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Take-all root rot (caused by Gaeumannomyces graminis var. tritici, Ggt) is one of the major diseases limiting winter wheat yields in western Oregon. Losses caused by take-all (TA) can be significantly reduced through crop management and fertilization practices.

Results from field experiments in western Oregon show that the use of chloride with NH_4-N is an effective tool to minimize grain yield losses in fields with TA. This study was undertaken to determine the effects of fall- and spring-applied chloride fertilizers on the components of leaf water potential, grain yield and disease severity of winter wheat with TA.

Winter wheat field plots were established on a Woodburn soil (Aquultic Argixeroll) on 15 October 1980 at a site previously cropped to first-year wheat after fallow. Spring fertilizer application was on 16 March 1981. Twenty treatments were arranged in a randomized complete block design to study the effects of source, rate, method of

application and timing of chloride fertilizers on grain yield, disease severity and leaf water potential components. Other comparisons included rates of P and Cu plus Zn banded in the fall, and fall and spring nitrogen rates. Grain was harvested with a plot combine on 30 July 1981, and grain yield, test weight and 1000 kernel weight were measured.

Disease severity was assessed using two methods, (1) visual estimation of black root lesions on three dates, and (2) whole plant fresh weights on 2 July 1981. Leaf osmotic potentials and plant nutrient concentration were measured on four dates. Leaf water potential components (turgor, osmotic and leaf water potentials) and plant nutrient concentrations were determined during May and June on second-year wheat and once on third-year wheat from an adjacent site. A partial diurnal water curve for $(NH_4)_2SO_4$- and NH_4Cl-treated plants was measured on 2 June 1981, on third-year wheat.

Grain yields were increased by 1000 kg/ha with the addition of spring chloride as NH_4Cl, KCl or $CaCl_2$. A rate of 92 kg spring Cl/ha was adequate to achieve the highest grain yield (6633 kg/ha). Grain yield was not significantly affected by rate, source or method of application of fall-applied chloride, fall or spring N rates, or by the application of P or Cu plus Zn banded with the seed at planting.

Application of 368 kg spring Cl/ha as NH_4Cl reduced severity of take-all and increased whole-plant fresh weight when compared to $(NH_4)_2SO_4$ at the same rate of N, but the differences were not statistically significant. Disease severity was not significantly affected by either rates or sources of spring chloride. Grain yields

were negatively correlated to disease severity indices. Spring chloride fertilizers applied as NH_4Cl or KCl significantly increased percent total N in flag leaves sampled in late spring, while the percent leaf chloride was increased with application of either KCl, NH_4Cl or $CaCl_2$.

Osmotic potentials in flag leaves of second-year wheat were significantly reduced (from -21.6 to -22.6 bars) over the nil Cl rate by application of spring chloride fertilizers. Ninety-two kg Cl/ha was adequate to reduce the osmotic potential. Spring chloride at 368 kg Cl/ha significantly increased turgor potentials in both second- and third-year winter wheat, and significantly decreased osmotic potentials (2 bars) in second-year wheat when compared to $(NH_4)_2SO_4$-treated plots at the same N rate. Potassium chloride significantly reduced leaf and osmotic potentials at the 185 kg Cl/ha rate. Potassium chloride did not increase turgor.

The results of this study support the recent literature indicating that application of spring chloride in combination with ammonium-nitrogen to moderately acidic soils reduces the severity of take-all and increases yield of winter wheat.

CHLORIDE FERTILIZER EFFECTS ON GRAIN YIELD, WATER POTENTIAL COMPONENTS AND DISEASE SEVERITY OF WINTER WHEAT WITH TAKE-ALL

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INTRODUCTION

There are many management practices used to reduce take-all (TA) root rot disease of wheat, caused by the soil-borne pathogen, Gaeumannomyces graminis var. tritici (Ggt). Since there are no economically effective fungicides and no resistant wheat varieties, farmers minimize the economic loss from take-all by using crop rotations, late seeding dates, moderate soil acidity and banding ammonium-nitrogen and phosphorus with the seed at planting.

However, with increased wheat production in western Oregon, fields that were cropped to wheat for only one year in the rotation are now being recropped to wheat for two or more consecutive years. With this increased monoculture of wheat comes increased severity of TA (MacNish, 1980; Powelson and Jackson, 1978; Taylor et al., 1983).

Researchers are now faced with the problem of trying to control TA without crop rotation, thought by many to be one of the best forms of control of TA (Taylor, 1981). Powelson and Jackson (1978) discovered that NH_4 sources of N, and Cl from NH_4Cl or KCl reduce the severity of TA when banded with the seed at planting. Taylor (1981) also noted better suppression of TA with NH_4Cl than with $(NH_4)_2SO_4$. These studies indicate that the use of chloride could be another effective tool against TA.

Observations by Christensen et al. (1981) that leaves from winter wheat plants fertilized with spring chloride (as NH_4Cl) were associated with a more erect leaf habit than $(NH_4)_2SO_4$ treated plants suggested a possible relationship between the chloride ion and increased turgor potentials. They also reported lower osmotic potentials in chloride fertilized leaves and proposed that the suppression of the take-all root rot by chloride might involve the reduction of the chemical potential of the water in the root. Since Cook, Papendick and Griffin (1972) showed that the growth of Ggt is reduced by one-half at -20 bars in osmotically controlled growth medium, the reduction of the chemical potential of water in the plant may slow the rate of colonization of the root by Ggt. More research on the effect of chloride on water potentials in winter wheat plants and on the severity of take-all was needed.

This study was undertaken to determine:

1. The effect of source, rate, method of application and timing of chloride on grain yield of take-all infested winter wheat.
2. The effect of Cu plus Zn, P and N rates on grain yield of take-all infested winter wheat.
3. The effect of source, rate, and timing of chloride on take-all severity.
4. The relationship between grain yield and disease severity.

5. The effects of chloride fertilizers on the concentration of chloride and other ions in leaf tissue.
6. The effect of chloride fertilizers on water potential components of wheat leaves.

LITERATURE REVIEW

Take-all Root Rot

Take-all Disease and Causal Organism

Take-all (TA) root rot is caused by the fungus Gaeumannomyces graminis (Sacc) Arx et Olivier tritici Walker (abbreviated Ggt). In the Pacific Northwest it is confined almost entirely to irrigated areas and to wheat or barley fields west of the Cascade Mountains, where the average annual rainfall is approximately 100 cm per year (Cook and Christen, 1976; Cook and Naiki, 1982). Take-all can be a major contributor to yield variability and low productivity, especially under environmental conditions that are favorable for nitrogen loss (Huber, 1981). Patches of stunted plants caused by TA are not as common today as they were in the past, but less severe root infections with no obvious above-ground symptoms prevent crops from achieving their total potential (Hornby and Goring, 1972).

The disease was first recognized in Australia in 1852 and by 1870 the name take-all was already in use. TA has a cosmopolitan distribution in the temperate climates of the world, and becomes a serious problem when wheat monoculture replaces the traditional crop rotations (Garrett, 1981; Powelson and Jackson, 1978).

The fungus causing TA was identified in 1890 by Prillieux and Delacroix as Ophiobolus graminis, and this name was in common usage until the 1970's. In 1972, Walker reclassified it as Gaeumannomyces graminis var. tritici (Garrett, 1981; Walker, 1975).

The symptoms of TA depend on the severity of the attack (Asher, 1972), and when the above-ground symptoms become obvious (i.e., reductions in plant height and tillering, and premature senescence) the yields are often reduced by more than 50% (Wiese, 1977). From the seedling stage onwards there is root blackening in infected plants and the lower culm tissues beneath the basal leaf sheath may be black (Garrett, 1981; MacNish, 1980; Powelson and Jackson, 1978). On plants that reach maturity there may be a reduction in plant height and tillering, premature senescence of the foliage and premature ripening.

If severe enough, take-all patches may occur. These patches are sparsely populated with stunted plants and may become invaded with weeds. Whiteheads (often sterile bleached ears that are usually empty but may contain small, shriveled grain) may also occur on scattered, infected plants throughout the field. Severely diseased plants easily break free at their crowns when pulled from the soil (Garrett, 1981; MacNish, 1980; Wiese, 1977).

Ggt grows primarily as a parasite, infecting roots of cereals and grasses such as rye, quackgrass, bentgrass, bromegrass, wheat and barley (Weste and Thrower, 1971). The development of TA usually originates from infected stubble residues, since many of its hosts are annuals and it must survive from crop to crop as a saprophyte (Garrett, 1981; Weste and Thrower, 1971). Its survival as a saprophyte is greatly affected by soil conditions (MacNish, 1980). Ggt is a poor competitive saprophyte and its activity usually declines over a period of 1 to 2 years (Weste and Thrower, 1971).

Saphrophytic survival is shortest in warm, moist, loose soils where there is maximum microbial activity (Garrett, 1981; Weste and Thrower, 1971).

Ggt is very dependent on adequate levels of soil moisture, and the spread of the TA disease is enhanced by cool, wet growing conditions (Garrett, 1981; MacNish, 1973). Cook et al. (1972) showed that the growth of Ggt along sterile wheat straws that were buried in two sterilized soils was fastest at the highest water potential (-1.5 bars). The growth was reduced to one-half at -20 bars and was inhibited copmletely at -50 bars. Papendick and Cook (1974) showed that common values of leaf water potential in wheat ranged from -15 to -20 bars in the juvenile stage in the field to -30 to -40 bars by maturity. According to Cook and Christen (1976) the common values of -25 to -30 bars recorded for maturing healthy, nonstressed wheat must be more limiting to the growth of the Ggt fungus than to the wheat, since its growth would be reduced to half. Cook (1973) reported that Ggt grows optimally at -5 bars and above.

Several other conditions favor the growth of Ggt and cause increased take-all; one of these is loose, open soil. Garrett (1934) noticed that improved soil aeration helped to increase the spread of the disease. The improved soil aeration would encourage a faster rate of advancement of Ggt mycelium along the roots (Garrett, 1981). Huber (1981) also noted that in sandy soils there is a greater moisture and nutrient stress for the host plant.

Alkaline soils also favor severe attacks of TA, although Ggt is capable of satisfactory growth over a wide pH range (Huber and Watson, 1974; Huber et al., 1968). Ggt has a more difficult time competing with other soil microorganisms as the pH of the soil decreases (Smiley and Cook, 1973).

Suppressive Soils and Take-all Decline

TA is usually controlled with crop rotation, late seeding and proper N fertilization, but it is also controlled with varying success by continuous monoculture of wheat (Cook, 1981). The disease may become severe during the initial two to four wheat crops, but may decline in severity with successive wheat crops. This decline, or depression of disease which occurs after a peak of TA is termed TA Decline (TAD) (Pope and Hornby, 1975). TAD results from a natural form of biological control. Cook (1981) stated that most evidence shows that Ggt remains present in soil after TAD, but no longer causes severe disease.

Most sources agree that the most severe expressions of the TA disease appear within the second to fourth wheat crop when monocultured in fields where wheat or barley have been grown in the past (Brown et al., 1973; Slope and Etheridge, 1971; Slope et al., 1969; Smiley, 1978). Shipton (1972) found that the disease increased from low levels to maximum amounts within 3 to 7 years, after which TA declined and yields increased. In fields where wheat or barley have not been grown for many years, the TA fungus may be rare and may increase only slowly in the first few susceptible crops. These

fields may not reach maximum expression of the disease until the 6th to 8th successive crop (Slope and Broom, 1972).

Shipton (1972) found that monoculture of wheat and barley both produced a consistent pattern of increasing disease intensity with each successive crop in the sequence. Maximum expression of TA in both wheat and barley was followed by an initial reduction in severity and incidence of disease. Slope et al. (1969) reported that during the periods when the disease was increasing there were no great yield losses in the barley. Winter wheat was planted after the barley to see if the TAD generated by the barley monoculture would extend to winter wheat, and found that TA proved less common and severe in wheat after continuous barley than in 4th year wheat. Slope et al. (1969) suggested that a sequence of barley may be a less costly way to establish TAD in a soil than continuous wheat.

General or specific antagonisms can suppress TA. General antagonism cannot be transferred from one soil to another and is resistant to 70°C moist heat for 30 minutes. Addition of organic amendments and warm soil temperatures (25°C) foster general antagonism. Specific antagonism can be transferred from soil to soil and is destroyed by 60°C moist heat for 30 minutes. Specific antagonism operates on or near the roots and is fostered by wheat monoculture, but may be lost by crop rotation with nonsusceptible crops (Cook and Rovira, 1976). Both general and specific antagonisms are destroyed by autoclaving (121°C).

Shipton (1972) suggested that TAD operates through a specific antagonism by some soil microbes to an increasing population of Ggt (i.e., that TAD develops only after a peak expression of disease development), and that monoculture of wheat in the absence of Ggt inoculum failed to induce antagonism in virgin non-antagonistic soils. Shipton (1972) also noted that repeated inoculation of a soil with a virulent isolate of Ggt in the absence of any crops induced strong antagonism. He concluded that TAD may be the result of a microbial response to the dominance of Ggt inoculum.

Brown et al. (1973) suggested that TAD operates through changes in the soil microflora in response to disease progress and that these changes modify the root environment nutritionally, thus limiting the disease.

Wildermuth (1980) also found that inoculating a soil with virulent strains of Ggt, in the absence of a host crop, induced the suppressive properties similar to those of a soil with TAD. Wildermuth also showed that addition of Ggt mycelium, instead of live Ggt inoculum in oat grain, to fumigated soils produced as much suppression to TA as the live inoculum in induced suppressive soils.

In the same study, Wildermuth also noted that only 2 of 10 suppressive soils he studied were from under continuous wheat, and disagreed with Cook and Rovira's (1976) definition that a specific antagonism has to be 'fostered by wheat monoculture'. He stated that the evidence presented in his paper indicated that the concept of specific antagonism (suppression) be expanded to include suppressive

soils induced in other ways, or that a new term, such as transferable (specific) suppression be adopted.

Researchers agree that TAD is linked to the disease development rather than to the monoculture of wheat (or barley). The wheat plant itself is unable to induce suppression in the absence of the disease. TAD seems to be a response to the increasing Ggt inoculum in the soil--even in the absence of wheat or barley host plants (Brown et al., 1973; Shipton, 1972; Wildermuth, 1980).

Soils suppressive because of TAD do not seem to offer protection against the initial infection (or incidence) of TA, but to the disease progress after the initial infection is suppressed (Cook, 1981; Cook and Rovira, 1976; Pope and Hornby, 1975; Shipton, 1972).

Cook and Rovira (1976) suggested that fluorescent pseudomonads are responsible for specific suppression. Smiley (1978) discovered that Pseudomonas spp. consistently appeared more suppressive in NH_4^+-N treatments than other microorganisms they studied. Rovira and Campbell (1975) also found some protection of wheat from Ggt with P. fluorescens, which caused lysis of the Ggt hyphae on the wheat roots.

Listed below are some of Cook and Rovira's (1976) observations supporting the hypothesis that fluorescent pseudomonads are responsible for the specific suppression.

1. The specific antagonism is eliminated by 60°C moist heat for 30 minutes. This kills pseudomonads but not sporulating bacilli nor many actinomycetes.

2. Their suppressive soil was found to contain 10^4 fluorescent pseudomonads per gram of soil, compared to the 10 per gram soil in

the conducive soil; but the counts of total bacteria, fungi, actinomycetes, and aerobic sporulating bacteria were similar in the two soils.

3. In other field trials, plots were fumigated with methyl bromide (which greatly decreases the populations of P. fluorescens pseudo.), and with chloropicrin (in which the populations of P. fluorescens were 500- to 1000-fold greater than in methyl bromide plots). When Ggt was reintroduced to the fumigated plots, those fumigated with methyl bromide had severe TA, while those fumigated with chloropicrin showed no above ground symptoms and high grain yields.

Once TAD is established, any interruption of the wheat or barley monocultures with a nonsusceptible rotation crop breaks the TAD, so that upon returning to wheat, the cycle of severe disease followed by TAD occurs again (Cook, 1981). Slope, Etheridge, and Palmer (1969) studied a site that had been in wheat almost continuously for 85 years and then planted to non-susceptible break crops for 4 years. They stated that if inhibition of Ggt had developed during the long wheat sequence, it did not survive the 4 year break.

According to Cook (1981), growers should either rotate with nonhost crops to control TA, or use continuous wheat cropping, but alternating between the two systems may be quite counterproductive.

Management Practices

Take-all is controlled through proper crop management, i.e., crop rotation, late planting date and fertilization. There are

currently no wheat varieties resistant to this disease (Hornby, 1985; Wiese, 1977), and no economically effective fungicides available to control it (Glynne et al., 1959; Hornby, 1985; Nilsson, 1969; Yarham, 1981).

Crop Rotation. The most effective control of TA is through the use of crop rotation to non-susceptible 'break' crops (Cook and Reis, 1981; Gorska-Poczopko, 1971; Huber et al., 1968; Prew, 1981; Slope and Etheridge, 1971; Taylor, 1981; Walker, 1975; Wiese 1977; Yarham, 1981).

Yarham (1981) suggested that the best method of TA control is to rotate wheat with economically viable break crops when weedy grass hosts are eliminated. Break crops that can be combine-harvested include peas, beans, oilseed rape and linseed (Yarham, 1981). Wheat grown in rotation with potatoes, corn, oats, or beets does not develop severe TA, provided successive crops of wheat and barley are not grown (Cook and Reis, 1981).

Grasses should not be sown after cereal crops that had high levels of TA disease if they are known to be hosts to Ggt. Susceptible grasses are able to maintain the TA fungus at high levels, causing severe disease in subsequent cereal crops (Walker, 1975).

In general, first year wheat after break crops has very little TA, but there are great differences in the TA severity of second year wheat (Prew, 1981). Occasionally, severe TA will occur in the first year of wheat after pasture, lucerne or soybeans. This is true

particularly for wheat following soybeans, which has been shown to support or maintain the level of the TA pathogen (Yarham, 1981).

Take-all may also be a problem in wheat if the previous crops were alfalfa, subclover, peas or a clover-grass pasture (Huber, 1972; Huber and Watson, 1974; Huber et al., 1968; Smiley, 1974). These leguminous crops tend to leave the soil nitrogen at high levels and this increases the chances of survival of TA during the carryover phase (Nilsson, 1969; Smiley, 1974). According to Nilsson (1969) low levels of available nitrogen in the interval between growth of susceptible crops helps to 'starve' out Ggt so long as it does not have access to susceptible host plants. During growth of susceptible plants the available soil N needs to be maintained at high levels to benefit the host plant and help to develop better root growth.

The best crop rotation is a cereal-break-cereal-break (C-B-C-B), although for farmers wanting two-thirds of their land in susceptible cereals, a break-wheat-wheat (B-W-W) is acceptable on some soils, though a break-wheat-barley (B-W-Bar) in considered safer because there is less yield reduction on TA-infected barley than with wheat (Yarham, 1981).

Although crop rotation was once regarded as essential for TA control, it is being replaced with increased cropping to cereals. High yield reductions from TA may occur in second year wheats, and third year wheats grown on most soils are often at considerable risk from TA. The peak of the TA build-up and the decline (TAD) vary in both the severity and the timing, and many researchers agree that spring barley should be used as the 3rd cereal to minimize yield

losses from TA (Prew, 1981; Slope and Broom, 1972; Yarham, 1981). Spring barley is a better choice than winter barley because the period for saprophyte survival of Ggt between crops is longer for spring barley (Prew, 1981).

If the farmer wants to have extended cereal crops, Yarham (1981) suggests the use of a break crop rotation on the part of the farm where the risk of TA is the greatest, using B-W-B-W to take advantage of high yielding first year wheats. The remainder of the acreage could be cropped to continuous cereals to more fully exploit take-all decline (TAD).

The success of the monoculture depends on the use of good husbandry techniques. The farmer must keep the land free from perennial weeds, maintain good structural condition of the soil and keep it well drained, and use a balanced fertilizer regime. When levels of TA are likely to be at their peak, 2nd to 5th year, high seeding rates should be avoided, spring barley should be used instead of wheat, planting date should be delayed and the fields should be plowed as early as possible in order to leave the maximum amount of time between plowing and drilling, i.e., decrease inoculum by increasing its saprophytic survival time (Prew, 1981; Yarham, 1981). Once TAD is established, winter wheat can be grown again.

Pesticides. Bateman (1980) stated that, although Ggt is susceptible to fungicides as shown in in vitro studies (Gorska-Poczopko, 1971), conventional fungicide treatments are not effective. He attributes this to the fact that seed treatments or soil drenches do not reach much of the inoculum in the soil and the

plants are susceptible to infection throughout much of the growing season, when fungicides that were applied early have become inactive. Bateman (1980) also noted that although some of the fungicides and herbicides he used to soil drench potted wheat plants were somewhat effective, the rates would probably be unacceptably high if applied on a field scale.

Williams and Salt (1970) also found some control of TA with soil sterilants like formalin, but also noted that the sterilants needed to be re-applied every year before the next crop or an increased infection of Ggt and reduced yields occurred. As many researchers have discovered, once the number of microbial species have been decreased by fumigation, reinfestations by pathogens like Ggt are likely to be even greater than in untreated soil.

Nilsson (1969) found that the use of mecoprop or CMPP, Cyclocel and methyl bromide did not reduce TA, but caused an even greater percentage of plants to become infected after their application. Many other researchers have found an increase in TA after fumigation with methyl bromide (Reis et al., 1982; Smiley and Cook 1971, 1973; Walker, 1975) and attributed this increased TA to the elimination of those microorganisms which were suppressing Ggt.

Planting Date. When the risks of yield loss from TA exist in winter wheat, i.e., second or third consecutive wheat crop or where there was evidence of TA infected roots in previous crops, the disease severity can be decreased through the use of delayed planting date (Christensen et al., 1982; Huber, 1981; Taylor et al., 1983).

Huber (1981) found severely diseased wheat fields in Indiana (yields <1000 kg/ha) in close proximity to healthy fields (>5000 kg/ha) and noted that the major differences between the fields were the management practices of the farmers. The more diseased fields were planted early and lacked proper N fertilization. He noted that with the release of new wheat cultivars resistant to the Hessian Fly, the farmers were able to plant the new cultivars earlier in the fall rather than waiting until the Hessian 'fly-free' date as before. However, by planting earlier in the fall, it prolonged the growing conditions which favored the TA pathogen more than the wheat plants, encouraging early infection and more severe expression of TA disease. Huber found no evidence that the new cultivars were more susceptible to Ggt because when seeded after the fly-free date, the same cultivars were less severely damaged by TA.

Taylor et al. (1983) found that grain yields were influenced more by seeding date than by any other factor. The average yield of all of the treatments seeded on Oct. 4, 1977, was 2904 kg/ha compared to 4260 kg/ha for the Oct. 27 seeding. The OSU Extension Service Fact Sheet 250 (Jackson et al., 1984) suggests planting after Oct. 15 in western Oregon, but cautions that late plantings followed by heavy rains may increase water and herbicide damage. Another consideration with the later seeding date is the possibility that heavy winter rains may make the field too wet and thus unsuitable for farm machinery.

