 60 to 120 lbs K2O/A, banded as KCl, reduced yield, depressed growth, and delayed the maturity of corn. Broadcasting KCl at these rates had no affect. Rominger et al. (1975) found that KCl and K2SO4, at rates up to 448 kg K2O/ha, increased the herbage yield of alfalfa, but depressed yield at higher rates. Potassium sulfate continued to increase yield beyond 448 kg K2O/ha. Several other researchers have found high levels of KCl to be detrimental to alfalfa yields, presumably due to the chloride ion (Smith and Struckmeyer, 1977; Smith and Peterson, 1975; LaCroix, 1969). Other crops have been found to react poorly to high levels of chloride (Murarka et al., 1973; Stewart, 1971; Hall, 1971), but no data could be found on the effects of chloride on small grain yield.

Protein

Literature could not be found concerning the effect of chloride on grain protein.

Nutrient Supply

Chloride is very reactive in the soil-plant system, and influences many other nutrients. Murarka et al. (1973) observed that chloride reduced nitrate accumulation in potatoes. Lundegardh (1959), using a solution culture technique, reported that chloride decreased the nitrate uptake in wheat roots. He concluded that the two anions were competitively antagonistic. Younts and Musgrave (1958) found that chloride decreased N absorption, but did not influence total N in corn. A chloride-nitrate antagonism has been reported for other crops as well (James et. al., 1970).

Nielson et al. (1967) reported that chloride decreased the uptake and concentration of P in oats. In a greenhouse study, Younts and Musgrave (1958) found that corn plants treated with K2SO4 absorbed 16% more P than similar plants treated with KCl. Shestakov and Shvuidenkov (1934) found that chloride tended to decrease the P concentration of flax, sunflowers, and potatoes. Other workers have reported that chloride does not affect P uptake (Lundegardh, 1959; James et al., 1970; Younts and

Musgrave, 1958).

Numerous authors indicate that chloride does not influence the uptake and concentration of K. Younts and Musgrave (1958) observed no noteworthy difference in the K concentration of corn plants when K was added as KCl, K2SO4, and KPO3. Lundegardh (1959) found the same to be true with wheat. Experiments by Elzam and Epstein (1965) showed that at low substrate K concentrations, a high K affinity mechanism is in operation that is indifferent to the counteranion, but that a different mechanism is in operation at K concentrations greater than 1.0 mM that is almost totally inhibited by sulfate but not chloride.

Chloride fertilizer may reduce the uptake and concentration of sulfate. Nielson et al. (1967) found that chloride decreased the uptake and concentration of sulfate in oats. Rominger et al. (1975) reported a tendency for chloride to decrease the sulfate content of alfalfa. LaCroix (1969) found that chloride decreased sulfate in alfalfa and attributed it to anion competition. Hayward and Long (1943) showed that increasing the substrate levels of chloride from 10 to 90 me/l decreased sulfate accumulation in tomatoes by 10%. However, Lundegardh (1959) found that chloride did not effect the sulfate in wheat.

Increasing substrate chloride produces large increases in the plant chloride concentration. Elzam and Epstein (1965) found chloride uptake to be a linear function of time. The uptake of chloride is rapid compared to most other anions, including sulfate. Eaton (1942) showed that barley accumulated more chloride than any of the other plant species studied. Barley sap concentrations of chloride reached 63 me/l when the substrate levels of chloride were only 0.6 me/l. The accumulation of chloride, the inhibiting effect of lowering the temperature, and the adverse effect of respiratory inhibitors, all indicate that chloride uptake is metabolically mediated.

ROOT ROT

Both wheat and barley are susceptible to common (dryland) root rot (Fusarium spp.). Root rot is a substantial problem in North America, reducing wheat yields about 6% annually. Barley yields are affected by root rot to a lesser extent. One of the main morphological manifestations of the fungal pathogen is a darkening of the subcrown internode. This charecteristic can be used to evaluate root rot. The severity of the disease is rated by the relative amount of darkening on the subcrown internode; from clean to completely discolored (Ledingham et al., 1973). The pathogen is particularly infectious when the plant is under moisture, nutritional, and other types of stress. There is some indication that the pathogens thrive in plants with low water potentials. Nutrition and balance are important because they prevent stress. If infected plants continue to produce enough new roots the disease can be tolerated (Wiese, 1977).

A considerable amount of research shows that chloride decreases several types of root and stalk rots in a variety of species, but nothing has been reported on the effect of chloride on dryland root rot in barley. Corn stalk rot was found to be suppressed by the addition of KCl but not K2SO4 (Younts and Musgrave, 1958). Powelson and Jackson (1978) found take-all root rot (Gaeumannomyces graminis) to be depressed by NH4Cl but not (NH4)2SO4. These data indicate that chloride decreases root rot. No definite explanation for the effect of chloride on root rot has been ventured. Soil pH and/or nitrogen form may be involved. High ammonium to nitrate ratios in the soil have been shown to reduce take-all (Hornby and Goring, 1972). Possibly the ammonium creates an unfavorable pH for root rot pathogens.