Soil Acidity. Liming a moderately acid soil has been found to increase TA (Christensen and Brett, 1985; Powelson and Jackson, 1978;

Taylor et al., 1983), although Taylor et al. (1983) also found that liming a severely acidic soil (pH 5.2) decreased TA by favoring the wheat plants more than the fungus. In that severely acidic soil, aluminum and/or manganese toxicity and/or P deficiency could have been problems. Except under such extreme conditions of pH, the severity of TA is usually reduced with increasing soil acidity (Taylor et al., 1983).

Mineral Nutrition. Deficiencies of any of the major plant nutrients (N, P, K, etc.) promote TA (Nilsson, 1969; Reis et al., 1982). The beneficial effects of P and K fertilizers in reducing TA losses is generally believed to be a reflection of a more vigorous host root development (Nilsson, 1969; Reis et al., 1982). Slope et al. (1976) found that where P was deficient, TA was worse, but where P levels were not deficient they saw no statistically significant decrease in TA severity with added P. Reis et al. (1982) found that increasing Cu or Zn supply reduced TA disease in both nutrient solution-sand culture and, to a lesser extent, in the field.

Nitrogen is usually the most frequently implicated nutrient related to disease severity. Huber (1972) found that application of N to low fertility soils decreased the severity of TA. However, it is generally the form of N that affects the disease severity rather than the amount of N, so long as N is not deficient (Christensen and Brett, 1985; Huber, 1969; Huber and Watson, 1970, 1974; Huber et al., 1965).

Within the last 20 years, the effect of N form on soil-borne plant disease has been studied in detail. Potato scab, verticillium

wilt and take-all of wheat were all decreased by application of the ammoniacal form of N, whereas the severity of stalk rot of corn and bean root rot were increased by ammoniacal N (Huber and Watson, 1970; Huber et al., 1968).

Ammoniacal-nitrogen applied under field conditions is often rapidly converted to nitrate-nitrogen (nitrified), and to maintain it in the NH_4^+ form, inhibition of nitrification is necessary (Huber and Watson, 1970). Stabilization of NH_4^+-N can be accomplished using a nitrification inhibitor like N-Serve [2-chloro-6-(trichloromethyl)-pyridine] which specifically inhibits Nitrosomonas spp. Huber and Watson (1974) found that stabilization of NH_4^+-N with N-Serve provided more effective control of TA than when using NH_4^+-N alone.

The form of N that is available to the plant and to the soil microorganisms influences microbial populations and the host physiology (Huber and Watson, 1970, 1974). Smiley and Cook (1971, 1973) and Smiley (1974) explained the advantage of NH_4^+-N over NO_3^--N for reducing take-all by showing a high correlation between disease severity and rhizosphere pH (pHr). Ammonium reduces the pH of the rhizosphere soil because as plants take up NH_4^+-N from the soil solution they release H^+ ions back into the root rhizosphere. This occurs because the plant must maintain an electrochemical equilibrium during the absorption of anions and cations. Absorption of the nitrate form of N is often balanced by the release of OH^- or HCO_3^- into the soil solution, both of which may cause an increase in the pHr. This is important because acidity reduces TA of wheat while alkalinity seems to favor an increase of the disease.

Smiley (1974) and Smiley and Cook (1971) also believed that the form of nitrogen effect on TA appears to have both a direct (chemical) effect, that of increased or decreased acidity; and an indirect or biological mechanism. By reducing the pHr to values less favorable to Ggt, NH_4^+ reduces the inoculum potential and increases the chances of antagonism from other microorganisms. They stated that there may be more antagonists (such as Pseudomonas and Streptomyces) along roots in soil fertilized with NH_4^+ when compared to NO_3^- fertilized soils.

Smiley and Cook (1971, 1973) found that in methyl bromide fumigated plots, TA was uniformly severe at all pHr values above 5.0, but that in fumgiated plots with extreme acidity (pHr 4.9 or less) there was no disease. They noted that there is a direct effect of pHr on Ggt, and that it seems to be unable to grow below a pHr of 5.0. Since fumigated plots with pHr above 5 all showed uniformity of infection, Smiley and Cook (1971, 1973) suggested that the pHr changes affected TA development directly at pHr values less than 5.0 and indirectly (through a biological mechanism) at pHr values greater than 5.0 by stimulating soil microorganisms antagonistic to Ggt.

In field studies, Smiley and Cook (1973) found that TA was controlled best in unlimed (pH of bulk soil 5.0 - 5.5), nonfumigated soil with NH_4^+-N rather than the nitrate form. They also found that liming and fumigation tended to negate the control with NH_4^+-N.

The above experiments using either NO_3^- or NH_4^+-nitrogen were done on nonleached soils that contained at least some nitrate. Hornby and Goring (1972) found that it is the ratio of NH_4^+ to NO_3^-

that is important in controlling TA. In experiments with plants grown strictly with the NH_4^+-N or NO_3^--N forms, TA was worst in those grown with only the NH_4^+ form, next with those grown with the NO_3^- form and least in those grown with a 1:1 ratio of both forms of N. They found that the toxicity of NH_4^+ is reduced when NO_3^- is present, even if only in small quantities.

Christensen and Brett (1985) estimated that a "critical" NH_4^+-N:NO_3^--N ratio of 3:1 or greater is required for a reduction in the rhizosphere pH (pH_r), and thus for the suppression of TA. They reported that the TA severity was negatively correlated (r^2 = 0.84) with the length of time the NH_4^+-N:NO_3^-N ratio remained above the estimated critical level.

Researchers have found that NH_4^+ fertilizers did not reduce the incidence (the number of lesions) of TA but did reduce disease severity (limited the extensions of the lesions) (MacNish and Speijers, 1982; Smiley and Cook, 1973). Smiley and Cook (1973) attributed this to the decreased soil pH with NH_4^+, noting that this favors soil microorganisms antagonistic to Ggt which may slow the ectotrophic growth of Ggt. This slows the disease progression after lesion establishment.

Chloride. A new tool for controlling TA severity is the use of fall banded and spring topdressed chloride fertilizers. The use of chloride has been cited in the literature in reducing different diseases. Younts and Musgrave (1958) noted a decrease in the severity of corn stalk rot (caused by Gibberella zeae and G. fujikuroi) with increased KCl application but not with KPO_3 or

K_2SO_4. Russell (1978) has shown that soil applications of sodium or potassium chloride can give partial control of yellow rust in wheat. Application of (certain) chloride salts to the soil reduced the severity of brown leaf rust on wheat, although foliar sprays of chloride did not affect the brown rust (Hashim and Russell, 1982).

Powelson and Jackson (1978) found that take-all of wheat was reduced with the application of chloride as NH_4Cl and as KCl when banded with the seed at planting. They discovered that the plots where a combination of NH_4-N and Cl fertilizers were used were greener and taller, and had less senescence of foliage than where chloride was not included.

Taylor et al. (1983) showed the greatest yield increases from delayed seeding and chloride fertilization in experiments with TA and concluded that chloride should be added to the list of management factors that influence TA. Powelson et al. (1983) also noted increased grain yield and reduced severity from TA disease, in fields at risk from TA, when the management practices included banding chloride, NH_4-N and P with the seed at planting and topdressing with chloride fertilizers in the spring. They showed an average yield increase of 807 kg/ha from field experiments conducted from 1979 to 1982, where Cl was applied in both autumn and spring on growers fields where wheat followed wheat. For the 1982 crop year, commercial growers who followed wheat after wheat reported average yield increases of 940 kg/ha more than those growers who did not apply Cl fertilizers at planting and in the spring (Powelson et al., 1983).

Powelson and Jackson (1978) suggested that the chloride salts may reduce nitrification, thus slowing the development of TA. Ghosh et al. (1956) also noted that the initial rate of nitrification of NH_4Cl in the soil is slower than that of $(NH_4)_2SO_4$, and that after 42 days, the fraction of NH_4-N nitrified was less with NH_4Cl (92%) than with $(NH_4)_2SO_4$ (100%). Christensen and Brett (1985) suggested that Cl may reduce TA severity on moderately acid soils in western Oregon by reducing nitrification and maintaining a favorable NH_4^+-N:NO_3-N ratio for disease suppression.

Another mechanism proposed by Christensen et al. (1981) is that chloride salts affect the plant water potential components. Since the growth of Ophiobolus graminis (G. graminis) was reduced by one-half at -20 bars when the water potential of the growth medium was controlled (Cook et al., 1972), Christensen et al. (1981) suggested that changes in the plant water potentials could also influence the rate of host colonization by Ggt. They suggested that there may be a reduction in the susceptibility of winter wheat plants to the colonization by Ggt when the chemical potential of the water in the plant is lowered, and that the osmotic potential in the wheat plants is affected by chloride fertilizers. They found that the osmotic potential was lowered at three different field sites with the application of chloride.

Water Potentials

Introduction

Water, like heat, flows from regions of high energy to regions of low energy, so it is best to think about the movement of water in terms of changes in its potential energy (Cook and Papendick, 1972). Water potential is defined as the capacity to do work relative to the work capacity of pure, free water at the same temperature. The units commonly used are joules/kg, bars (1 bar = 100 joules/kg), or atmospheres (1 atm = 1.013 bars). Water with a work capacity less than pure free water, such as that water adsorbed to a matrix or with dissolved salts or sugars in it, is at a negative water potential (i.e., -5 bars) (Cook, 1973).

Water Potential Components.

Total water potential of plant cells and tissue is usually divided into three components:

$$\Psi_L = \Psi_P - \Psi_\pi - \Psi_\tau = P - \pi - \tau$$

where Ψ_L is the leaf water potential, Ψ_P is the pressure potential, which is identified with turgor pressure, Ψ_π is the osmotic potential due to particles in solution (solutes), and Ψ_τ is the matric potential due to adsorption of water on the tissue matrix (colloidal particles or cell walls) (Cook, 1973; Cook and Papendick, 1972; Papendick and Campbell, 1975; Turner, 1981). The gravitational

potential, caused by changes in elevation, is generally negligible when the elevation differences are less than 1 to 2 meters (Cook, 1973; Cook and Papendick, 1972; Papendick and Campbell, 1975).

Therefore, the water potential of a plant cell is the sum of the osmotic π (negative), the matric τ (negative) and the pressure potential, P (positive, although it was once thought that it could have either positive or negative values) (Cook and Papendick, 1972; Tyree, 1976). The water potential of the fungus will be determined by the chemical potential of water in its surrounding environment (Cook, 1973).

Water potentials of most plants are highest when the plants are young and tend to decrease as plants age. Diurnal variation of water potential can be wide (high at night, low during daytime) in many plants (Papendick and Campbell, 1975). Scholander et al. (1965) reported that winter wheat has had diurnal fluctuations of 20 bars. Papendick and Campbell (1975) reported osmotic potential variations of 8 to 12 bars when wheat is less stressed (of which daytime osmotic potentials of -15 to -20 bars were reached).

Apoplastic and Symplastic Water

Apoplastic water is that which resides mainly in the cell walls and the xylem. The water potential of the xylem is due mostly to negative pressure. This negative pressure is due to the surface tension phenomenon at the evaporating surfaces of the leaf and is propogated back to the xylem because of the cohesiveness of water (Tyree, 1976). The osmotic potential of the xylem water was found to

be less than -0.1 bars in soybeans (Boyer and Ghorasky, 1971) and in several other plant species to be less than -0.5 bars by Tyree (1976).

The cell wall's water potential is a combination of the negative pressure described above as well as matric and osmotic effects (Tyree, 1976). The matric potential (τ) is identified with hydrogen bonding of water with solids. The surface to volume ratio is the largest in the cell walls, so the matric potential could be very large there (Tyree, 1976). "Bound water" is the term used for water held by matric forces (Wilson, 1967a).

Symplastic water is that water in the "living" portions of the plant: that water in all cells excluding cell walls and xylem tissues (Tyree and Hammel, 1972).

Turgor Maintenance and Osmotic Adjustment

Adequate turgor is necessary for the growth of plant cells because it supplies the internal "push" for expansive cell growth. It is also critical for the swelling of guard cells, necessary to cause stomatal opening and effective gas exchange. Turgor decreases rapidly in most plants as water deficits develop. In drought hardy plants, turgor is maintained despite tissue water deficits (Culter et al., 1977).

Weatherly (1966) reasoned that a cell with lower osmotic potential could maintain turgor-mediated processes to lower values of water potential than a cell with a higher osmotic potential.

One of the mechanisms hypothesized to allow for the maintenance

of turgor is the lowering (more negative) of the vacuolar osmotic potential through solute accumulation (Cutler et al., 1977). Reports in the literature indicate that leaves of higher plants increase their solute concentration, thus lowering their osmotic potential, in response to slowly developing water deficits. Osmotic adjustment is the term given to the process whereby the osmotic potential is lowered by solute accumulation instead of a solute concentration due to a decrease in the cell volume (Jones and Turner, 1980).

Osmotic adjustment has been measured in expanded leaves of several higher plants (Brown et al., 1976; Hsiao et al., 1976; Munns et al., 1979; Simmelsgaard, 1976). This solute accumulation has been shown in leaves, roots, hypocotyl and reproductive organs of many plant species as fully reviewed by Jones and Turner (1980).

Measuring Water Potential Components

Leaf Water Potential. Leaf water potentials are most commonly measured with a pressure chamber. This measurement of leaf water potential involves the apoplastic water of the leaf tissue, providing the leaf cells are still turgid.

Pressure chamber. The original pressure chamber was devised by Dixon in the early 1900's to determine the stress that plants could withstand during transpiration (from Tyree and Hammel, 1972). Dixon enclosed a twig in a strong glass cylinder while allowing the lower portion of the twig to project through an air-tight seal to the outside where it dipped into a vessel containing a weighed quantity of water. He raised the pressure in the glass cylinder (using carbon

dioxide) to determine the balancing pressure at which water neither left nor entered the twig when it was under transpiration stress. He also determined the pressure at which wilting would occur. After several explosions and other difficulties, Dixon abandoned the project.

Scholander et al. (1965) independently devised a similar pressure chamber. They used nitrogen gas in a stainless steel pressure chamber to apply pressure to an excised leaf (or twig) to bring the xylem sap back to the cut surface.

Pressure chambers have since been used to estimate leaf water potentials. Measurements of leaf water potentials are done by sealing the petiole of a leaf in the pressure chamber lid so that the cut surface of the petiole is projected to the outside, but the remainder of the leaf blade and most of the petiole are subjected to pressure within the chamber (Boyer, 1967a; Scholander et al., 1965; Waring and Cleary, 1967). As pressure is applied to the leaf the water potential of the xylem sap rises until it equals the potential of the xylem sap at atmospheric pressure. At equilibrium, the pressure required to bring the xylem sap up so that it just moistens the cut surface of the leaf is related to the leaf water potential (Ψ_L) by $\Psi_{leaf} = \Psi_P{}^{xylem} + \Psi_\pi{}^{xylem} = P + \pi^{xylem}$ (Boyer and Ghorashy, 1971).

This works because the water column in the plant's vascular system is generally under tension due to the evapotranspiration of the leaves and the inability of the roots to supply water rapidly enough from the soil. When the leaf is severed from the plant, this

water column is broken and water recedes into the leaf a short distance because the atmospheric pressure on the outside is greater (higher) than the pressure within the capillary. If the pressure within were once again restored to the pressure that existed before it was severed, the meniscus would move back to the place where it was when the leaf was cut (Boyer and Ghorashy, 1971; Scholander et al., 1965; Waring and Cleary, 1967). This balancing pressure is then noted and its negative value ideally equals that which existed in the petiole before it was cut from the plant (DeRoo, 1969; Scholander et al., 1965; Waring and Cleary, 1967).

Tyree (1976) and Boyer and Ghorashy (1971) used a thermocouple psychrometer to measure the osmotic potential of the xylem sap and found it to be under -0.5 bars. With the osmotic component of the xylem sap found to be negligibly small, the leaf water potential found with the pressure chamber equals P^{xylem}, and π^{xylem} can be ignored.

Possible errors in the method can be minimized by:

1. Preventing an excessive rate of pressurization of the nitrogen gas, which might cause one to overshoot the end points (the leaf would not have time to come to equilibrium).
2. Being aware that haze or partial cloud cover may cause the endpoint to be misread since the change in light intensity makes it hard to see the endpoint (i.e., when the cut surface of the leaf just begins to moisten).

3. Avoiding water losses between sampling and measurement in order to avoid artificially lowering the water potential of the leaf. This can be accomplished by covering the leaf with a plastic bag just before removing it from the plant and leaving it in the bag until it is at the pressure chamber.
4. Making only one cut on the leaf or petiole.
5. Minimizing the length of petiole external to the chamber.
6. Leakage of gas from the chamber should be prevented, particularly if the leaf is not enclosed in a plastic sheath while in the pressure chamber (Scholander et al., 1965; Turner, 1981).

Scholander et al. (1965) noted that it is essential that all of the liquid that receded from the original cut be brought back up to the cut surface before the pressure is measured. If continued pressure is applied so that sap exudes from the leaf until the leaf becomes limp, the balancing pressure measures the osmotic pressure of the leaf (Scholander et al., 1965). In this way, the pressure chamber may be used to measure all or part of the Pressure-Volume Curve (Tyree and Hammel, 1972) (see section on the P-V curve).

Other Techniques. The pressure chamber technique is the most commonly used method today (Turner, 1981) because it is the most rapid, efficient (Boyer and Ghorashy, 1971) and reliable method in the field. Other techniques are available to measure total (leaf) water potentials. A portable freezing point meter as described by

Cary and Fisher (1971) and vapor pressure techniques (vapor pressure psychrometers) as described by Boyer (1969), Boyer and Ghorashy (1971) and Turner (1981) are also available. The most accurate method for measuring plant water potentials under laboratory conditions is probably with the vapor pressure psychrometer (Cary and Fisher, 1971), however, it requires long equilibration times, from 45 minutes to many hours (Turner, 1981), and has limited use in determining water potentials in the field.

Osmotic Potentials. Osmotic potentials in this study were measured with a dewpoint hygrometer (psychrometer) on expressed sap of tissue that was frozen and then thawed. This component was once thought to be the symplastic water of the cell with only negligible dilution by apoplastic water, i.e., bound water (Cook and Papendick, 1972; Cutler et al., 1977; Sepaskhah and Boersma, 1979; Tyree and Hammel, 1972). However, Boyer (1967) and Tyree (1976) showed that plant leaves do have significant matric potentials, and presented evidence that those matric potentials observed were associated mainly with the cell walls.

The leaf water potentials at equilibrium will be the same in the apoplastic and symplastic water, but the factors contributing to the water potential in the apoplast and symplast are different (Tyree, 1976).

Correcting for bound water. When "osmotic potential" is measured with a psychrometer on tissue that has been frozen and thawed, the cells are disrupted and the turgor potential becomes zero

(Boyer, 1967; Campbell et al., 1979; Warren-Wilson 1967a). The equation describing the water potential is

$$\Psi_L = -\pi + -\tau \text{ since } P = 0 \text{ (Boyer, 1967; Warren-Wilson, 1967)}$$

Previously it was assumed that the matric effect was negligible (Cook and Papendick, 1972; Cutler et al., 1977; Tyree and Hammel, 1972). However, Boyer (1967), Tyree (1976), Campbell et al. (1979), and Wenkert (1980), among others, all showed that leaves do have significant matric potentials and that the apoplastic (or bound water), which is essentially solute free and which remains solute free in the presence of semi-permeable membranes, will flood and dilute the symplastic water when those membranes are destroyed by freezing (Jones and Turner, 1980; Ladiges, 1975; Turner, 1981; Wilson, 1967; Wilson et al., 1979). This dilution of the symplastic water causes the measured osmotic potentials to be less negative (higher) than the true values.

The "osmotic potential" measured by freezing and thawing the leaf material is the sum of both the osmotic and the matric potentials (Campbell et al., 1979). Wenkert (1980) stated that the dilution may cause an error in osmotic potential calculations of 10 to 20%, and Tyree (1976) noted that these errors in osmotic may cause relatively large errors in the calculation of P (which is $P = \Psi_L + \pi$). Tyree (1976) believed that these dilution effects probably explain the frequent reports of negative turgor potential in the literature.

Wenkert (1980) concluded from his studies that a correction factor for "bound water" is required when osmotic pressure is measured using expressed call sap. He also noted that, even though the errors from using expressed sap are large, errors are likely to be even greater when using frozen and thawed whole tissue discs because of the incomplete mixing of cell sap. Even though membranes are disrupted in both methods, the mixing may be more complete when the sap is expressed and the cell surfaces are no longer present.

One method for determination of this correction factor for bound water is to use the Pressure-Volume Curve technique.

Pressure-volume curve. Matric, osmotic and turgor potentials respond differently to changes in water potential, and should be evaluated separately. A pressure-volume curve (PV curve) is a good technique to do this.

Scholander et al. (1964, 1965) used the pressure chamber technique (described in the following section) to express water from tissue while concurrently measuring the water potential. The PV method consists of a series of water potential measurements using the pressure chamber, while alternating it with periods of over-pressurization during which sap is forced out of the petiole and is either collected (Ladiges, 1975; Scholander et al., 1964, 1965; Tyree and Hammel, 1972) or the leaf itself is blotted off and reweighed after each new pressure (Campbell et al., 1979; Wilson et al., 1979).

The water content and potential relationship is usually established for a single leaf (Campbell et al., 1979; Ladiges, 1975; Scholander et al., 1965; Turner, 1981; Wilson et al., 1979), although

Wenkert (1980) used a different leaf for each point on the PV curve, thus using several leaves to determine his PV curve. By using either the single leaf or a series of leaves, the measurements can be done rapidly enough so that other responses to dessication, e.g., osmotic adjustment, are minimized (Wenkert et al., 1978).

The procedure usually involves a leaf that is fully hydrated (at 100% turgidity), either by sampling the tissue in the early morning (Ladiges, 1975) or by artificially rehydrating it (Campbell et al., 1979; Cook and Christen, 1976; Turner, 1981; Wilson, 1979; Wilson et al., 1979). However, some researchers (Wenkert, 1980; Wenkert et al., 1978) did neither. Wenkert et al. (1978) stated that by making measurements at different times of the day, without rehydrating the tissue, the PV curve could serve as a check and comparison between predictions of a single pressure-volume relation and the actual changes under field conditions. Wenkert (1980) also believed that by taking samples in the morning while dew was still present, the original water content would not be far from that at full hydration.

If the leaf tissue was not brought to full turgor, the weight of the leaf at full turgor can be estimated by plotting the balancing pressure against the weight of the leaf at each pressure. The linear portion of the graph is then extrapolated to $\Psi_{leaf} = 0$ (illustrated in Figure 9).

The relative water content (RWC) corresponding to each balancing pressure could then be determined.

$$RWC = \Theta = \frac{(FW-DW)}{(TW-DW)}, \text{ (Ladiges, 1975; Tyree, 1976)}$$

where FW (fresh weight) is the weight of the leaf at one particular balancing pressure, and DW is the dry weight of the tissue after oven drying for 24 hours. Turgid weight, TW, is the fresh weight at Ψ_L = 0, or at full turgor. The FW is not the same as the TW unless the leaf was at full turgor when sampled (Ladiges, 1975; Turner, 1981; Tyree, 1976; Wilson et al., 1979).

The components of the PV curve are described in Figure 1.

Once the PV curve has been plotted, the % bound water can be determined from the graph, and the correction for the osmotic potential can be calculated.

To correct the osmotic potential, π :

$$\pi \text{ actual} = (\pi \text{ measured}) \left(\frac{RWC}{(RWC - \% \text{ bound water})}\right).$$

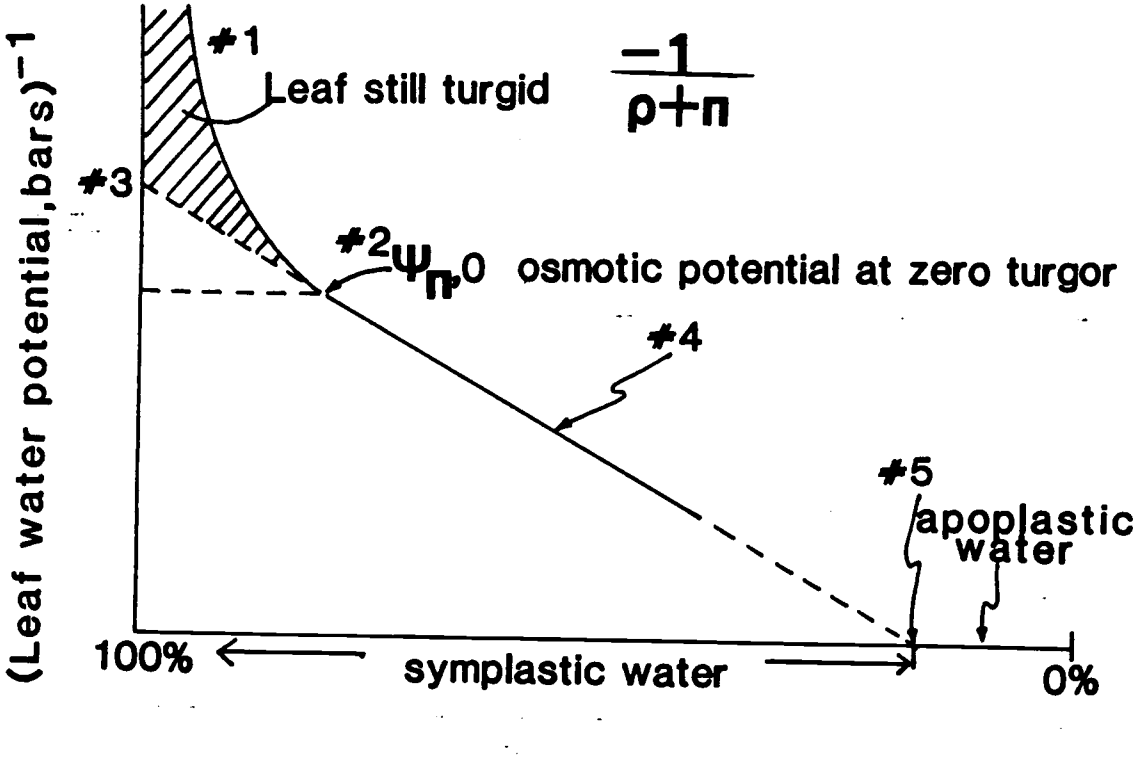

Figure 1. Components of the PV curve.

1. The PV curve is non-linear at first. The leaf maintains some turgidity at these water potentials. Some xylem sap is expressed at first.

2. $\Psi_{\pi,0}$ is the point of incipient plasmolysis, now Ψleaf = Ψosmotic since P = 0.

3. $\Psi_{\pi,100}$ is the osmotic potential at full turgor which is found by extrapolating the linear portion of the curve to RWC = 100%.

4. The linear part of the PV curve is established after the turgor pressure of the leaf cells has reached zero and the balancing pressure is equal to the average osmotic pressure of the cell sap. This part of the PV curve provides an estimate of the osmotic potential of the tissue at various water contents.

5. Extrapolation of the linear portion of the PV curve to $(-\Psi_L)^{-1}$ = 0 (i.e., $\Psi_L = \infty$) gives an estimate of the bound water content (Boyer, 1969; Ladiges, 1975; Tyree and Hammel, 1972).

METHODS AND MATERIALS

Site Selection and Characteristics

Winter wheat (Triticum aestivum L. var. Stephens) plots were established at the Hyslop Crop Science field laboratory on Oct. 15, 1980, on a site previously cropped to a first-year wheat variety trial. This site was chosen because there had been signs of a take-all infection in the first-year wheat, and there was a high probability of take-all in the second consecutive wheat crop.

The soil type is a Woodburn silt-loam (fine-silty, mixed, mesic, Aquultic Argixeroll) with a 1:2 soil:water pH of 5.4, 86 mg dilute acid-fluoride extractable P kg^{-1} soil and 235 mg ammonium-acetate-extractable K kg^{-1} soil.

Experimental Design

The experiment was designed as a randomized complete block (RCB) with 20 treatments (Table 1), replicated 4 times. Each subplot consisted of 18-ft lengths of two 5-ft drill widths, and was divided into an eastern and a western section, each 5 x 18 ft. Water potential components, plant nutrient content and disease assessment samples were taken from the eastern section only.

The effects of spring chloride treatments were determined in three ways: (1) comparison of nil vs. 368 kg spring Cl/ha (treatments 3 and 5 vs. treatments 12 and 15), (2) comparison of four rates of Cl applied as NH_4Cl (treatments 5, 12, 13 and 14), and (3)

Table 1. Treatment schedule of fall and spring fertilizer source, rate and method of application.

Trt No.	Nutrient rates†											
	Fall							Spring				
	N	P	K	S	Cl	Chloride source	Chloride method††	N	K	S	Cl	Chloride source
	- - - kg/ha - - -							- - - kg/ha - - -				
1	--	--	--	--	--			--	--	--	--	--
2	22	--	--	25	--			146	--	167	--	--
3	22	22	--	25	--			146	--	167	--	--
4	22	--	--	--	56	NH_4Cl		146	--	167	--	--
5	22	22	--	--	56	NH_4Cl		146	--	167	--	--
6	22	22	--	13	28	NH_4Cl		146	--	167	--	--
7	34	22	--	--	84	NH_4Cl		134	--	153	--	--
8	22	22	30	25	28	KCl	bnd	146	--	167	--	--
9	22	22	62	25	56	KCl	bnd	146	--	167	--	--
10	22	22	62	25	56	KCl	bdc	146	--	167	--	--
11	22	22	123	25	112	KCl	bdc	146	--	167	--	--
12	22	22	--	--	56	NH_4Cl		146	--	167	368	NH_4Cl
13	22	22	--	--	56	NH_4Cl		146	--	167	185	NH_4Cl
14	22	22	--	--	56	NH_4Cl		146	--	167	92	NH_4Cl
15	22	22	--	25	--			146	--	--	368	NH_4Cl
16	22	22	--	--	56	NH_4Cl		146	204	167	185	KCl
17	22	22	--	--	56	NH_4Cl		146	--	167	185	$CaCl_2$
18	22	45	--	--	56	NH_4Cl		146	--	167	368	NH_4Cl
19§	22	22	--	--	56	NH_4Cl		146	--	167	368	NH_4Cl
20	22	22	--	--	56	NH_4Cl		202	--	64	368	NH_4Cl

† All fertilizers, except KCl from treatments 10 and 11 were banded with the seed at planting on October 15, 1980. Spring fertilizers were topdressed on March 16, 1981. N supplied as $(NH_4)_2SO_4$ where S was applied, and as NH_4Cl where indicated under chloride source.

†† Method of chloride application: banded (bnd) or broadcast (bdc).

§ Cu and Zn (5 and 2 kg/ha, respectively) banded with the seed at planting.

comparison of NH_4Cl, KCl and $CaCl_2$ sources at 185 kg Cl/ha (treatments 13, 16, and 17).

Treatments involving different rates, sources and methods of application were used to evaluate the effect of fall-applied Cl. Treatments 2 and 3 vs. 4 and 5 provide a contrast between nil and 56 kg Cl/ha. Treatments 3, 6 and 5 provide rates of 0, 28, and 56 kg Cl/ha, respectively. Comparison of treatments 5 and 6 vs. 8 and 9 provides a contrast between NH_4Cl and KCl sources of Cl. Lastly, treatment 9 was compared to treatment 10 to evaluate the effect of method of application.

In addition to fall chloride treatments, fall treatments of Cu plus Zn and rates of P were included. The comparison of treatments 19 vs. 12 showed the effects of the addition of Cu plus Zn to the fertilizer band. Phosphorus rate comparisons involve treatments 2 and 4 vs. 3 and 5, and treatments 4, 5 and 18.

Cultural Practices

'Stephens' soft white winter wheat was sown on Oct. 15, 1980, with a double disc drill at 150 kg of seed ha^{-1} in six rows spaced 23 cm apart. All fall fertilizers, except the KCl treatments on trt 10 and 11, were banded with the seed at planting. The KCl in trt 10 and trt 11 was broadcast. Weeds were controlled with Karmex. Spring fertilizers were topdressed on March 16, 1981.

The eastern and western sections of each subplot were harvested separately on July 30, 1981, with a plot combine. Grain from the eastern and western sections was weighed separately in the field.

Grain was then cleaned by passing it once through a fan cleaner, then test weights and 1000 kernel weights were determined.

Disease Assessment

Two methods were used to estimate the disease severity: 1) whole plant fresh weight measurements, and 2) visual examination of crown roots for evidence of lesions.

Fresh weight measurements were taken on July 2, 1981, and involved weighing the aerial portion of the wheat from two one-meter sections from the outside of each of the subplots on all 20 treatments. Although fresh weights are not a direct measure of the severity of the disease, they have been shown to be good indicators of disease severity (Christensen et al., 1982; Powelson and Jackson, 1978).

On April 17, June 8 and July 2, 1981, visual disease assessments were made on root cores that were randomly sampled from within selected treatments. Root cores were sampled with a bucket auger (6 cm diameter by 10 cm deep) and labelled with indelible-ink tags. To facilitate the removal of soil from the roots, the cores were soaked in water overnight. The following day the roots were washed with a jet of water from a hose, then stored in a dark, cold, walk-in cooler until the disease severity was assessed. The crown roots were examined under water against a white background.

The methodology involved in both the sampling and the disease assessment evolved over time. On April 17 (Feekes 8+), treatments 1-6 and 8-17 were sampled to study the effects of fall and spring

chloride on the disease severity. Four cores were taken from each of the subplots, giving 16 observations per treatment. The crown roots were counted and assessed as to overall percent of attack (PA) (Table 2). Individual roots were each assessed a lesion class value based on the severity of the lesions present: (1) mild (small dark lesions, not near the crown), (2) moderate, or (3) severe (large black lesions near the crown). The total number of roots in each of the lesion classes was also tabulated. PA assessment was very subjective, so all of the cores from within a block were evaluated by the same person.

Due to the difficulty in analyzing large numbers of roots before they decomposed, the number of treatments was reduced, as well as the number of cores per subplot (from 4 to 3), for the June 8 date. Treatments 1, 3, 5 and 12-17 were selected to evaluate the effect of rate of fall chloride on disease severity, and to evaluate the effects of rate and source of spring chloride on severity. In addition to the PA rating described above, a disease rating based on a scale of 1 to 5 was also done on each plant, and assigned as follows:

Rating	% Root Surface Area Infected
1	0-15
2	15-35
3	35-70
4	75-90
5	90-100

Table 2. Take-all root rot disease severity classification.

PA[†]	Description[††]	LOGIT VP[§]
0	No infection	0
0.1	1-2 lesions per plant	0.001
0.5	5% roots with one lesion	0.005
0.25	25% roots with one lesion	0.0025
1	average of one lesion per root	0.0101
5	5% root surface attacked	0.0513
10	10% root surface attacked	0.105
25	25% root surface attacked	0.288
50	50% root surface attacked	0.693
75	75% root surface attacked	1.386
90	90% root surface attacked	2.303
95	95% root surface attacked	2.996
99	99% root surface attacked	4.605

[†] PA = Percent of attack

[††] On secondary roots

[§] LOGIT = LN (100/100-PA)

On July 2, the method of disease assessment was simplified further. Two cores per subplot were sampled. The treatment samples were the same as the April sampling (treatments 1-6, 8-17). Only the values for the overall PA and the 1 to 5 scale were noted; roots were not counted nor were lesion classes tabulated.

The area under the disease progress curve (AUDPC) from April 17 to June 8 was calculated for each subplot for treatments 3, 5, and 12-17.

Plant Nutrient Content

Whole plant samples were taken from treatments 1-11, 18 and 19 on Dec. 8, 1980, and on Jan. 13 and March 5, 1981, for winter plant nutrient analysis. On April 30, 1981, samples of the most recently matured leaves were randomly selected from treatments 1-20 to study the effects of spring fertilizer applications.

On May 12, 27, 29, and June 24, flag leaves (14 to 19 leaves per treatment) were sampled to determine the fresh and turgid weights for the osmotic correction factors. These samples were also analyzed for plant nutrient content.

All plant samples (except the May 12, 27 and 29, and June 24 samples, procedures described on page 45) were placed in paper bags and placed in a 53°C oven for a minimum of 48 hours. After drying, the samples were ground in a Wiley mill and stored in coin envelopes in a 53°C oven.

Chloride was extracted with 0.1N HNO_3 and titrated with $AgNO_3$ to a potentiometric endpoint. An Orion (Model 407) specific ion meter

used in conjunction with an Orion (Model 94-17A) specific chloride electrode was used to determine the potentiometric endpoint (Cantliffe et al., 1970).

Total S was determined by dry ash oxidation of plant material in a muffle furnace at 550°C for 5 hours after the plant samples were treated with ethanol and $Mg(NO_3)_2$. The residue was extraced with 3N HCl, and the total S was determined by $BaCl_2$ turbidometric analysis with a colorimeter (Bausch and Lombe Spec. 100), as described by Tabatabai and Bremner (1979) and modified by Dale Westermann, USDA, Snake River Conservation Research Center, Kimberly, Idaho, 83341.

Cations (Ca, Mg, K, Na, Mn, Cu and Zn) were analyzed with an atomic absorption spectrometer (Model 4000, Perkin-Elmer) after nitric-perchloric acid digestion.

Samples were prepared for analysis of total N and P using a Kjeldhal digest. Plant tissue was prepared for NO_3-N analysis after extraction with double-distilled water. Total N as NH_4^+-N, total P as PO_4^--P, and NO_3^--N were determined colorimetrically (NH_4^+ by salicylate/nitroprusside, PO_4^--P by molybdate/anitmony, and NO_3^- after Cd reduction) using a Scientific Instruments CFA 200 autoanalyzer.

Plant nutrient contents were converted from percent and ppm to meq/g so that the sum of the inorganic cations (C) and of the inorganic anions (A) could be determined. The organic anion content was estimated as the sum of the cations minus the sum of the anions for each sample.

Water Potentials

Randomly selected flag leaf samples were taken on May 12, 27, 29, and June 24, 1981, from treatments 3, 5, 12-17 to study the effect of spring chloride fertilizer treatments on water potential components. Care was taken, however, to select all of the leaves from similar positions in the canopy. Leaves were excised just above the ligule and placed into the pressure chamber (Soil Moisture Equipment, Model 3050 Plant Water Status Console with Model 3015G2 Specimen Holder) for determination of leaf water potentials (Scholander et al., 1964; Tyree and Hammel, 1972). The pressure chamber was centrally located among the treatments being sampled, so that the time between excision and placement into the pressure chamber was approximately 30 seconds. Immediately after the leaf water (Ψ_L) potential was noted, the pressure was released and the leaf removed from the specimen holder. The leaf was then rolled up and placed inside a pre-labelled, pre-cut section of 9.5 mm diameter tygon tubing and sealed on both ends with clean rubber stoppers. The sample was placed on dry ice until thoroughly frozen, then stored in a freezer until the osmotic potential was determined. The average total time elapsed from leaf excision until placement on the dry ice was approximately 3 minutes. Leaf water potentials were measured between 10:30 a.m. and 3:30 p.m. After each of the treatments had been sampled, the process was repeated 6 times (i.e., replicates were blocks in time).

Osmotic potential was determined using the dewpoint mode on a Wescor Dew Point Microvoltmeter HR-33, using a Model C-52 sample

chamber. Preliminary data collected in 1980 with the microvoltmeter was done in an open laboratory where the temperature fluctuated 3 to 4°C. The data collected was not very reliable due to the calibration difficulty, because even small changes in the temperature affected the calibration curve and sample readings. Therefore, the osmotic potential analysis for 1981 was completed in a constant temperature room in which the temperature rarely fluctuated more than 1°C. The microvoltmeter was calibrated with KCl molal solutions before beginning the readings, and was rechecked several times throughout the day.

The frozen leaf tissue was thawed inside the tygon tubing for one hour before a reading. The thawed leaf tissue was crushed with a rolling pin, then placed into a vice containing two closely placed rollers. This caused the leaf tissue in the tube to become thoroughly mixed and pressed to the top of the tube, where a filter paper disc, held by tweezers, absorbed the expressed cell sap. The disc was immediately placed into the sample chamber. Osmotic potentials measured between May 12 and June 24 were later corrected for dilution of the symplastic water by the solute-free apoplastic water based on results of a pressure-volume curve analysis, described later.

Flag leaves from the same plots the leaf water measurements were taken from were also sampled to determine their relative water contents during that time period. This was done in order to obtain a more accurate bound water correction factor for the osmotic potentials. 'Fresh weights' were calculated by collecting 10 to 15

leaves per treatment and placing them into tightly sealed, preweighed metal containers. The containers were reweighed (W_m), opened up and placed into a 100°C oven overnight. The containers were cooled to room temperature before determination of the dry weights (W_{dry}). The Θ_{fresh} for each treatment was calculated as:

$$\Theta_{fresh} = \frac{W_m - W_{dry}}{W_{dry}}$$

The 'turgid weight' was estimated by placing 4 flag leaves per treatment in double-deionized water in a dark, cold walk-in cooler overnight. The leaves were then weighed (W_{turgor}), dried in a 100°C oven overnight, and reweighed (W_{dry}). Θ_{turgor} was calculated by:

$$\Theta_{turgor} = \frac{W_{turgor} - W_{dry}}{W_{dry}}$$

Relative was content (RWC) for each treatment was calculated as:

$$RWC = \frac{\Theta_{fresh}}{\Theta_{turgor}}$$

The correction factor for the osmotic potentials for each treatment was then estimated using the RWC calculated for each treatment on that date and the average value for the apoplastic (bound, b) water fraction from the 1981 pressure-volume curves (Appendix Tables 2 and 3):

$$\text{osmotic correction factor} = \frac{RWC}{RWC-b}$$

The corrected osmotic potential is calculated as:

$$\pi \text{ corrected} = (\pi \text{ measured})\frac{(RWC)}{RWC-b}.$$

'Corrected' turgor potentials (P) were calculated as the difference between leaf water potential (Ψ_L) and the corrected osmotic potential (π).

On May 27, 1981, an additional study of the effects of fall and spring chloride on third-year wheat severely infected with TA was conducted on Dr. Jackson's field site immediately adjacent to my study site. The treatments included were:

Trt* No.	Chloride treatment	
	Fall	Spring
	- - - hg Cl/ha - - -	
1	0	0
2	56	0
3	56	368
4	0	368

* Each treatment received 22 kg P ha^{-1} banded with 22 kg N ha^{-1} Oct. 15, 1980, and 146 kg N ha^{-1} topdressed in March 1981. Cropping history (1977-1980): F-W-W-W.

Treatments 1 and 2 were compared against 3 and 4 to show the effects of the addition of spring chloride on leaf water, turgor, and osmotic potentials, while trt 1 and 4 vs. 2 and 3 were compared to show the effects of the addition of fall chloride on the components of water potentials.

Diurnal Water Relations

On June 2, 1981, a partial characterization of a diurnal water relations curve was done on treatment 1 (without chloride) and

treatment 3 (with chloride) from Dr. Jackson's field plots described above. Water potentials were measured from 5:58 a.m. to 9:56 p.m. for a total of 64 readings per treatment. A flashlight was used to observe the true leaf water endpoints during periods of darkness or cloudiness.

Leaf water (Ψ_L), osmotic (π) and turgor (P) potentials were obtained using the technique described earlier. Estimations of RWC for each treatment was made at 6:23 a.m., 10:57 a.m., 3:40 p.m., 6:34 p.m., and 9:56 p.m., when flag leaves were sampled for fresh weights. Θ_{fresh} was calculated as described on page 45. Θ_{turgor} (2.53) for this experiment was estimated from the mean value for Θ_{turgor} generated during the PV curve determination on May 20 and 25, 1981 (Appendix Tables 3 and 4). The relative water contents for each treatment was calculated as:

$$RWC = \Theta = \frac{\Theta_{fresh}}{\Theta_{turgor}}$$

Corrected osmotic potentials were obtained using the RWC calculations, measured osmotic potentials and the PV curve determination of the percent bound (b) water:

$$\pi \text{ corrected} = (\pi \text{measured})\frac{(RWC)}{RWC-b}$$

(where b = 17.73%).

Pressure-volume Curve

In order to determine the corrected osmotic potentials, a correction factor (b) as described above, is required to account for the dilution of the symplast by the solute-free bound (apoplastic) water fraction. Pressure-volume curves (PV curves) were generated on June 10, 1980, and on May 20 and 25, 1981.

On June 10, 1980, pressure volume curves (Campbell et al., 1979; Wilson, 1979) were done on two treatments, one receiving NH_4Cl in both the fall and the spring, the other receiving $(NH_4)_2SO_4$ in both the fall and the spring. Whole plants, including the first 8 to 12 inches of root and soil, were collected very early in the morning and placed in large plastic bags. The plants were brought to the laboratory and placed in a dark, cold walk-in cooler. Just prior to the experiment, the flag leaf was cut from the plant and immediately placed in the pressure chamber for the first reading. All sap that was expressed was blotted off with tissue until equilibrium was reached. The pressure was noted and released. The leaf was taken out, weighed, and re-inserted into the pressure chamber. The sequence was repeated, with the pressures increased 1.5 to 2 bars for each reading under -21 bars. After -20 bars was reached the pressure increments were approximately 3 to 4 bars each. After the final leaf weight, the leaf was dried and the dry weight noted (Appendix Tables 1 and 2).

The weight at full turgor (W_{turgor}) was estimated by plotting the pressure chamber's balance pressure (Ψ_L, -bars) against (moist)

leaf weight at that pressure and extrapolating the best fit line. Θ_{turgor} was found by:

$$\Theta_{turgor} = \frac{\text{weight at full turgor } (W_{turgor}) - \text{weight dry } (W_{dry}).}{\text{weight dry } (w_{dry})}$$

The Θ_{fresh} at each pressure was found by:

$$\Theta_{fresh} = \frac{\text{leaf weight at that pressure (Wm)} - \text{weight dry } (W_{dry})}{\text{weight dry } (W_{dry})}$$

which was then used to calculated the relative water content (RWC), or Θ at each balance pressure:

$$RWC = \Theta = \frac{\Theta_{fresh}}{\Theta_{turgor}}.$$

Apoplastic, or bound water, b, was found by plotting the inverse leaf water potential $(-\Psi_L)^{-1}$ against Θ and extrapolating the best fit line for the lineal portion of the graph. The intercept when $-1/\Psi_L = 0$ is known as the bound (b) or apoplastic water content.

The corrected osmotic potential is calculated as follows:

$$\pi_{corrected} = (\pi_{measured}) \left(\frac{RWC}{RWC-b}\right)$$

In 1981 the pressure volume curves were repeated, but were modified slightly (Appendix Tables 3 and 4). Whole plants were not collected, instead the culms with the upper 3 leaves and head were cut, immediately placed in double-deionized water and placed in a dark, cold walk-in cooler overnight (guttation had occurred by morning). The flag leaf was cut and immediately weighed. This weight was then assumed to be the weight at full turgor, eliminating the need to estimate the weight at full turgor by graphing. The remainder of the technique was the same as described for the 1980 PV curve.

Uncorrected Osmotic Analysis

Mid-winter osmotic potentials were measured on treatments 1-11, 18 and 19 on December 9, 1980, January 17 and March 9, 1981, to determine what effect source, rate and method of application of fall chloride had on uncorrected osmotic potentials. Five to 10 non-soiled leaves were randomly selected from each subplot, and ice crystals, if present, were carefully wiped off of the leaves before the leaves were rolled up and placed into prelabelled, precut lengths of tygon tubes. The tubes were sealed with rubber stoppers and placed on dry ice until thoroughly frozen. The tubes were then stored in a freezer until the osmotic potentials were analyzed.

On April 30, 1981, treatments 1-20 were sampled for osmotic potentials to determine what effects fall and spring chloride rates and sources had on the uncorrected osmotic potentials. Three to 5 of

the most recently matured leaves were randomly selected from each subplot, rolled up and placed into the tygon tubes as described above.

The frozen leaf tissue was thawed inside the tygon tubing for one hour. Immediately before a reading, the tygon tube containing the thawed leaf tissue was crushed with a rolling pin, then placed into a vice. While in the vice a filter paper disc, held by tweezers, absorbed the sap. The disc was immediately placed into the sample chamber. These osmotic potentials were not corrected for bound water dilution since turgor potentials were not being measured. (The complete procedure describing the osmotic analysis is on page 44).

Statistical Analysis

Yield. Statistical analysis of the yield data (grain yield, 1000 kernel, test weights) consisted of analysis of variance (ANOVA) with LSD comparisons on a randomized complete block (RCB) design of 20 treatments with 4 blocks. The yield data was analyzed as east yield, west yield and as averaged yield (east + west).

Disease. The disease data required a data transformation of the percent of attack (PA) values to LOGIT values [LOGIT = LN (100/100-PA)] in order to linearize the data for statistical comparison. Analysis of variance and LSD comparisons were then performed. The ANOVA design for the April, June and July logit data was a RCB design with multiple observations per block (4, 3, 2, respectively). Fresh weights were analyzed as RCB with 20 treatments, 4 blocks.

The area under the disease progress curve (AUDPC) was calculated for each subplot and subjected to ANOVA and LSD comparisons (a RCB design with 9 treatments, 4 blocks).

Yield and disease regressions. East grain yield was plotted against several measures of disease severity to examine the relationship between yield and disease severity. Simple linear regressions were then computed between east grain yield and three measurements of disease severity: April logit values, fresh weights, and AUDPC.

Plant analysis. Plant analysis data from the January, March and April 1981 dates were analyzed as RCB with 4 blocks and 13, 13, and 20 treatments, respectively. Plant analysis data from the May 12, May 27, May 29 and June 24, 1981, dates were not replicated due to insufficient plant material. However, the data from each of these 4 dates were treated as replications (blocks) in time and the entire data set subjected to ANOVA as a RCB with 8 treatments, 4 blocks.

Water potentials. The water potential data from the May 12, 27, 29 and June 24, 1981, dates were each subjected to an ANOVA of a RCB design having eight treatments and six replications in time. An ANOVA was also performed on the data from a file created with the treatment means of the osmotic (π), turgor (P), and leaf water (Ψ_L) potentials from the 4 dates (RCB with 8 treatments, and 4 replications across time). The water potentials collected on May 29, 1981, from Dr. Jackson's field site (RCB, 4 treatments, 6 replications across time) were also subjected to analysis of variance.

The design from the diurnal water characterizations was a RCB with multiple observations (4) per block (16). After the appropriate ANOVA was performed, the overall LSD comparisons were used to determine if significant differences in osmotic, turgor or leaf water potentials existed between the NH_4Cl and the $(NH_4)_2SO_4$ treatments.

Statistical analysis of the winter (January and March 1981) and early spring (April) osmotic data consisted of ANOVA and LSD comparisons on the proper RCB design (13, 13, and 20 treatments, respectively) with 4 blocks.

RESULTS

Yield

Treatment comparisons for grain yields were based on the total grain yields from the eastern and western sections (Appendix Table 5). This allowed for a larger sample area (a total of 10 x 18 ft/plot), which helped to minimize the problems associated with the patchy nature of take-all. The coefficient of variability (CV) was smaller with the total yields (CV = 19.3%) than with either the eastern (CV = 25.2%) or the western (CV = 20.6%) yields. A paired t-test comparison between the eastern and the western halves of the plots showed an average decrease in the grain yield of 810 kg ha^{-1} in the half of the plot where root, fresh weight and water potential samples were taken.

Grain yield was significantly affected by rate of spring-chloride but not by spring-chloride source (Table 3). A rate of 368 kg Cl ha^{-1} increased grain yield by 1000 kg ha^{-1} as well as increased the 1000 kernel and test weights significantly above the 0 kg Cl ha^{-1} rate. Although there were no statistically significant increases in grain yields between the individual spring chloride rate comparisons (Table 3), the data suggests that a spring chloride rate of 92 kg Cl ha^{-1} is adequate, and that NH_4Cl, KCl or $CaCl_2$ sources could be used.

Fall chloride rates, source or method of application had no significant effect on grain yield, although addition of 56 kg Cl ha^{-1} did significantly increase the 1000 kernel and test weights over the other rates (Table 4).

Table 3. Spring chloride rate and source effects on mean grain yield, 1000 kernel weight, and test weight.

Comparisons	Treatment numbers	Grain yield	1000 kernel weight	Test weight
		kg/ha	mg	kg/hl
Spring Cl rate (kg/ha)†				
0	3, 5	5468 a††	46.0 a	69.5 a
368	15, 12	6477 b	48.0 b	72.0 b
LSD .05		810	1.1	0.7
0	5	5681 a	46.6 ab	70.0 a
92	14	6633 a	47.3 b	71.0 b
185	13	5771 a	45.2 a	70.0 a
368	12	6490 a	47.2 b	72.0 c
LSD .05		1146	1.6	0.9
Spring Cl source (185 kg Cl/ha)				
NH_4Cl	13	5771 a	45.2 a	70.0 a
KCl	16	6441 a	45.8 a	70.0 a
$CaCl_2$	17	6794 a	47.5 b	71.9 b
LSD .05		1146	1.6	0.9

† Chloride applied as NH_4Cl.

†† Values followed by the same letter are not significantly different at the 5% probability level.

Table 4. Effects of fall chloride rate, source and method of application on mean grain yield, 1000 kernel weight and test weight.

Comparisons	Treatment numbers	Grain yield	1000 kernel weight	Test weight
		kg/ha	mg	kg/hl
Fall Cl Rate (kg/ha)†				
0	2, 3	5537 a††	44.3 a	68.0 a
56	4, 5	5761 a	45.7 b	69.5 b
LSD .05		801	1.1	0.7
0	3	5254 a	44.4 a	69.0 a
28	6	6095 a	44.7 a	69.0 a
56	5	5681 a	46.6 a	70.0 b
LSD .05		1146	1.6	0.9
Fall Cl source (mean of 42 kg Cl/ha)				
NH_4Cl	5, 6	5888 a	45.7 a	69.5 a
KCl	8, 9	5718 a	45.4 a	69.5 a
LSD .05		801	1.1	0.7
Fall Cl method (56 kg Cl/ha)				
banded	9	5736 a	46.4 a	70.0 a
broadcast	10	6430 a	44.7 b	69.0 b
LSD .05		1146	1.6	0.9

† Chloride applied as NH_4Cl.

†† Values followed by the same letter are not significantly different at the 5% probability level.

Grain yield was not significantly affected by rates of fall or spring nitrogen or by addition of P or Cu plus Zn to the fall fertilizer band (Table 5). Test weights were significantly lower for the highest rates of fall P, Cu plus Zn, and fall and spring N rates (Tables 5 and 6).

Disease Assessment

There was a significant reduction in disease with the fertilized plots as compared to the zero N kg ha^{-1} check plots (Table 7). There was a trend toward lower disease logit scores (i.e., less severe disease) and increased fresh weight values with the 368 kg Cl ha^{-1} spring chloride rate. LSD comparisons of the logit values revealed no significant differences between chloride sources or rates. Figure 2 illustrates the rapid increase in disease severity from April to June and that, for most treatments, the disease progress slowed considerably from June to July.

Disease readings averaged across fertilizer treatments on each of the three sampling dates are presented in Table 8. It is evident from this data that the disease ratings also progressed from the mild to severe lesion classes from April to June, with a concurrent increase in the PA (percent of attack) scores. On April 17, 1981, approximately 49% of all roots (and 100% of all plants) had some TA lesions, with the lesion classes approximately evenly distributed among the 3 classes. By June, 82% of the roots were infected, with the majority of the lesions in the severe classification.

Table 5. Effects of fall banded P rates and fall banded Cu plus Zn on mean grain yield, 1000 kernel weight, and test weight.

Comparisons	Treatment numbers	Grain yield	1000 kernel weight	Test weight
		kg/ha	mg	kg/hl
Fall P rate (kg/ha)				
0	2, 4	5830 a†	44.5 a	68.0 a
22	3, 5	5468 a	45.5 a	69.5 b
LSD .05		810	1.1	0.7
22	12	6490 a	47.2 a	72.0 a
45	18	6997 a	47.2 a	71.0 b
LSD .05		1146	1.6	0.9
Cu plus Zn rates (kg/ha)				
0 + 0	12	6490 a	47.2 a	72.0 a
2 + 5	19	5931 a	47.4 a	71.0 b
LSD .05		1146	1.6	0.9

† Values followed by the same letter are not significantly different at the 5% probability level.

Table 6. Effects of fall and spring rates of nitrogen on mean grain yield, 1000 kernel weight and test weight.

Comparisons	Treatment numbers	Grain yield	1000 kernel weight	Test weight
		kg/ha	mg	kg/hl
Fall N rate (kg/ha)				
22	5	5681 a†	46.6 a	70 a
34	7	5608 a	45.5 a	69 b
LSD .05		1146	1.6	0.9
Spring N rate (kg/ha)				
146	12	6490 a	47.2 a	72 a
202	20	7040 a	47.2 a	71 b
LSD .05		1146	1.6	0.9

† Values followed by the same letter are not significantly different at the 5% probability level.

Table 7. Influence of rates and source of spring chloride on disease severity.

Comparisons	Treatment numbers	April logit	June logit	July logit	Fresh weight
					g/2m
Check	1	0.96	2.90	3.0	281
Spring Cl rate (kg/ha)†					
0	3, 5	.50	1.18	1.26	615
368	12, 15	.24	1.07	1.18	746
LSD .05		.60	0.85	1.08	309
0	5	.41	.93	1.18	621
92	14	.31	1.04	1.48	860
185	13	.36	.97	1.26	758
368	12	.19	.81	.67	871
LSD .05		.70	1.00	1.27	365
Spring Cl source (185 kg Cl/ha)					
NH_4Cl	13	.36	.97	1.26	758
KCl	16	.11	.93	1.05	894
$CaCl_2$	17	.37	.70	.69	718
LSD .05		.70	1.00	1.27	365

† Chloride applied as NH_4Cl

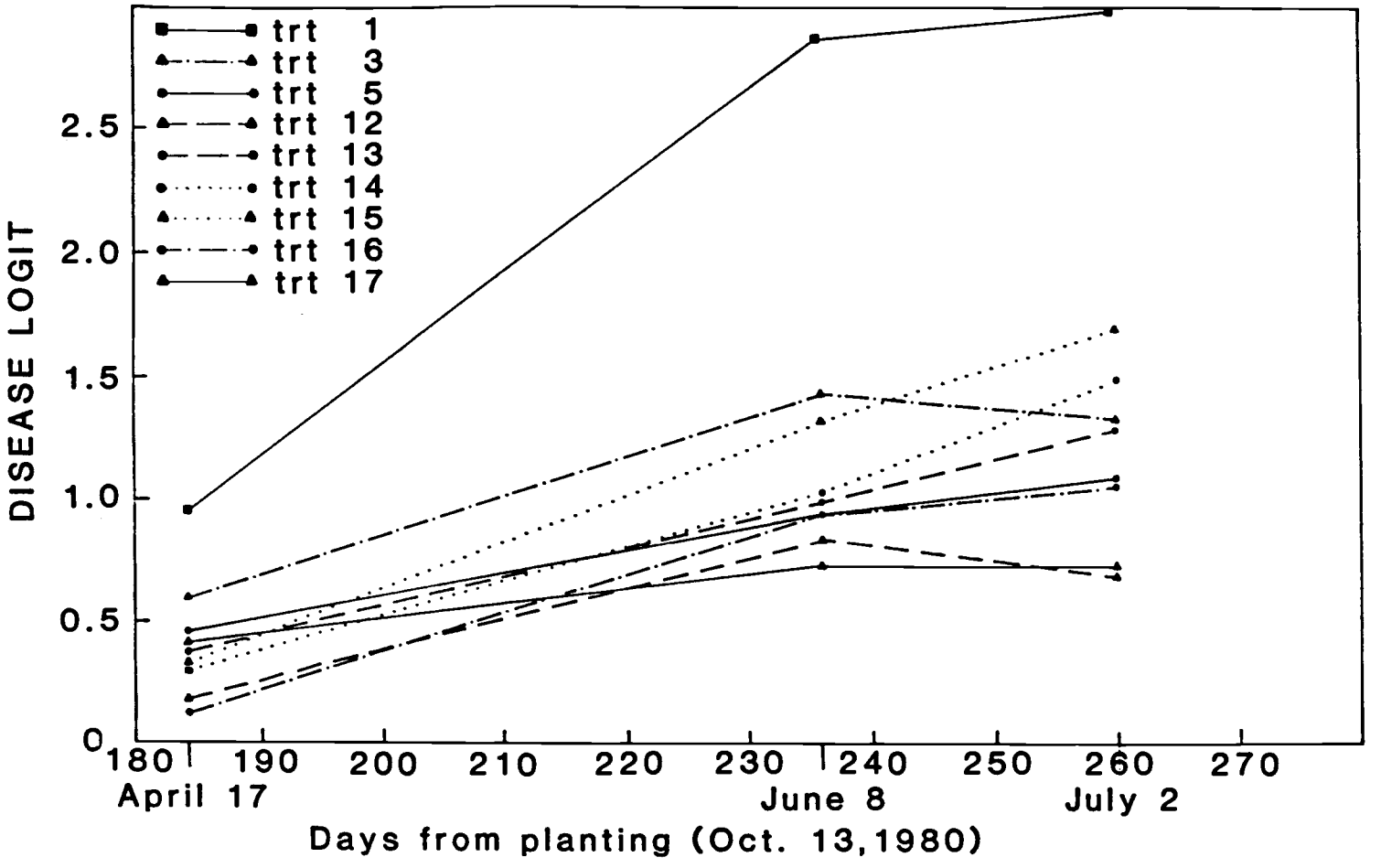

Figure 2. Take-all disease progression over time for the following treatments (kg Cl ha^{-1} in fall/kg Cl ha^{-1} in spring): (1) check, (3) 0/0, (5) 56/0, (12) 56/368, (13) 56/185 NH_4Cl, (14) 56/92, (15) 0/368, (16) 56/185 KCl, (17) 56/185 $CaCl_2$.

Table 8. Take-all disease assessment parameter means for three dates in 1981.

Date	Lesion classes†			PA	LOGIT values	Scale 1-5
	Mild	Moderate	Severe			
	- - - - - - % - - - - - -			%		
April 17 (Std dev)	14.9 (2.96)	16.5 (5.33)	17.1 (6.68)	26.5 (11.9)	0.400 (0.249)	--
June 8 (Std dev)	5.7 (1.53)	17.9 (2.87)	58.6 (15.1)	58.9 (15.95)	1.23 (0.669)	3.36 (0.74)
July 2†† (Std dev)	-	-	-	59.8 (15.6)	1.37 (0.70)	3.34 (0.663)

† The combined average (mean) of treatments 1, 3, 5, and 12-17 on each date is given because there were no statistical differences between any treatments (except when compared to the check plot).

†† Lesion classification not noted on July 2.

Relationship Between Disease Severity and Yield

Since the TA pathogen (Ggt) exhibits great variability (often referred to as 'patchiness') across short distances, the fresh weights and visual root disease assessments were correlated to the grain yields from the same plots. Eastern grain yield was negatively correlated to the TA-severity (Table 9), with the best correlation to the April TA logit values (R^2 = 0.58) (Figure 3). Fresh weight and AUDPC accounted for somewhat less of the grain yield variability (53% and 47%, respectively).

Plant Nutrient Analysis

Analysis of variance of the January plant nutrient data (Table 10) showed significant differences for P and Cl concentration only (Appendix Table 6). Leaf P concentration was significantly increased by 0.03% with each of the three rates of fall banded P, from 0.49% P at the 0 kg P/ha rate (trt 2 and 4) to 0.55% P at the 45 kg P/ha rate (trt 18). There was no effect of Cl fertilizers on leaf P concentration. Addition of fall chloride at 56 kg Cl/ha (trt 4 and 5) increased leaf Cl concentration from 0.39 to 0.42%, but the difference was not statistically significant. There were no significant differences in leaf chloride concentration between sources or method of application of fall chloride, however KCl resulted in consistently higher leaf chloride concentrations.

Analysis of variance of the March plant analysis (Table 10) showed no significant differences in P, but did show significant differences in Cl and total S (Appendix Table 7). Leaf Cl increased

Table 9. Relationships between grain yield, fresh weight (grams/2 meters) and indices of take-all severity for treatments 3, 5 and 12-17.†

Dependent variable (Y)	=	Y-intercept (A)	+	Slope (B)	Independent variable (X)	R^2
I. East grain (kg/ha)						
Yield	=	6955	-	3774.7	(April logit)	0.58
Yield	=	2539.8	+	2.13	(Fresh wt)	0.53
Yield	=	7929.98	-	62.53	(AUDPC)††	0.47
II. Fresh weight (g/2 meters)						
Fresh weight	=	1846.1	-	1078.8	(April logit)	0.40
Fresh weight	=	2180	-	19.43	(AUDPC)	0.38

† All treatments received 22.4 kg fall N/ha with 145 kg spring N/ha.

†† AUDPC = Area Under Disease Progress Curve from 184 to 236 days after sowing (Oct. 15, 1980).

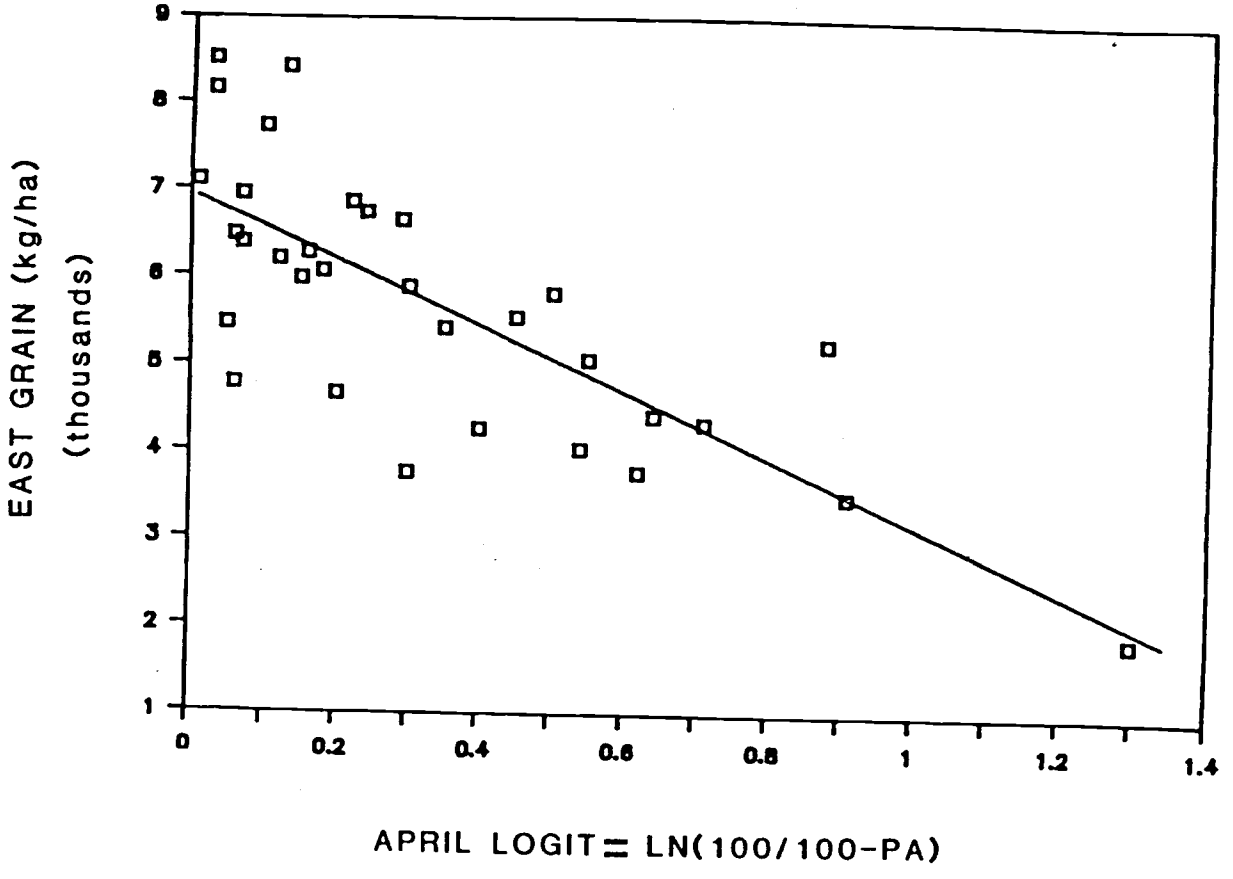

Figure 3. Relationship between grain yield and the April 17, 1981, TA logit values.

Table 10. Analysis of variance (ANOVA) of nutrient concentration in plant tissue.

Source	df	Nutrients							
		Ca	Mg	K	Na	Total P	Total S	Cl	Total N
						JANUARY			
total	51								
blocks	3								
treatments	12	NS†	NS	NS	NS	***	NS	*	NS
error	36								
						MARCH			
total	51								
blocks	3								
treatments	12	NS	NS	*	NS	NS	*	***	NS
error	36								
						APRIL			
total	79								
blocks	3								
treatments	19	***	***	**	NS	NS	***	***	***
error	57								
						MAY-JUNE			
total	33								
blocks	3								
treatments	7	**	**	NS	NS	*	***	***	***
error	21								

† NS = not significant, * = significant at 5%, ** = significant at 1%, *** = significant at 0.1%.

†† May-June data is from the mean values of plant analysis averaged over the four dates: May 12, May 27, May 29 and June 24, 1981.

significantly (P = 0.01) from 0.17% (trt 2 and 3), to 0.28% (trt 4 and 5) with addition of 56 kg Cl/ha in the fall. Leaf chloride increased significantly with each addition of fall Cl from 0 kg Cl/ha (trt 3) to 28 kg Cl/ha (trt 6) to 56 kg Cl/ha (trt 5). There were, however, no differences in leaf chloride between the two chloride sources (trt 5 and 6 vs. 8 and 9), nor from method of application (trt 9 vs. trt 10). The increase in total sulfur concentration in plants from treatments 4 and 5 when compared to treatments 2 and 3 is probably the result of addition of gypsum to the chloride plots on February 17, 1981 as insurance against S deficiencies later in the season. Total S concentrations indicate that S was not deficient in any of the treatments sampled in March or later in the season.

Analysis of variance for the April plant analysis (Table 10) showed highly significant differences between treatments for all plant nutrients except Na and P (Appendix Table 8). Addition of Ca as $CaCl_2$, and of K as KCl increased the leaf nutrient concentration of Ca and K by 0.06% and 0.13%, respectively. There was no interaction between spring chloride and Ca or K. Addition of 368 kg Cl/ha (trt 12 and 15) did appear to significantly lower leaf Mg content over the 0 kg Cl/ha rate (trt 3 and 5), but the difference was very small. Total S was significantly higher in those treatments fertilized with $(NH_4)_2SO_4$ in the spring, 0.54% compared to 0.31% (trts 3 and 5 vs. trts 12 and 15), and as the rate of S was decreased from 167 kg S/ha (trt 5) to 0 kg S/ha, the percent total S in the leaf decreased also. There was no effect of spring chloride treatment on total S. Increasing spring chloride from 0 (trt 3 and

5) to 368 (trt 12 and 15) kg Cl/ha significantly increased leaf chloride from 0.16% to 0.68%. Leaf chloride increased significantly from increased rates of spring chloride up to 185 kg Cl/ha, but there was no significant increase in % Cl above that rate. There was no effect of spring chloride source on leaf chloride concentration however.

The results of the ANOVA spring chloride analysis (Table 10) from May 12 through June 24 showed significant F values for Ca, Mg, P, S, Cl, and total N (Appendix Table 9). Addition of Ca as $CaCl_2$ increased the leaf Ca content from .75 to .84% (trt 13 vs. 17). There also appeared to be an increase in leaf Ca content as the rate of spring applied chloride increased. As the rate of spring chloride increased from 0 to 368 kg Cl/ha, the calcium content of the leaves increased from 0.67 to 0.82% Ca. There was no significant effect of Cl on the percent Mg, or percent total P. Total S concentration increased significantly from 0.28 to 0.58% S as the rate of $(NH_4)_2SO_4$ increased from 0 to 167 kg S/ha (trt 3 and 5). Leaf chloride concentration increased significantly as the rate of spring chloride fertilizers was increased. At 0 kg Cl/ha the leaf chloride content was 0.08%, and increased to 0.46% Cl with the application of 92 kg Cl/ha. There were no significant increases in percent Cl above the 92 kg Cl/ha rate, and no significant differences between the three chloride sources.

The plant analysis from the May-June data reflects an interesting effect of chloride fertilizers on total N (Appendix Table 9). Increasing Cl application from 0 to 368 kg Cl/ha increased the

total N concentration in plants from 2.9 to 3.4%. Total N increased significantly from 2.9% at 0 and 92 kg Cl/ha to 3.2% at 185 kg Cl/ha to 3.4% at 368 kg Cl/ha. However, in comparisons of chloride sources, the effect of increased total N with chloride application was not evident with the application of $CaCl_2$, which had a total N content of 3.0% as compared to 3.2 and 3.3% with NH_4Cl and KCl sources of chloride. The author has no explanation for the decreased total N with the addition of $CaCl_2$.

Water Potential Components

Water potential components measured from May 12 to June 24 were influenced by spring chloride rate and source (Table 11). Mean leaf and corrected osmotic potentials from the May 12, 27, 29, and June 24 sampling dates were significantly lower with the addition of 368 kg Cl ha^{-1} from treatments 12 and 15, while mean turgor potentials were increased 1 bar with addition of 368 kg Cl ha^{-1}. Mean leaf water and osmotic potentials did not decrease significantly with Cl rates above 92 kg Cl ha^{-1}. The trend for the turgor potentials, although not significant, was to increase slightly as the Cl rate increased. Overall, the trend for the osmotic and leaf water potentials was for the NH_4Cl treatment to be associated with the least negative potentials, followed by $CaCl_2$ and for KCl to have significantly more negative (lower) potential than the NH_4Cl treatment. KCl was also associated with a slightly higher turgor potential (Table 11 and Appendix Table 14).

Table 11. Spring chloride rate and source effects on leaf water potential components averaged over May 12, 27, 39 and June 24, 1981 sampling dates.

Comparisons	Treatment Numbers	Leaf water potential component: Osmotic (π)	Leaf (Ψ_L)	Turgor (P)
		- - - - - - bars - - - - - -		
Spring Chloride rate (kg/ha)†				
0	3, 5	-21.2 at††	-13.7 a	7.5 a
368	12, 15	-23.4 b	-15.0 b	8.5 b
LSD .05		0.9	0.7	.88
0	5	-21.6 a	-13.6 a	8.0
92	14	-22.6 ac	-14.3 ac	8.2
185	13	-22.6 ac	-14.4 ac	8.2
368	12	-22.9 bc	-14.6 bc	8.4
LSD .05		1.3	1.0	NS
Spring Chloride source (185 kg Cl/ha)				
NH_4Cl	13	-22.6 a	-14.4 a	8.2
KCl	16	-24.a b	-15.7 b	8.5
$CaCl_2$	17	-23.3 ab	-15.2 ab	8.1
LSD .05		1.3	1.0	NS

† Chloride applied as NH_4Cl.

†† Values followed by the same letter are not significantly different at the 5% probability level.

Figure 4 illustrates the effects of fall and spring chloride on turgor, leaf and osmotic potentials measured on four dates in 1981. As the season progressed, the trend was for spring chloride fertilizers to be associated with lower osmotic potential and higher turgor potentials. No significant differences in leaf water potentials were observed after May 12th, although the trend was for the spring chloride treatments to show slightly more negative leaf water potentials.

The effect of spring chloride rates on water potential components on four dates is illustrated in Figure 5. The least negative osmotic potentials and lowest turgor potentials were associated with the 0 kg Cl ha^{-1} rate. Once again, the trend of the data from these four dates has been for the highest turgor potentials to be associated with (1) the 368 kg spring Cl ha^{-1} and (2) the most negative osmotic potentials.

Spring chloride source effects on water potential components on four dates are illustrated in Figure 6, and show a trend for the KCl treatment to have the lowest (more negative) osmotic and highest leaf water potentials. The KCl treatment was associated with significantly higher turgor potentials on May 12 and June 24 (probability levels 0.05 and 0.10, respectively). Raw data for the water potential experiments from May 12, 27, 29 and June 24, 1981, are included in Appendix Tables 10-14.

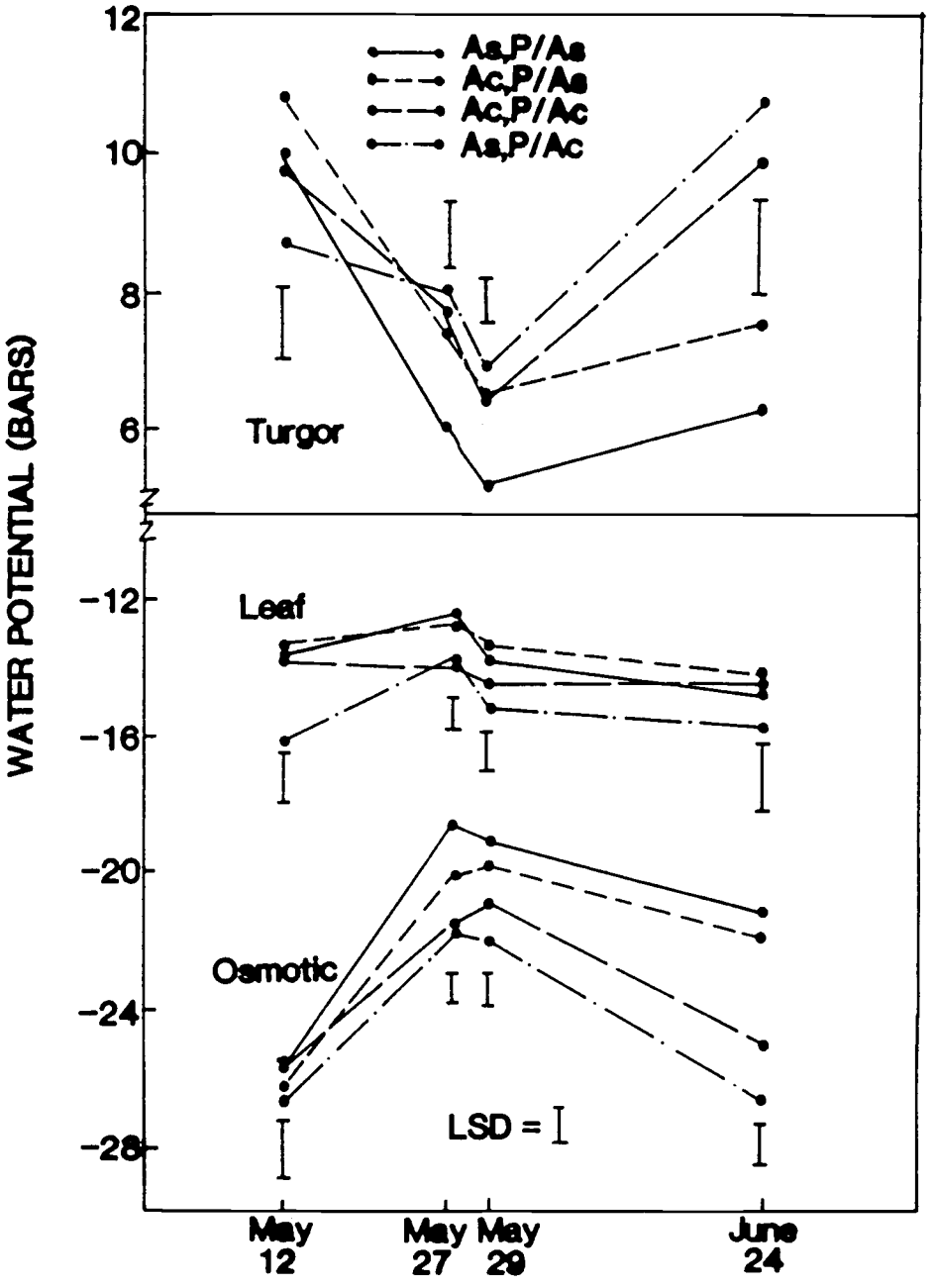

Figure 4. Effects of fall and spring chloride on turgor, leaf water and osmotic potentials measured in second-year wheat on four dates in 1981 [where AS = $(NH_4)_2SO_4$; AC = NH_4Cl].

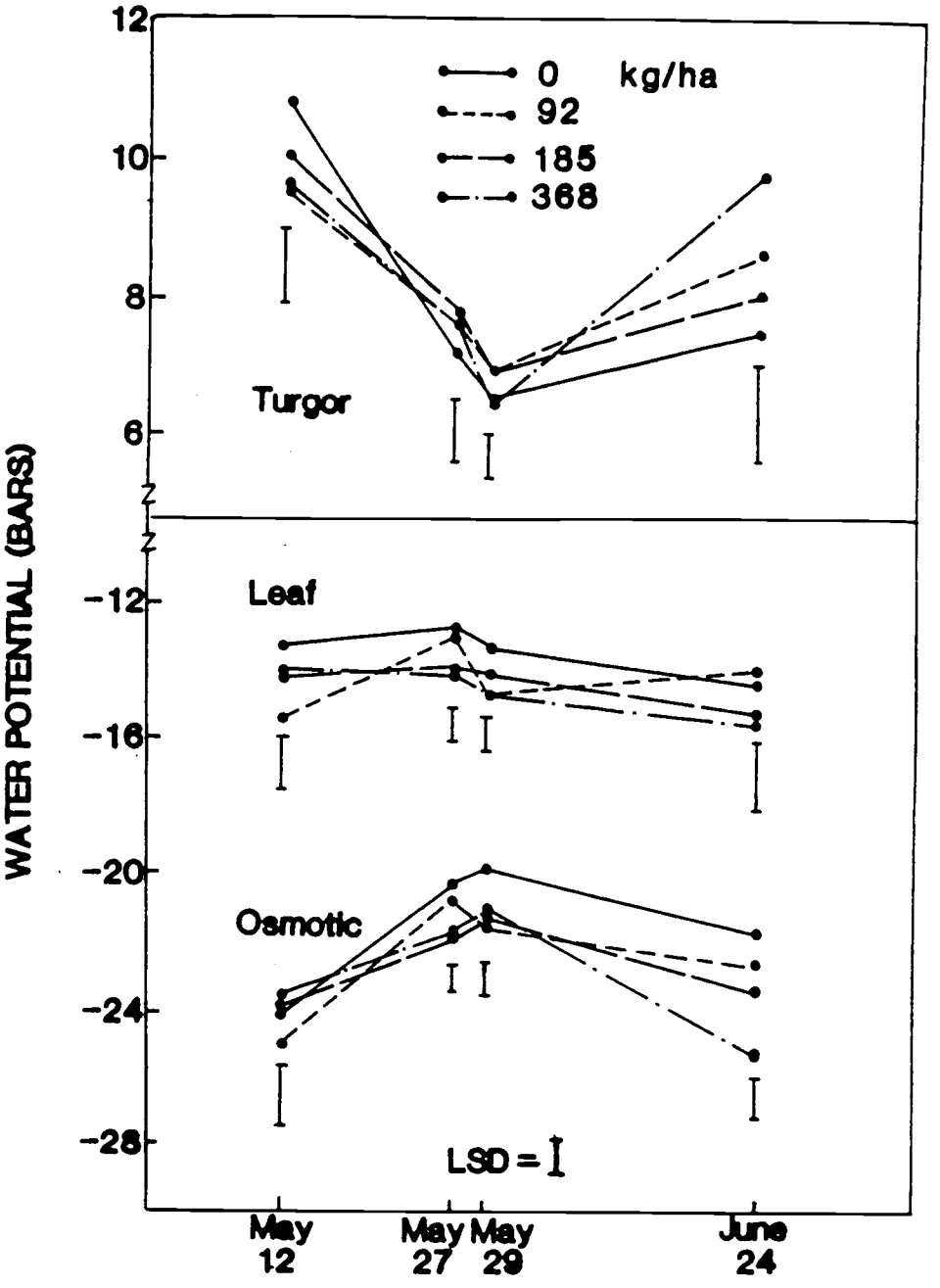

Figure 5. Effects of rates of spring chloride on turgor, leaf water and osmotic potentials measured in second-year wheat on four dates in 1981.

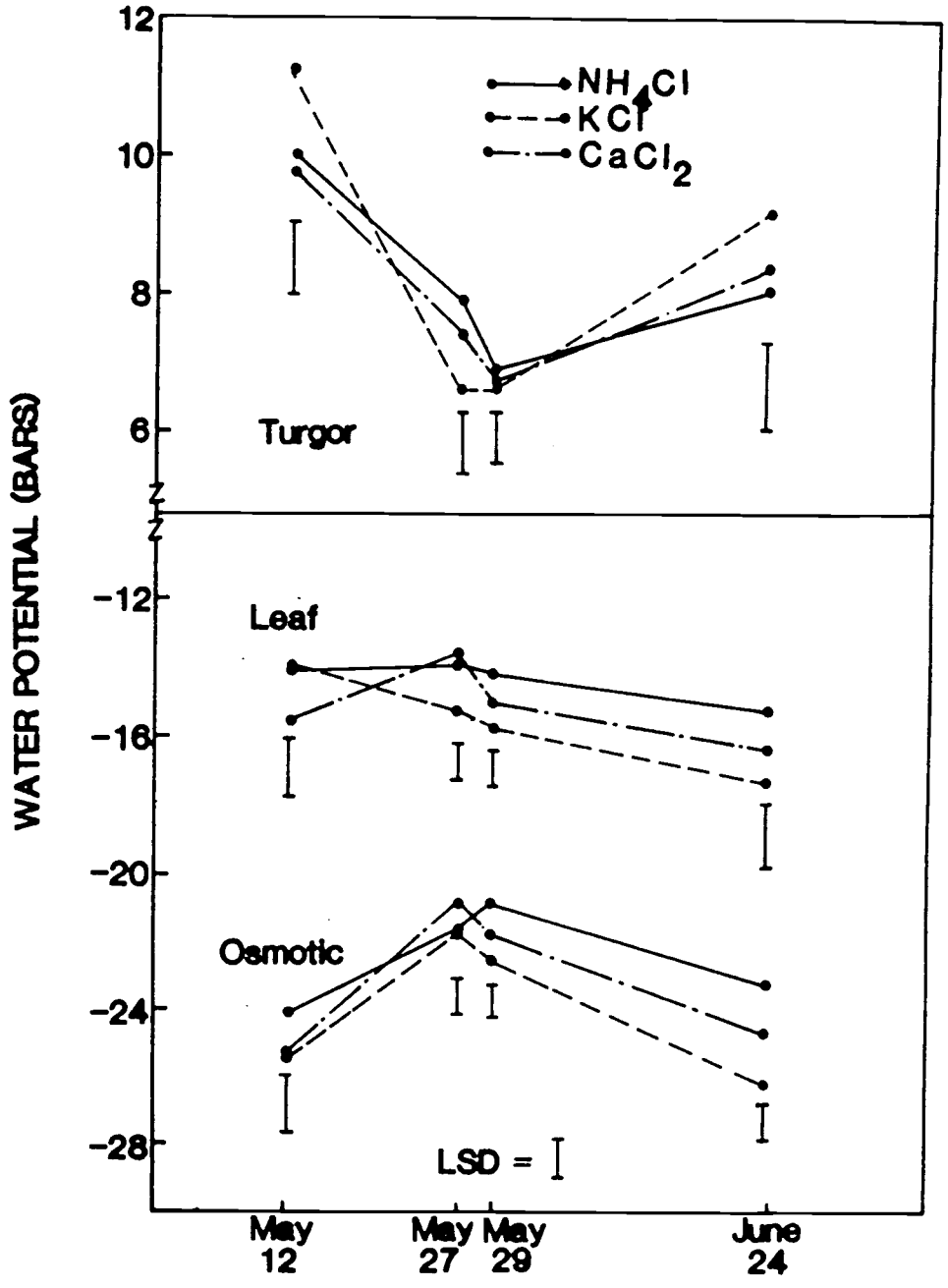

Figure 6. Effects of spring chloride sources on turgor, leaf water and osmotic potentials measured in second-year wheat on four dates in 1981.

Osmotic potential was negatively correlated with leaf chloride concentration in the flag leaves on May 27 (R^2 = 0.69) and May 29 (R^2 = 0.80) (Figure 7). However, there was no clear correlation between the two on May 12 or June 24.

The results of the water potential study from Dr. Jackson's field site are shown in Table 12 and, although the addition of spring chloride did significantly increase turgor potentials by 50%, it was not associated with decreased osmotic potentials. Leaf water potentials were, however, significantly more negative with addition of spring chloride fertilizers.

Diurnal water relations

The diurnal water potential characterization on June 2, 1981, showed significantly higher overall osmotic and leaf water potentials on the NH_4Cl treatment than with the $(NH_4)_2SO_4$ (Appendix Table 15). Overall osmotic water potentials for NH_4Cl and $(NH_4)_2SO_4$ treatments were -22.5 and -24.2, respectively. Overall leaf water potentials were 2.6 bars lower (-11.3 vs. -13.9) with the $(NH_4)_2SO_4$ treatment. There were no significant differences in the overall turgor potentials between the two treatments.

The diurnal water relations for turgor, osmotic and leaf water potentials are illustrated in Figure 8. Of particular interest is that the $(NH_4)_2SO_4$ treatment is associated with the highest turgor potentials in five out of the first seven time blocks (from 6 a.m. to 1:30 p.m.), while the NH_4Cl treatment consistently showed higher turgor potentials for the remaining nine blocks. Osmotic and leaf

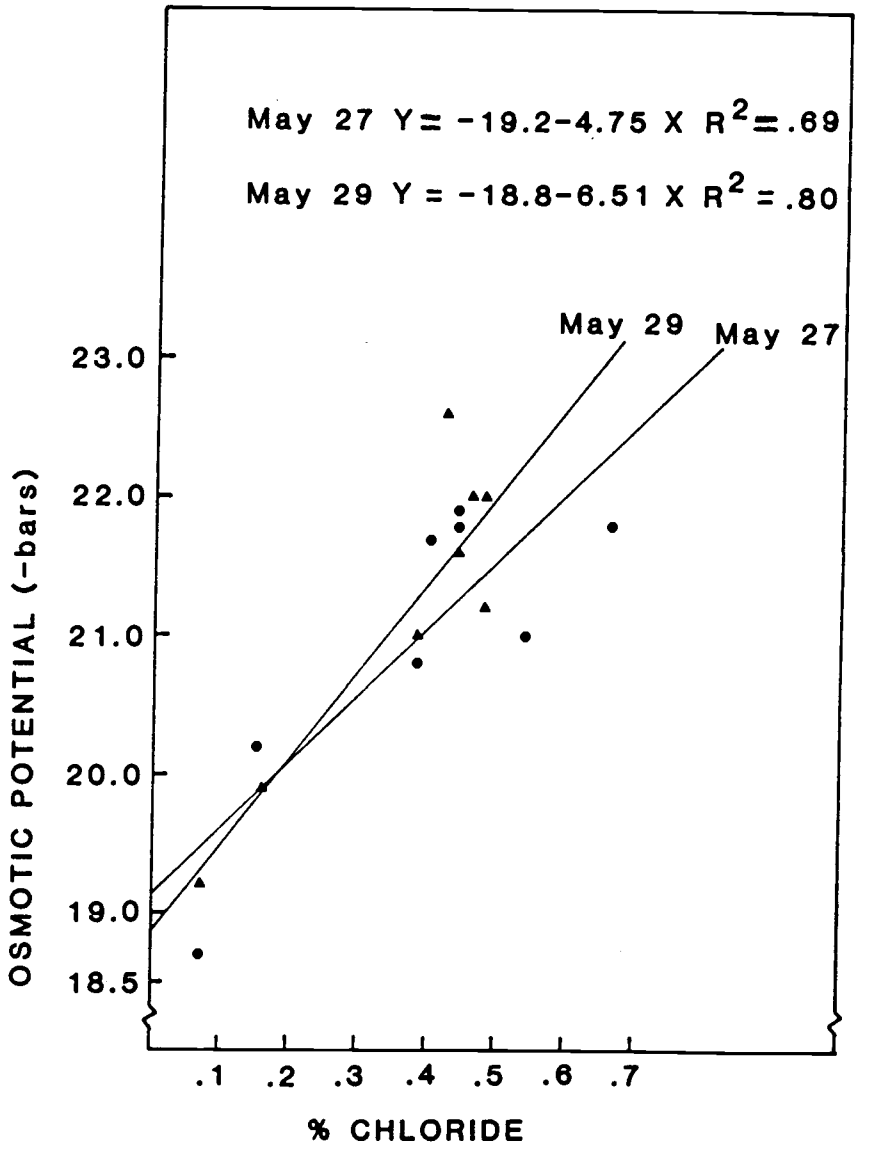

Figure 7. Mean osmotic potentials as influenced by chloride content of flag leaves in second-year wheat on two dates in 1981.

Table 12. Xylem (Ψ_L), uncorrected osmotic (π) and turgor (P) potentials as affected by NH_4Cl and $(NH_4)_2SO_4$ fertilizers. (May 27, 1981)

Trt no.	Fertilizer trt*				
	Fall	Spring	Ψ_L	π	P
			bars		
1	AS,P	AS	-16.7a	-19.0a	+2.3a
2	AC,P	AS	-15.9b	-18.9a	+3.0ab
3	AC,P	AC	-15.1bc	-18.8a	+3.7bc
4	AS,P	AC	-14.9c	-19.3a	+4.4c

Analysis of Variance Table

Source of variation	df	Mean squares		
		Ψ_L	π	P
Total	23			
Treatment	3	4.08	.28	4.77
Block	5	2.99	1.35	1.14
Error	15	.66	.40	.79
P-value		.0061	NS	.0067
LSD 5%		.9998		1.0435

* AC = NH_4Cl, AS = $(NH_4)_2SO_4$; all plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

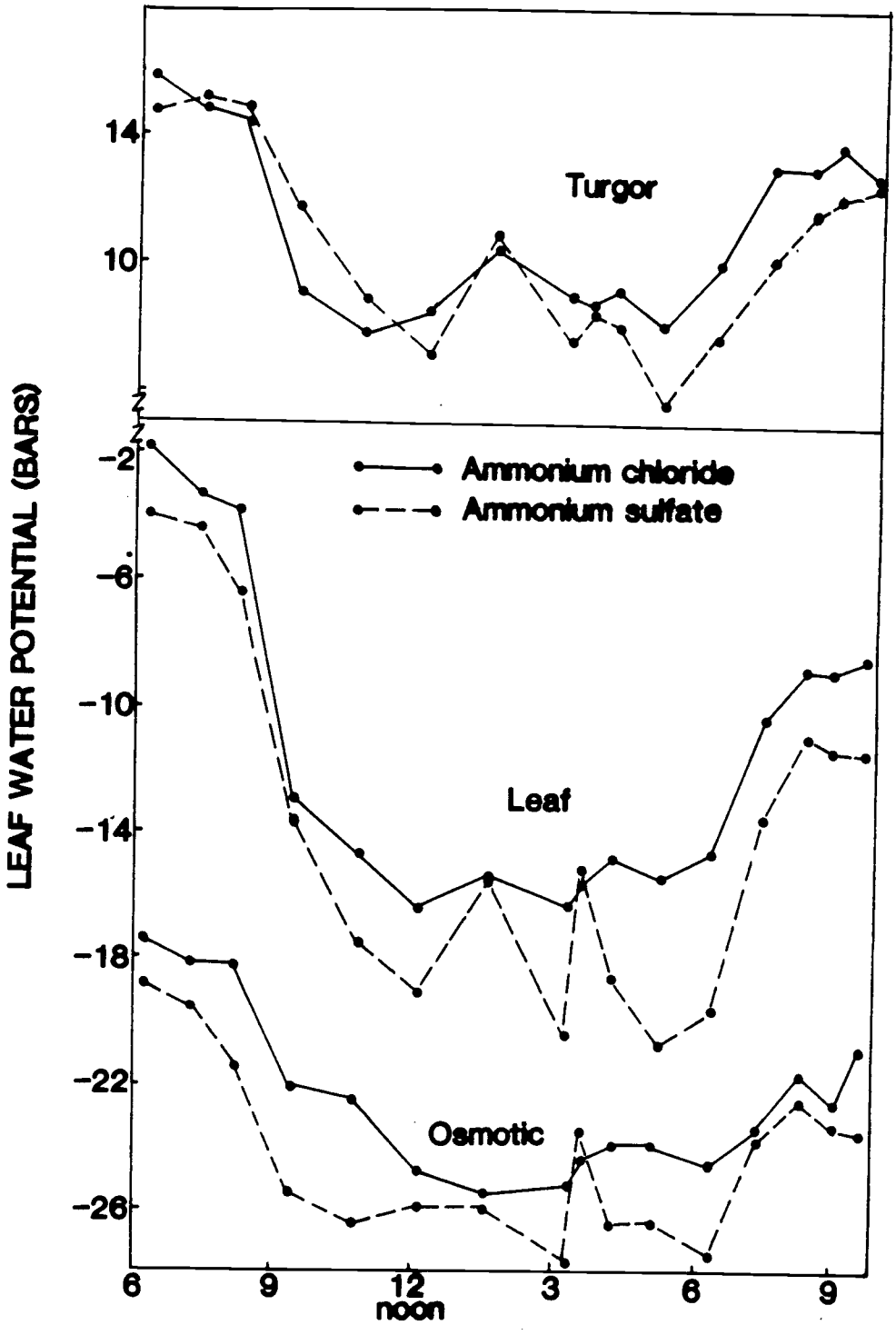

Figure 8. Diurnal variation of leaf water, turgor and osmotic potential components for $(NH_4)_2SO_4$ and NH_4Cl fertilized third-year wheat on June 2, 1981.

water potentials were lower for 15 of the 16 time blocks with $(NH_4)_2SO_4$.

Pressure-volume Curves

The determination of the weight at full turgor (W_{turgor}) is necessary in the calculations of the RWC portion of the PV curve. In 1980, the leaves sampled were not at full turgor; the first leaf water potentials measured were at least -10 bars. Therefore, it was necessary to estimate the weight at full turgor by plotting the moist leaf weight against the leaf water potentials. The y-intercept represents the estimated weight at full turgor, and is illustrated for 2 samples in Figure 9.

To eliminate the need to estimate the weight at full turgor by graphing, culms with the upper 3 leaves and head were artificially hydrated overnight in a dark, cool room in 1981. Guttation had occurred by morning and the first leaf water potential readings were in the -1 to -2 bar range.

The mean bound (apoplastic) water fraction (b) in 1980 was 28% and was the average of two NH_4Cl and two $(NH_4)_2SO_4$ samples (Figure 10). The mean bound water fraction from the 1981 pressure-volume curves was 18%. The bound water fraction ranged in value from 15% and 17% [NH_4Cl and $(NH_4)_2SO_4$, respectively] on May 20, to 19% and 20% [NH_4Cl, $(NH_4)_2SO_4$, respectively] on May 25. Figure 11 illustrates the lineal portion of a PV curve for NH_4Cl and $(NH_4)_2SO_4$ on May 25, 1981.

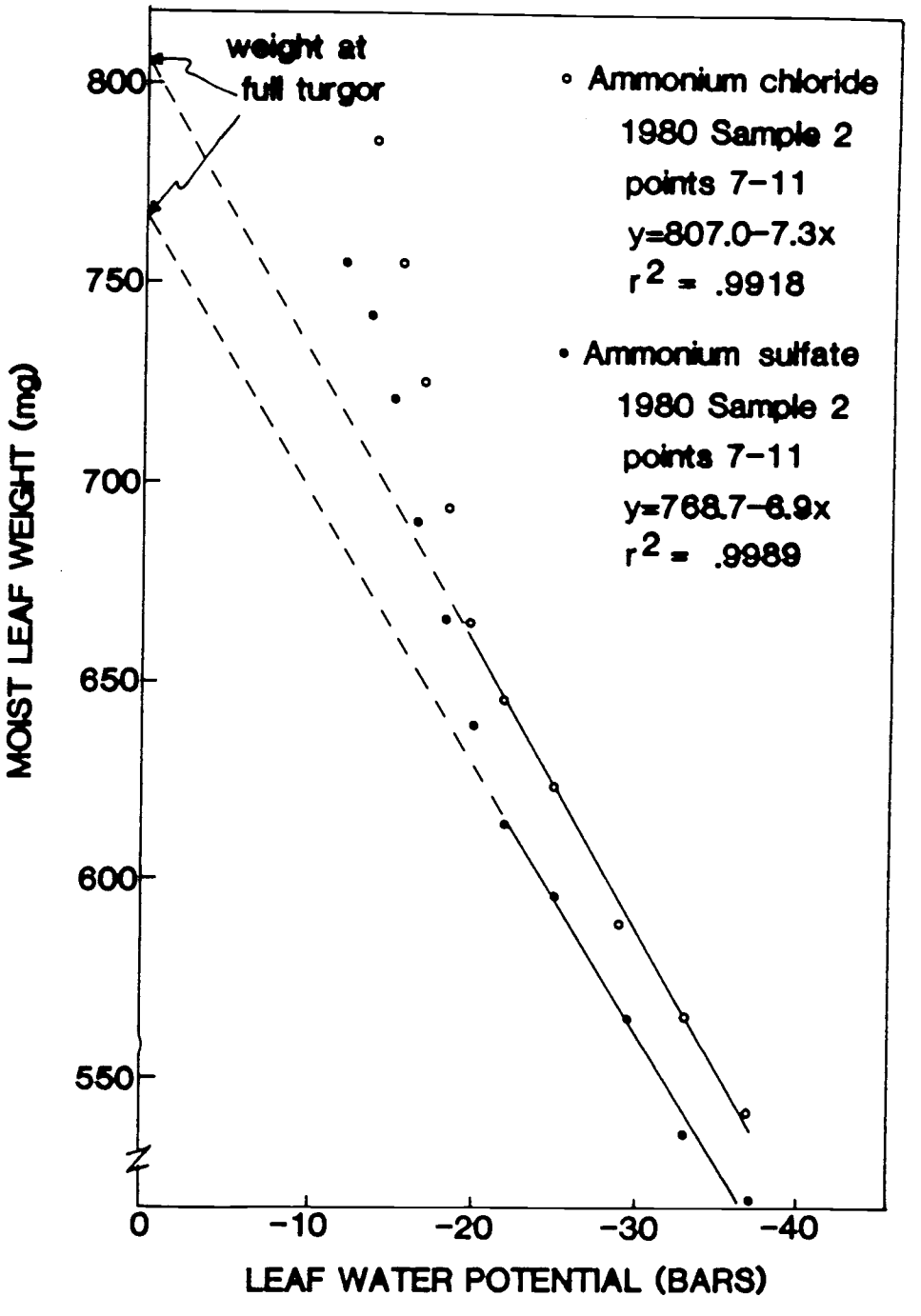

Figure 9. Determination of the weight at full turgor for two samples in 1980.

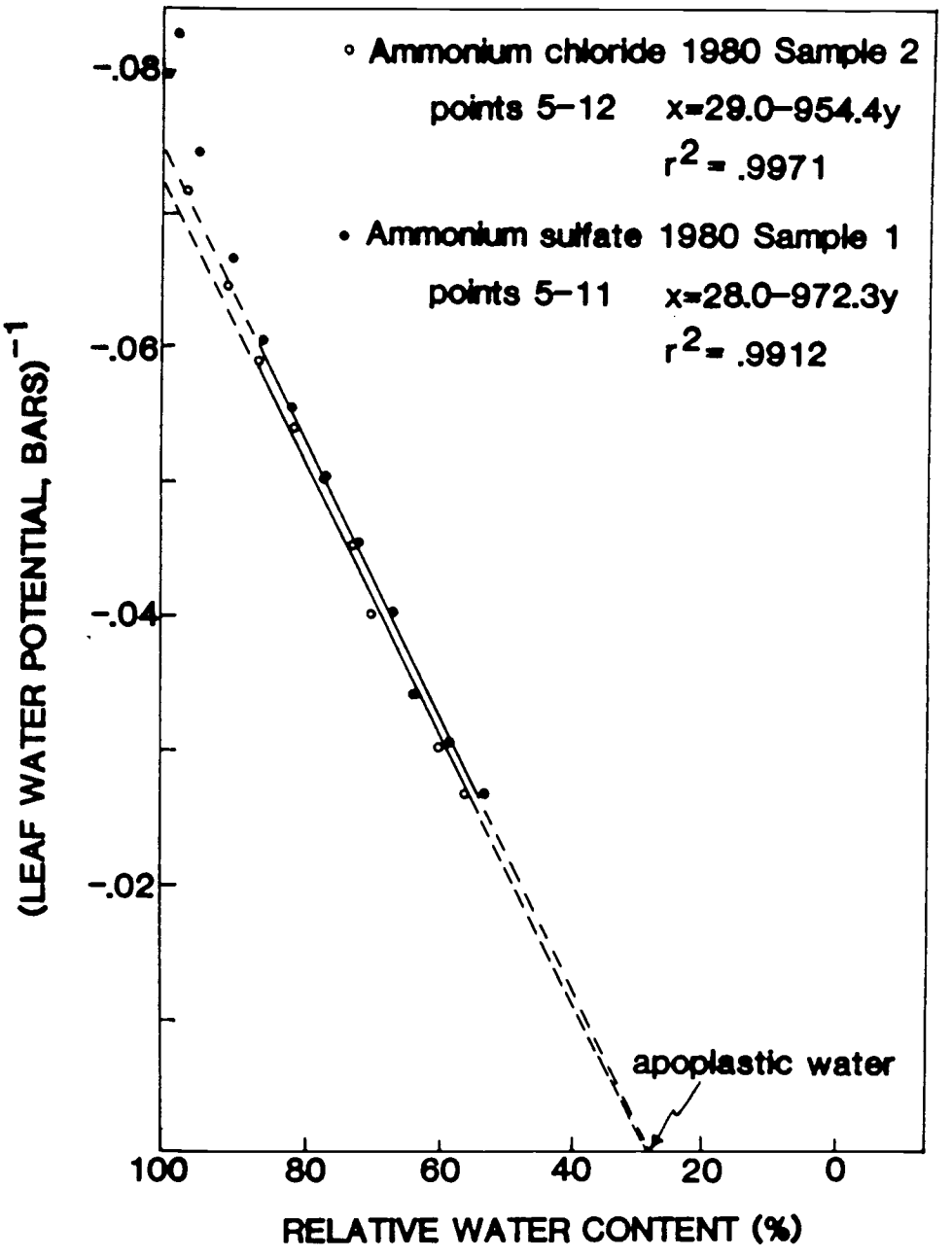

Figure 10. Determination of the apoplastic (bound) water fraction for two samples on June 10, 1980.

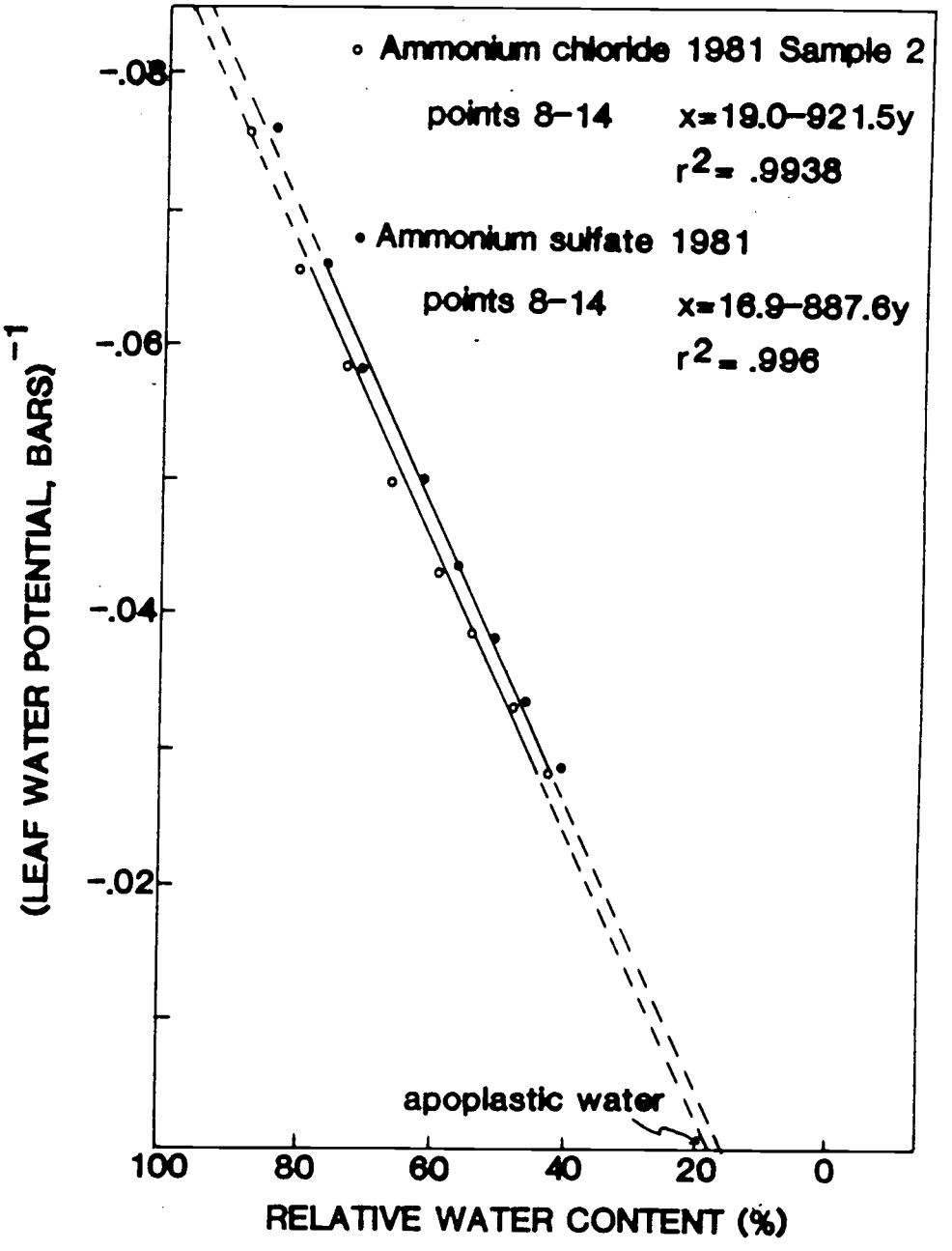

Figure 11. Determination of the apoplastic (bound) water fraction for two samples on May 25, 1981.

Uncorrected Osmotic Analysis.

Analysis of variance for uncorrected osmotic analysis for all 3 mid-winter sampling dates (9 Dec. 80, 17 Jan. 81, 9 Mar. 81) showed no significant differences from fall chloride sources, rates or method of application (Appendix Table 16). The mean uncorrected osmotic potentials for the treatment comparisons are shown on Table 13, as are the mean leaf chloride concentrations across the 3 dates.

Analysis of variance showed that the uncorrected osmotic potentials on April 30, 1981 (Table 14), were not significantly influenced by spring chloride rate at the 5% probability level. The uncorrected osmotic potentials were significantly lower for the NH_4Cl treatment than for either the KCl or $CaCl_2$ treatments. Mean leaf chloride content was significantly increased with increasing rates of spring chloride. There were no significant differences in leaf chloride content with spring chloride sources.

Table 13. Mean osmotic potentials and leaf chloride concentrations as influenced by the rate, source and method of application of fall chloride fertilizers averaged over Dec. 8, 1980 and Jan. 17 and March 9, 1981.

Comparison	Treatment numbers	Osmotic potential†	Chloride
		-- bars --	-- % --
Fall chloride rate (kg/ha)			
0	2, 3	-16.97	.33
56	4, 5	-17.19	.43
LSD .05		NS	.05
0	3	-17.10	.32
28	6	-17.19	.41
56	5	-17.25	.42
LSD .05		NS	.07
Fall chloride source			
NH_4Cl	5, 6	-17.22	.38
KCl	8, 9	-17.18	.42
LSD .05		NS	.05
Fall chloride method			
banded	9	-17.23	.44
broadcast	10	-17.15	.43
LSD .05		NS	.07

† Osmotic potentials not corrected for bound water dilution.

Table 14. Osmotic potentials and leaf chloride concentrations as influenced by rate and source of spring chloride fertilizers. April 30, 1981.

Comparison	Treatment numbers	Osmotic potential†	Chloride
		-- bars --	-- % --
Spring chloride rates (kg/ha)††			
0	3, 5	-16.48	.15
368	12, 15	-15.88	.68
LSD .05		NS	.05
0	5	-16.63	.18
92	14	-15.93	.53
185	13	-17.40	.66
368	12	-15.60	.69
LSD .05		NS	.07
Spring chloride source (185 kg/ha)			
NH_4Cl	13	-17.40	.66
KCl	16	-16.23	.65
$CaCl_2$	17	-16.33	.67
LSD .05		NS	.07

† Osmotic potentials not corrected for bound water dilution.

†† Chloride applied as NH_4Cl.

DISCUSSION AND CONCLUSIONS

Introduction

Most treatment differences in grain yield and take-all severity were not statistically significant at the P = 0.05 probability level. The inability to measure significant differences between the individual treatment comparisons on the 1980-81 field experiment could be attributed to several factors, the first of which is from the variable nature of take-all throughout the field.

Another contributing factor to the large experimental error for the disease logits was the inefficient method of sampling. Root core samples for assessment of TA should be started earlier in the spring, as Christensen and Brett (1985) and Christensen et al. (1986) reported, and should be sampled only up to the time of anthesis. The root cores sampled on July 2 were difficult to obtain because of the hard, dry soil, and were of little use in predicting grain yield.

A third and possibly more influential factor became apparent in the spring of 1981. The field plots began to show large variability within the individual subplots. By late spring there was a definite lack of uniformity in height and vigor of the wheat within the subplots. It became apparent that the 1980-81 field plots had not been directly superimposed over the previous years plots. The 1980-81 field plots overlapped, to various extents, areas that had been alleyways and walkways in earlier field experiments. These particular areas had been kept free of vegetation with Roundup, thus providing areas without a susceptible Ggt host. Therefore, during

the 1980-81 field year, the Ggt inoculum potential was probably much less in these areas. Reduced levels of the pathogen, possibly in combination with some residual nitrogen from the previously fallow-like conditions helped produce extra-vigorous, taller wheat in those areas of the subplots that overlapped previous years borders.

These 'strips' or rows of taller wheat varied from block to block, and varied in width from subplot to subplot. These 'strips' cut across the rows in each block, but did not cut across the blocks. In an effort to minimize the large error term associated with this variability in vigor, the treatments were re-assigned to blocks based on vigor, from block 1 (the most vigorous subplots of the 20 treatments) to block 4 (least vigorous). The error term was not significantly reduced, so the original field plot design was retained and used throughout the 80-81 experiment. To avoid future problems such as this it would seem that the practice of maintaining walkways and borders with the use of Roundup should be eliminated, as well as exercising greater care in superimposing the current year's field plots over the previous year's plot.

Yield

Even though the above factors probably affected and complicated the yield results, there was a significant increase in the yield with the addition of spring chloride, up to 92 kg Cl/ha. This is consistent with the results of Christensen et al. (1981) which showed that grain yield did not increase significantly above the 101 kg Cl/ha rate, and with Christensen et al. (1982) who obtained near

maximal yields with 92 kg spring chloride ha^{-1}. Comparisons of yields from treatments without spring chloride to those treatments that received spring chloride did show significantly higher yields with the addition of spring chloride (5468 kg/ha, 6476 kg/ha, respectively). There were no differences in grain yield from the fall or spring chloride sources, or from the varied rates of fall chloride or method of application which is also consistent with the results of Christensen et al. (1982) and Christensen and Brett (1985). No significant differences in the grain yields were obtained with the addition of fall P, or from varying the rates of fall and spring nitrogen.

Disease

There were no consistent differences between treatments that were used to evaluate the disease severity, except that the 0 N kg/ha check plots had significantly higher disease. Problems with the field plot overlays (overlapping the walkways and borders) complicated the assessment by making it more difficult to find significant differences between treatments. Furthermore, take-all root sampling and assessment methods used in this study proved to be inadequate to separate treatment effects. Although there were differences in the logit values between treatments, as shown by the overall F-test values for the April, June and July sampling dates (statistically significant at the 0.05, 0.00 and 0.02 probability levels, respectively), there were no consistent significant differences between treatment comparisons. The within treatment

(subsampling) variations were very high and masked most between treatment (experimental) variation. Only in the April logit data was the experimental (between treatment comparisons) significantly higher (P = .001 level) than the subsampling error (0.353 vs. 0.092, respectively). The subsampling error was so large in the June and July logit data that there were no significant differences between experimental and subsampling errors (0.685 vs. 0.578 and 1.15 vs. 0.89, respectively). The present method of sampling did not allow for the large error associated with the extremeley variable nature of the disease.

By the first root sampling on April 17, 100% of the plants were infected with TA to some degree (100% incidence), with the disease severity ranging from 10% (trt 16, KCl) to 52% (trt 1, checkplot). The last root sampling date, July 2, was too late in the season to get good root cores. The soil was very dry and hard, and many of the crown roots broke off and were lost during sampling. These results indicate that to improve TA assessment, disease assessments on the crown roots should begin the day that the spring fertilizers are applied in early to mid-March. Even so, Christensen and Brett (1985) measured a 91% incidence rate on March 15, 1983, in second year wheat predisposed to TA. However, on March 6, 1984, on the same site (with third year wheat), the incidence rate was only 3%, which increased to 60% by mid-April.

In addition to earlier sampling, Christensen et al. (1986) took crown root core samples approximately once a month, from March until anthesis in late May or early June. Five soil core samples were

taken in an "X" pattern within the rows in each subplot. Four plants per core were selected at random for disease assessment. The number of infected crown roots per tiller was used as one estimate of the disease severity, and, each plant was assigned a take-all disease score from 1 to 10 that corresponded to nil, 0.1, 1.0, 5.0, 10, 25, 50, 75, 90 and 99% of the root surface area attacked by take-all, respectively.

Relationship Between Grain Yield and Disease Severity

Grain yield was negatively correlated to disease severity with 58% of the yield variability explained with April logit values. The fresh weights and AUDPC were also negatively correlated to yield, with R-squared values of 0.53 and 0.47, respectively. These results are similar to those presented by Christensen et al. (1986), who found significant negative correlation between yield and disease severity indices.

Using improved sampling techniques, Christensen et al. (1986) noted that the number of infected crown roots per tiller at anthesis accounted for 66% of the variability in grain yield, while the TA score at anthesis accounted for only 62%. Yet, they were not able to measure any significant differences in the disease severity between NH_4Cl and $(NH_4)_2SO_4$ treatments.

This is in contrast to an earlier study by Christensen and Brett (1985), who measured a 34% increase in grain yield in 1983 with spring chloride fertilization on unlimed soils (pH 5.5), and on April 25 and May 31 of the same year, they measured significantly less

disease with NH_4Cl over $(NH_4)_2SO_4$ in their highest disease severity class rating (76 to 100% of the roots having one or more take-all lesions). Christensen and Brett (1985) showed that the application of NH_4Cl slowed the disappearance of NH_4 and appearance of nitrate in unlimed soils as well as maintained the highest NH_4:NO_3 ratios.

Christensen and Brett (1985) suggested that the chloride ion may reduce take-all severity (and increase grain yield) by reducing nitrification and maintaining a favorable NH_4:NO_3-N ratio for disease suppression on moderately acid soils. These chloride effects on NH_4:NO_3-N ratio and disease suppression did not occur on recently limed soils (pH 6.6).

Plant Nutrients

Application of fall chloride produced higher leaf chloride contents in March (20 weeks after sowing), but not in January (13 weeks after sowing). This is probably due to the leaching of the Cl ion down the soil profile with the late fall and winter rains. Leaf chloride increased significantly with each increase in fall chloride application, with no differences from varying sources of methods of application.

Leaf chloride content also increased significantly from addition of spring chloride as shown in the April and May-June data. It appears that application of 92 to 185 kg Cl/ha in the spring is all that is required to maximize leaf chloride contents.

Application of spring chloride at rates above 92 kg Cl/ha was associated with significantly higher total N concentrations in the

leaf tissue during May-June. One possible explanation may be the fact that chloride has been shown to inhibit nitrification (Christensen and Brett, 1985; Powelson et al., 1983; Roseberg et al., 1986). Inhibition of nitrification may reduce leaching losses of N and result in more total N in the soil where chloride is applied.

Noggle (1966) varied the inorganic anion content of plant tissue by applying either SO_4 or Cl to the soil. His findings indicated that all of the chloride-treated plants had higher inorganic anion (A) concentration than those treated with SO_4, and that 10 of 16 species had lower organic anion (C-A) concentrations. Although there was a significantly higher anion concentration on March 5, with fall chloride (trt. 4 and 5) vs. sulfate (trt. 2 and 3), there was a significantly lower anion concentration with the addition of spring chloride (as measured on April 30 and the May-June mean potential file, Appendix Tables 19 and 20).

There was no significant difference in organic anion (C-A) (Appendix Tables 17, 18) concentration in the January and March data. However, the April (Appendix Table 19) and the May-June mean data (Appendix Table 20) suggests a trend for the organic anion concentration to increase with the addition of chloride with significant increases between the 0 (trt 3 and 5) and the 368 kg spring Cl/ha (trts 15 and 12) rates.

De Wit et al. (1963) suggested that plants appear to maintain a fairly constant organic anion (C-A) value under their experimental conditions. This was not the case in the present study. Organic anion (C-A) concentrations in January ranged from 656 to 848 meq/kg

and decreased with time so that by April they ranged in value from 143 to 321 meq/kg (Appendix Tables 16-19).

There were no significant differences in the (C-A) concentration between treatments from January through March. The April and the May-June data suggest that addition of the spring chloride from 0 kg/ha to 368 kg/ha caused an increase in the organic anion concentration, with significant differences between the 0 and 368 kg Cl/ha rates.

Water Potential Components

Addition of spring chloride fertilizers increased turgor potentials and decreased osmotic and leaf water potentials in second year wheat in this study (May 12, 27, 29 and June 24) (Figure 12). However, there was no decrease in osmotic potentials in third year wheat from an experiment on May 27 on an adjacent field site, even though there was significantly higher turgor potentials with the addition of spring chloride. Overall, turgor potentials were increased approximately one bar with the addition of spring chloride at the 368 kg Cl/ha rate.

Leaf water potentials were also decreased with the addition of spring chloride fertilizers on the second-year wheat, but the data from the third-year wheat measured on May 27 showed significantly lower leaf water potentials with the $(NH_4)_2SO_4$ treatments (0 kg spring Cl/ha). One possible reason for this difference in leaf water potentials between the second- and third-year wheat might be that the third-year wheat was more stressed, having more severely pruned roots

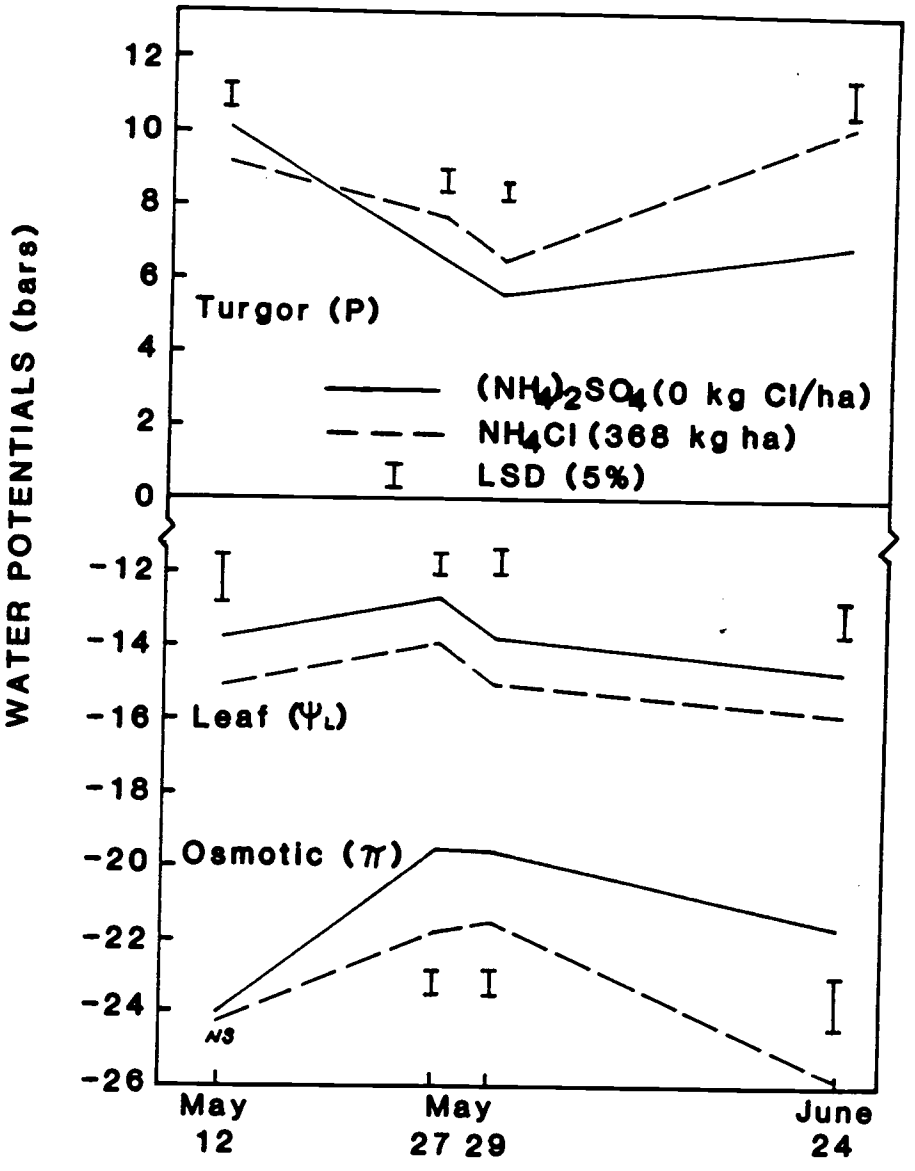

Figure 12. Spring chloride effects on turgor, leaf water and osmotic potential in second year wheat infected with TA on four dates in 1981.

due to greater severity of TA. This would also help explain the lower turgor potentials in the $(NH_4)_2SO_4$ treatments.

Christensen et al. (1981) also measured lower osmotic and leaf water potentials in 'Stephens' winter wheat in May 1980 at the Hyslop farm site when spring NH_4Cl was applied at 355 kg Cl/ha. The spring chloride lowered the osmotic potential 2 bars below the spring $(NH_4)_2SO_4$ treatment. At another location there were no significant differences in leaf water potentials between NH_4Cl and $(NH_4)_2SO_4$ treated plants, and the osmotic potentials were only significantly lower with NH_4Cl on two of the four dates. The lower osmotic potential was associated with slightly higher turgor potentials on those two dates as well. They noted that rainstorms and cloudy weather at the latter location may have contributed to the lack of significant treatment differences on the other two dates. They observed that there needed to be about one week of dry, sunny weather prior to measuring water potential components in order to minimize the large within treatment differences obtained during periods of cloudy weather. The 1980 to 1981 season in the Willamette Valley from planting through grain filling was wet (Powelson et al., 1983), and limited the number of times field plant water measurements could be made. Except for the May 29 water potential measurements when it was mostly (90%) overcast with a thin covering of light clouds, pressure chamber measurements were done only on completely sunny days.

The KCl treatment consistently produced the most negative osmotic potentials and except for the May 12 date, produced the most

negative leaf water potentials. This decreased osmotic potential with KCl over that of NH_4Cl probably reflects the dual effects of both the K and the Cl ions. KCl was associated with higher turgor potentials only on two of the four dates, and overall, there were no differences in turgor potentials associated with difference sources of spring chloride.

Osmotic potential was negatively correlated with leaf chloride concentration on two of the four dates (R-squared values of .69 and .80). Christensen et al. (1981) also found good correlation (R^2 = .86) between osmotic potentials measured on May 7, 1980, and chloride concentration in leaves sampled on May 20, 1980. They found that lower osmotic potentials were linearly related to tissue Cl contents, which ranged from 0.16 to 1.04% Cl. More data is needed before a cause and effect relationship between osmotic potential and tissue chloride contents can be confirmed. The osmotic response to spring chloride fertilizers is not always consistent, although there does seem to be a trend for decreased osmotic potentials with application of spring chloride fertilizers.

The RWC (relative water content) correction factor did not change greatly, and there was no difference between the chloride and sulfate treatments. The results of this study show that there is no need to determine the RWC values for each treatment on each date, and that the osmotic correction factor can be calculated by using a RWC value of 0.9 (or 90%) for all treatments is sufficient (Christensen et al., 1981; Wenkert, 1980).

Diurnal

Diurnal variations of the osmotic, leaf water and turgor potentials on third year wheat showed the same range of fluctuations for both the NH_4Cl and $(NH_4)_2SO_4$ treatments. Leaf water, osmotic and turgor potentials varied 15-17 bars, 8-9 bars and 8 bars, respectively. As expected, the osmotic, leaf water and turgor potentials were highest in the predawn hours, and lowest in the mid-afternoon hours.

Lower (more negative) values for the overall osmotic and leaf water potentials for the $(NH_4)_2SO_4$ treatment was not expected; however, this experiment was done on 3rd year wheat experiencing a severe attack of TA. Severely pruned roots on the $(NH_4)_2SO_4$ treatment could have caused the plants to be more stressed (leaf water potentials were approximately 2 to 3 bars lower for $(NH_4)_2SO_4$ in both the predawn and late evening hours). Turgor potentials were higher for the $(NH_4)_2SO_4$ plants in the morning hours, but were consistently higher for the NH_4Cl treated plants after 1 p.m.

Uncorrected Osmotic Analysis

There were no significant differences between uncorrected winter osmotic data from December 1980 to March 1981.

The April data showed that the only significant difference between treatments was that osmotic potentials were significantly lowered for the NH_4Cl source of chloride.

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APPENDIX

Table A1. Moisture release curve data for winter wheat (var. Stephens) fertilized with NH_4Cl in the fall and spring (Feekes 10.5). June 10, 1980.†

Sample 1					Sample 2				
Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)	Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)
---bars---	---mg---		bars	--%--	---bars---	---mg---		bars	--%--
-11.3	793.0	2.1976	-.0885	99.85	-10.8	817.5	2.5966	-.0926	
-12.5	784.4	2.1629	-.0800	98.28	-12.5	801.5	2.5262	-.0800	99.04
-14.0	768.3	2.0978	-.0714	95.32	-14.0	786.3	2.4593	-.0714	96.42
-15.5	748.4	2.0177	-.0645	91.68	-15.5	756.0	2.3260	-.0645	91.19
-17.0	723.0	1.9153	-.0588	87.03	-17.0	725.1	2.1901	-.0588	85.86
-18.5	696.4	1.8081	-.0541	82.16	-18.5	693.4	2.0506	-.0541	80.39
-20.0	671.3	1.7067	-.0500	77.55	-20.0	665.4	1.9274	-.0500	75.56
-24.0	636.6	1.5669	-.0417	71.20	-22.0	644.0	1.8333	-.0455	71.87
-28.0	606.6	1.4460	-.0357	65.70	-25.0	623.6	1.7435	-.0400	68.35
-32.0	576.0	1.3226	-.0313	60.10	-29.0	587.4	1.5842	-.0345	62.11
-36.0	558.2	1.2506	-.0278	56.82	-33.0	564.6	1.4839	-.0303	58.18
					-37.0	540.0	1.3757	-.0270	53.93

† Whole plants with roots and soil were brought in from the field in the early morning to a dark, cold walk-in cooler. The individual flag leaf was cut from the plant and immediately placed in the pressure chamber for the first reading.

†† RWC = relative water content.

§ Sample 1: Dried leaf weight (Wd) = 248 mg; $\theta_t = (W_{turgor}-Wd)/Wd$ = (793.8 mg - 248 mg)/248 mg = 2.2008; Sample 2: Dried leaf weight (Wd) = 227.3 mg; $\theta_t = (W_{turgor}-Wd)/Wd$ = (807.1 - 227.3)/227.3 = 2.5507. [W_{turgor} = weight at full turgor estimated by plotting Wm(mg) vs. Ψ_L(-bars) and extrapolating the best fit line. (See Figure 9).]

Table A2. Moisture release curve data for winter wheat (var. Stephens) fertilized with $(NH_4)_2SO_4$ in the fall and spring (Feekes 10.5). June 10, 1980†

Sample 1					Sample 2				
Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)	Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)
---bars---	---mg---		bars	--%--	---bars---	---mg---		bars	--%--
-10.2	824.1	2.1513	-.0980	94.92	-12.1	756	2.3304	-.0826	97.65
-12.0	817.5	2.1238	-.0833	93.71	-13.5	743.1	2.2736	-.0741	95.27
-13.5	795.0	2.0378	-.0741	89.91	-15.0	720.5	2.1740	-.0667	91.09
-15.0	783.1	1.9922	-.0667	87.90	-16.5	690.0	2.0396	-.0606	85.46
-16.5	761.2	1.9087	-.0606	84.22	-18.1	667.4	1.9401	-.0552	81.29
-18.0	734.4	1.8063	-.0556	79.70	-20.0	640.0	1.8194	-.0500	76.24
-19.5	711.3	1.7180	-.0513	75.80	-22.0	616.2	1.7145	-.0455	71.84
-21.5	681.4	1.6036	-.0456	70.75	-25.0	596.0	1.6256	-.0400	68.11
-24.5	654.5	1.5010	-.0408	66.23	-29.0	567.5	1.5000	-.0345	62.85
-28.5	623.0	1.3806	-.0351	60.91	-33.0	537.6	1.3681	-.0303	57.33
-32.5	591.5	1.2602	-.0308	55.60	-37.0	513.6	1.2626	-.0270	52.90
-37.0	571.6	1.1842	-.0270	52.52					

† Whole plants with roots and soil were brought in from the field in the early morning to a dark, cold walk-in cooler. The individual flag leaf was cut from the plant and immediately placed in the pressure chamber for the first reading.

†† RWC = relative water content.

§ Sample 1: Dried leaf weight (Wd) = 261.7 mg; $\theta_t = (W_{turgor}-Wd)/Wd$ = (854.8 mg - 261.7 mg)/261.7 mg = 2.2663; Sample 2: Dried leaf weight (Wd) = 227.0 mg; $\theta_t = (W_{turgor}-Wd)/Wd$ = (768.7 - 227.0)/227.0 = 2.3863. [W_{turgor} = weight at full turgor estimated by plotting Wm(mg) vs. Ψ_L(-bars) and extrapolating the best fit line. (See Figure 9).]

Table A3. Moisture release curve data for winter wheat (var. Stephens) fertilized with NH_4Cl and P in the fall and NH_4Cl in the spring. May 20 and May 25, 1981.†

May 20					May 25				
Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)	Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t§)
---bars---	---mg---		bars	--%--	---bars---	---mg---		bars	--%--
-1.2	760.5	2.4319	-0.8333	98.92	-1.0	853.6	2.4199	-1.000	99.02
-2.0	757.7	2.4192	-.05000	98.40	-3.0	845.0	2.3854	-.3333	97.61
-3.0	754.4	2.4043	-0.333	97.80	-5.0	840.1	2.3658	-.2000	96.80
-5.0	748.4	2.3773	-0.2000	96.70	-7.0	833.55	2.3395	-.1429	95.73
-7.0	743.5	2.3551	-0.1429	95.79	-9.0	826.8	2.3125	-.1111	94.62
-9.0	737.3	2.3272	-0.1111	94.66	-11.0	819.4	2.2829	-.0909	93.41
-11.0	728.5	2.2875	-0.0909	93.04	-13.0	789.7	2.1639	-.0769	88.54
-13.0	689.2	2.1101	-0.0769	85.83	-15.0	741.6	1.9712	-.0667	80.66
-15.0	650.1	1.9337	-0.0667	78.65	-17.0	703.0	1.8165	-.0588	74.33
-17.0	617.5	1.7863	-0.0588	72.66	-20.0	653.1	1.6166	-.0500	66.15
-20.0	574.0	1.5903	-0.0500	64.68	-23.0	613.25	1.4569	-.0435	59.61
-23.0	539.7	1.4355	-0.0435	58.39	-26.0	584.0	1.3397	-.0385	54.82
-26.0	507.6	1.2904	-0.0385	52.49	-30.0	541.7	1.1703	-.0333	47.89
-30.0	474.3	1.1403	-0.0333	46.38	-35.0	507.7	1.0341	-.0286	42.31
-35.0	430.0	0.9404	-0.0286	38.25					

† Leaves (culms with upper 3 leaves and head) cut and placed immediately in double deionized water and left in a dark, cold walk-in cooler overnight.

†† RWC = relative water content.

†§ May 20, 1981: Dried leaf weight (Wd) = 221.6 mg; weight at full turgor (W_{turgor}) estimated at 766.4 mg; θ_t = (W_{turgor} - Wd)/Wd = 2.4585. May 25, 1981: Dried leaf weight (Wd) = 249.6 mg; weight at full turgor (W_{turgor}) estimated at 859.6 mg; θ_t = (W_{turgor}-Wd)/Wd = 2.4439.

Table A4. Moisture release curve data for winter wheat (var. Stephens) fertilized with $(NH_4)_2SO_4$ + P in the fall and $(NH_4)_2SO_4$ in the spring. May 20 and May 25, 1981.†

May 20					May 25				
Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t §)	Total leaf water potential (Ψ_L)	Moist leaf weight (Wm)	$\frac{(Wm-Wd)}{(Wd)}$	$1/\Psi_L$	RWC†† (θ/θ_t §)
---bars---	---mg---		bars	--%--	---bars---	---mg---		bars	--%--
-2.2	1050.5	2.7625	-.4545	98.90	-1.0	821.4	2.3851	-1.000	99.09
-3.0	1050.5	2.7625	-.4545	98.90	-3.0	815.0	2.3587	-.3333	97.99
-5.0	1035.3	2.7081	-.2000	96.95	-5.0	810.2	2.3390	-.2000	97.18
-7.0	1028.2	2.6827	-.1429	96.04	-7.0	805.6	2.3200	-.1429	96.39
-9.0	1018.7	2.6486	-.1111	94.82	-9.0	801.8	2.3043	-.1111	95.73
-11.0	999.4	2.5795	-.0909	92.34	-11.0	793.0	2.2681	-.0909	94.23
-13.0	935.2	2.3496	-.0769	84.11	-13.0	785.7	2.2380	-.0759	92.98
-15.0	874.6	2.1325	-.0667	76.34	-15.0	766.7	2.1597	-.0667	89.73
-17.0	826.4	1.9599	-.0588	70.16	-17.0	725.6	1.9903	-.0588	82.69
-20.0	761.0	1.7256	-.0500	61.78	-20.0	674.7	1.7805	-.0500	73.97
-23.0	719.0	1.5752	-.0435	56.39	-23.0	630.0	1.5963	-.0435	66.32
-26.0	676.2	1.4219	-.0385	50.90	-26.0	589.5	1.4294	-.0385	59.39
-30.0	632.5	1.2654	-.0333	45.30	-30.0	536.8	1.2122	-.0333	50.36
-35.0	595.4	1.1325	-.0286	40.54	-35.0	499.1	1.0569	-.0286	43.91

† Leaves (culms with upper 3 leaves and head) cut and placed immediately in double deionized water and left in a dark, cold walk-in cooler overnight.

†† RWC = relative water content.

§ May 20, 1981: Dried leaf weight (Wd) = 279.2 mg; weight at full turgor (W_{turgor}) estimated at 1059.1 mg; θ_t = (W_{turgor} - Wd)/Wd = 2.7933. May 25, 1981: Dried leaf weight (Wd) = 242.65 mg; weight at full turgor (W_{turgor}) estimated at 826.7 mg; θ_t = (W_{turgor}-Wd)/Wd = 2.4070.

Table A5. Grain yield, test weight, 1000 kernel weight and fresh weight of 'Stephens' winter wheat as influenced by source, timing, and rate of N, P, K and Cl fertilizers.

No.	Nutrient ratest							Grain yield			Test weight			1000 kernel wt			Fresh weight
	Fall				Spring			East	West	Ave.	East	West	Ave.	East	West	Ave.	
	N	P	K	Cl	N	K	Cl										
	kg/ha							kg/ha			lb/bu			mg			g/2 m
1	-	-	-	-	-	-	-	1131	1741	1436	67	58	67	38.6	41.1	39.9	562
2	22	-	-	-	146	-	-	5469	6170	5819	68	67	67	43.9	44.5	44.2	1726
3	22	22	-	-	146	-	-	4721	5789	5254	69	69	69	43.7	45.2	44.4	1220
4	22	-	-	56	146	-	-	5429	6254	5841	70	68	69	44.1	45.3	44.7	1646
5	22	22		56	146	-	-	4927	6436	5681	69	69	70	45.0	48.1	46.6	1243
6	22	22	-	28	146	-	-	5943	6246	6095	69	70	69	44.6	44.8	44.7	1464
7	34	22	-	84	134	-	-	5108	6107	5608	69	70	69	43.9	47.0	45.5	1203
8	22	22	30	28	146	-	-	5224	6177	5700	68	70	69	43.5	45.2	44.3	1340
9	22	22	62	56	146	-	-	5243	6229	5736	69	70	70	45.8	47.0	46.4	1300
10	22	22	62	56	146	-	-	6160	6699	6430	69	69	69	44.9	44.5	44.7	1623
11	22	22	123	112	146	-	-	6058	6543	6301	70	70	70	45.1	46.2	45.6	1424
12	22	22	-	56	146	-	368	6170	6810	6490	72	72	72	47.4	47.0	47.2	1742
13	22	22	-	56	146	-	185	5551	5991	5771	70	70	70	43.6	46.8	45.2	1515
14	22	22	-	56	146	-	92	6270	6996	6633	71	71	71	47.0	47.5	47.3	1719
15	22	22	-	-	146	-	368	5685	7241	6463	72	72	72	48.2	49.4	48.8	1243

Continued

Table A5. Grain yield, test weight, 1000 kernel weight and fresh weight of 'Stephens' winter wheat as influenced by source, timing, and rate of N, P, K and Cl fertilizers. (Continued)

No.	Nutrient rates†							Grain yield			Test weight			1000 kernel wt			Fresh weight
	Fall				Spring			East	West	Ave.	East	West	Ave.	East	West	Ave.	
	N	P	K	Cl	N	K	Cl										
	kg/ha							kg/ha			lb/bu			mg			g/2 m
16	22	22	-	56	146	-	185	6083	6799	6441	69	71	70	43.9	47.7	45.8	1788
17	22	22	-	56	146	-	185	6213	7375	6794	71	71	71	47.0	48.1	47.5	1436
18	22	45	-	56	146	-	368	6895	7100	6997	71	72	71	46.6	47.8	47.2	1600
19	22	22	-	56	146	-	368	5448	6414	5931	71	72	71	46.5	48.4	47.4	1680
20	22	22	-	56	146	-	368	6630	7450	7040	71	72	71	46.5	47.9	47.2	1679
SEM (57df) (n = 4)								696.4	653.3	572.1	1.12	1.06	0.94	1.69	1.76	1.56	350.13

† Fall fertilizer banded with seed at planting on October 15, 1980. Spring fertilizer topdressed on March 16, 1981.

Table A6. Nutrient concentrations in winter wheat leaves sampled on January 13, 1981.

Trt No.†	Chloride	Cations						Anions			Total N
		Ca	Mg	K	Na	Cu	Zn	P	S	Cl	
	kg/ha	%	%	%	%	ppm	ppm	%	%	%	%
1	0	.48	.16	4.17	.007			.50	.39	.46	5.38
2	0	.50	.15	3.95	.006			.49	.41	.42	5.56
3	0	.50	.15	4.35	.006			.52	.39	.36	5.37
4	56	.52	.15	3.85	.006			.49	.39	.41	5.57
5	56	.51	.14	3.77	.007	8.25	27.75	.52	.38	.42	5.38
6	28	.51	.15	3.80	.006			.54	.39	.43	5.63
7	84	.51	.14	3.85	.007			.54	.39	.41	5.67
8	28	.50	.15	3.88	.009			.54	.39	.44	5.53
9	56	.50	.14	3.85	.006			.52	.38	.48	5.47
10	56	.49	.15	4.15	.007			.53	.39	.46	5.59
11	112	.47	.15	3.88	.008			.54	.40	.51	5.63
18	56	.52	.15	3.85	.007			.55	.39	.45	5.66
19	56	.51	.14	3.70	.008	9.50	44.00	.50	.41	.39	5.59
P value		NS	NS	NS	NS	.0154	.0060	.0002	NS	.0542	NS
EMS						.125	10.8	.0004		.0030	
df						3	3	36		36	
SE						.25	2.32	0.014		0.038	

† All treatments except trts 1 and 7 received 22 kg N/ha banded with the seed at planting. Trt 7 received 34 kg N/ha, while trt 1 received none. Trt 19 received Cu plus Zn (2 kg and 5 kg, respectively) with the seed at planting.

Table A7. Nutrient concentrations in winter wheat leaves sampled on March 5, 1981.

Trt No.†	Chloride	Cations						Anions			Total N
		Ca	Mg	K	Na	Cu	Zn	P	S	Cl	
	kg/ha	%	%	%	%	ppm	ppm	%	%	%	%
1	0	.42	.12	2.75	.010			.36	.34	.24	4.09
2	0	.45	.11	2.84	.008			.35	.35	.18	4.08
3	0	.45	.11	2.68	.010			.36	.31	.15	3.94
4	56	.47	.11	2.87	.009			.37	.37	.27	4.09
5	56	.45	.11	2.76	.011	7.50	21.8	.36	.34	.29	3.93
6	28	.44	.12	2.87	.095			.38	.33	.24	4.13
7	84	.47	.11	2.89	.010			.35	.37	.27	4.12
8	28	.44	.11	2.95	.010			.37	.34	.24	3.97
9	56	.44	.11	2.86	.009			.38	.33	.30	4.02
10	56	.43	.11	2.95	.008			.38	.33	.28	4.19
11	112	.42	.11	3.11	.009			.38	.33	.36	4.21
18	56	.47	.12	2.96	.010			.38	.37	.27	4.21
19	56	.44	.11	2.78	.011	7.75	29.5	.34	.35	.23	4.00
P value††		NS	NS	.0171	NS	NS	.0098	NS	.0328	.0000	NS
EMS				.0235			3.458		.0006	.0008	
df				36			3		36	36	
SEM				.1009			1.315		.0176	.0198	

† All treatments except trts 1 and 7 received 22 kg N/ha banded with the seed at planting. Trt 7 received 34 kg N/ha, while trt 1 received none. Trt 19 received Cu plus Zn (2 kg and 5 kg, respectively) banded with the seed at planting.

†† NS means not significant at the .05 probability level.

Table A8. Nutrient concentrations in winter wheat leaves sampled on April 30, 1981.

Trt No.	Nutrient ratest				---------- Nutrient concentrations in leaves ----------										
	Fall		Spring		Cations							Anions			Total N
	K	Cl	K	Cl	Ca	Mg	K	Na	Mn	Cu	Zn	Total P	Total S	Cl	
	- - - kg/ha - - -				%	%	%	%	ppm	ppm	ppm	%	%	%	%
1	-	-	-	-	.20	.10	2.17	.003	37.8			.31	.26	0.27	3.11
2	-	-	-	-	.40	.12	2.43	.003	80.5			.31	.52	0.12	4.68
3	-	-	-	-	.43	.12	2.15	.003	80.8			.31	.55	0.13	4.68
4	-	56	-	-	.38	.11	2.19	.003	81.8			.33	.55	0.16	4.68
5	-	56	-	-	.38	.11	2.24	.003	77.5			.33	.53	0.18	4.70
6	-	28	-	-	.41	.12	2.11	.003	83.8			.33	.57	0.16	4.77
15	-	-	-	368	.38	.10	2.22	.002	83.8			.32	.31	0.67	4.61
12	-	56	-	368	.40	.10	2.12	.003	80.5	5.5	27.8	.31	.31	0.69	4.55
13	-	56	-	185	.38	.10	2.19	.003	80.0			.32	.39	0.66	4.81
14	-	56	-	92	.42	.11	2.11	.004	77.8			.32	.40	0.53	4.51
16	-	56	204	185	.39	.11	2.32	.003	95.3			.32	.45	0.65	4.84
17	-	56	-	185	.44	.11	2.15	.003	88.0			.32	.42	0.67	4.66
7	-	85	-	-	.39	.11	2.15	.003	77.8			.32	.56	0.19	4.70
18	-	56	-	368	.43	.10	2.18	.004	89.0			.33	.34	0.76	4.74
19	-	56	-	368	.38	.09	2.25	.003	81.8	7.0	35.8	.31	.33	0.70	4.76
20	-	56	-	368	.44	.10	2.08	.003	90.3			.33	.40	0.69	5.10

Continued

Table A8. Nutrient concentrations in winter wheat leaves sampled on April 30, 1981. (Continued)

Trt No.	Nutrient ratest				Nutrient concentrations in leaves										
	Fall		Spring		Cations							Anions			
	K	Cl	K	Cl	Ca	Mg	K	Na	Mn	Cu	Zn	Total P	Total S	Cl	Total N
	- - - kg/ha - - -				%	%	%	%	ppm	ppm	ppm	%	%	%	%
8	30	28	-	-	.43	.13	2.19	.003	78.8			.34	.58	0.14	4.81
9	62	56	-	-	.41	.11	2.26	.003	81.3			.32	.59	0.18	4.68
10	62	56	-	-	.37	.12	2.28	.003	81.8			.32	.51	0.20	4.48
11	123	112	-	-	.41	.11	2.30	.003	85.3			.33	.57	0.25	4.66
P value					.0000	.0000	.0037	NS	.000	.0577	NS	NS	.0000	.0000	.0000
EMS					.0016	.0001	.0112		80.52	.500			.0016	.0025	.0350
df					57	57	57		57	3			57	57	57
SEM					.0280	.0067	.0749		6.345	.500			.0283	.0352	.1323

† All treatments received a total of 168 kb N/ha except trt 1 which received no fertilizer, and trt 20 which received 224 kg N/ha. All treatments with P received 22 kg P/ha except trt 18 which received 40 kg P/ha.

Table A9. Nutrient concentrations and mean leaf water potentials in winter wheat leaves sampled on four dates in May and June, 1981.†

Date	Trt no.	Ca	Mg	K	Na	Total P	Total S	Cl	Total N	Mean leaf water potentials		
										Ψ_L	π	P
		%	%	%	%	%	%	%	%	- - - bars - - -		
May 12	3	.42	.12	1.84	.00	.20	.42	.13	3.18	-13.9	-23.8	10.0
	5	.40	.10	1.82	.00	.20	.51	.16	3.18	-13.5	-24.2	10.7
	12	.50	.10	2.04	.00	.22	.27	.56	3.72	-14.0	-23.7	9.7
	13	.42	.10	1.74	.00	.22	.34	.49	3.46	-14.1	-24.1	10.0
	14	.48	.12	1.92	.00	.22	.37	.67	3.23	-15.4	-25.1	9.6
	15	.52	.08	2.06	.00	.22	.24	.63	3.71	-16.2	-24.8	8.6
	16	.46	.10	1.46	.002	.22	.41	.60	3.60	-14.0	-25.3	11.3
	17	.48	.10	1.94	.002	.22	.38	.60	3.31	-15.4	-25.2	9.8
SEM (35 df)										.87	.75	.52
May 27	3	.68	.14	1.50	.005	.19	.64	.07	3.02	-12.6	-18.7	6.0
	5	.72	.14	1.68	.007	.21	.53	.15	3.30	-12.8	-20.2	7.4
	12	.86	.12	1.76	.005	.23	.30	.40	3.73	-14.0	-21.7	7.7
	13	.80	.12	1.80	.003	.22	.42	.66	3.52	-14.0	-21.8	7.8
	14	.84	.14	1.78	.005	.22	.45	.38	3.32	-13.1	-20.8	7.7
	15	.82	.12	1.54	.005	.22	.29	.44	3.73	-13.9	-21.9	8.0
	16	.68	.12	2.02	.005	.22	.51	.44	3.66	-15.2	-21.8	6.6
	17	.90	.12	1.70	.007	.22	.51	.54	3.40	-13.6	-21.0	7.4
SEM (35 df)										.40	.48	.45

Continued

Table A9. Nutrient concentrations and mean leaf water potentials in winter wheat leaves sampled on four dates in May and June, 1981.† (Continued)

Date	Trt no.	Ca	Mg	K	Na	Total P	Total S	Cl	Total N	Mean leaf water potentials		
										Ψ_L	π	P
		%	%	%	%	%	%	%	%	- - - bars - - -		
May 29	3	.90	.16	1.68	.005	.21	.82	.07	3.34	-13.9	-19.2	5.2
	5	.76	.14	1.88	.007	.20	.53	.16	3.076	-13.5	-19.9	6.5
	12	.98	.14	1.74	.007	.22	.31	.38	3.71	-14.6	-21.0	6.4
	13	.82	.14	1.92	.005	.23	.37	.48	3.39	-14.3	-21.2	6.9
	14	.72	.14	1.96	.009	.23	.39	.44	3.14	-14.7	-21.6	6.9
	15	.90	.12	1.76	.007	.22	.26	.48	3.69	-15.3	-22.0	6.8
	16	.74	.10	2.02	.005	.23	.47	.42	3.54	-16.0	-22.6	6.6
	17	.90	.14	1.72	.005	.23	.41	.46	3.21	-15.2	-22.0	6.80
SEM (35 df)										.47	0.52	0.32
June 24	3	.90	.14	1.44	.007	.14	.56	.08	1.88	-14.8	-21.3	6.50
	5	.78	.14	1.60	.005	.17	.60	.17	2.16	-14.4	-21.9	7.5
	12	.92	.14	1.88	.005	.15	.30	.51	2.41	-15.6	-25.3	9.7
	13	.92	.16	1.82	.005	.15	.29	.58	2.36	-15.3	-23.3	8.0
	14	.92	.18	1.66	.005	.14	.34	.35	1.98	-14.1	-22.7	8.6
	15	1.18	.14	1.42	.007	.14	.24	.62	2.35	-15.9	-26.6	10.7
	16	.96	.14	1.92	.007	.15	.37	.49	2.35	-17.4	-26.7	9.3
	17	1.08	.16	1.80	.005	.14	.39	.71	1.97	-16.5	-24.9	8.4
SEM (35 df)										0.62	.98	.72

Continued

Table A9. Nutrient concentrations and mean leaf water potentials in winter wheat leaves sampled on four dates in May and June, 1981.† (Continued)

Date	Trt no.	Ca	Mg	K	Na	Total P	Total S	Cl	Total N	Mean leaf water potentials		
										Ψ_L	π	P
		%	%	%	%	%	%	%	%	- - - bars - - -		
Averaged over time	3	.73	.14	1.62	.004	.18	.61	.09	2.86	-13.8	-20.8	6.9
	5	.67	.13	1.75	.005	.19	.54	.16	2.93	-13.6	-21.6	8.0
	12	.82	.13	1.86	.004	.20	.30	.46	3.39	-14.6	-22.9	8.4
	13	.74	.13	1.82	.003	.20	.36	.55	3.18	-14.4	-22.6	8.2
	14	.74	.15	1.83	.005	.20	.39	.46	2.91	-14.3	-22.6	8.2
	15	.86	.12	1.70	.005	.20	.26	.54	3.37	-15.3	-23.8	8.5
	16	.71	.12	1.86	.005	.20	.44	.49	3.29	-15.7	-24.1	8.5
	17	.84	.13	1.79	.005	.20	.42	.58	2.97	-15.2	-23.3	8.1
SEM (21 df)		.0487	.0078	NS	NS	.0061	.0443	.054	.0650	.47	.62	NS

† Plant analysis data for each of the 4 dates was not replicated. Each treatment number represents only 1 sampling on that date.

Table A10. Xylem (Ψ_L), osmotic (π), and turgor (P) potential as affected by timing, rate and source of chloride in second-year wheat (May 12, 1981).

Trt no.	Nutrient rates† Fall Cl	Spring K	Spring Cl	Mean leaf water potentials Ψ_L	π	P	Chloride
	--- kg/ha ---						-- % --
3	-	-	-	-13.9	-23.8	+10.0	0.13
5	56	-	-	-13.5	-24.2	+10.7	0.16
12	56	-	368	-14.0	-23.7	+9.7	0.56
13	56	-	185	-14.1	-24.1	+10.0	0.49
14	56	-	92	-15.4	-25.1	+9.6	0.67
15	0	-	368	-16.2	-24.8	+8.6	0.63
16	56	204	185	-14.0	-25.3	+11.3	0.60
17	56	-	185	-15.4	-25.2	+9.8	0.60

Analysis of Variance Table

Source of variation	df	Mean squares Ψ_L	π	P
Total	47			
Treatment	7	5.60	2.36	3.71
Block	5	4.02	10.41	19.82
Error	35	2.25	1.68	.80
P-value		.0346	NS	.0009
LSD 5%		1.76	-	1.05

†All plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

Table A11. Xylem (Ψ_L), osmotic (π), and turgor (P) potential as affected by timing, rate and source of chloride in second-year wheat (May 27, 1981).

Trt no.	Nutrient ratest Fall Cl	Spring K	Spring Cl	Mean leaf water potentials Ψ_L	π	P	Chloride
	--- kg/ha ---						-- % --
3	-	-	-	-12.6	-18.7	+6.0	0.07
5	56	-	-	-12.8	-20.2	+7.4	0.15
12	56	-	368	-14.0	-21.7	+7.7	0.40
13	56	-	185	-14.0	-21.8	+7.8	0.66
14	56	-	92	-13.1	-20.8	+7.7	0.38
15	0	-	368	-13.9	-21.9	+8.0	0.44
16	56	204	185	-15.2	-21.8	+6.6	0.44
17	56	-	185	-13.6	-21.0	+7.4	0.54

Analysis of Variance Table

Source of variation	df	Mean squares Ψ_L	π	P
Total	47			
Treatment	7	4.10	7.42	2.65
Block	5	2.69	3.99	7.57
Error	35	.48	.70	.60
P-value		.0000	.0000	.0013
LSD 5%		.81	.98	.91

† All plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

Table A12. Xylem (Ψ_L), osmotic (π), and turgor (P) potential as affected by timing, rate and source of chloride in second year wheat (May 29, 1981).

Trt no.	Nutrient rates† Fall Cl	Spring K	Spring Cl	Mean leaf water potentials Ψ_L	π	P	Chloride
	--- kg/ha ---						-- % --
3	-	-	-	-13.9	-19.2	+5.2	0.07
5	56	-	-	-13.5	-19.9	+6.5	0.16
12	56	-	368	-14.6	-21.0	+6.4	0.38
13	56	-	185	-14.3	-21.2	+6.9	0.48
14	56	-	92	-14.7	-21.6	+6.9	0.44
15	0	-	368	-15.3	-22.0	+6.8	0.48
16	56	204	185	-16.0	-22.6	+6.6	0.42
17	56	-	185	-15.2	-22.0	+6.8	0.46

Analysis of Variance Table

Source of variation	df	Mean squares Ψ_L	π	P
Total	47			
Treatment	7	3.95	7.93	1.78
Block	5	5.18	9.41	2.42
Error	35	.657	.82	.31
P-value		.0001	.0000	.0002
LSD 5%		.95	1.06	0.66

† All plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

Table A13. Xylem (Ψ_L), osmotic (π), and turgor (P) potential as affected by timing, rate and source of chloride in second-year wheat (June 24, 1981)

Trt no.	Nutrient rates† Fall Cl	Spring K	Spring Cl	Mean leaf water potentials Ψ_L	π	P	Chloride
	--- kg/ha ---						-- % --
3	-	-	-	-14.8	-21.3	+6.5a	0.08
5	56	-	-	-14.4	-21.9	+7.5b	0.17
12	56	-	368	-15.6	-25.3	+9.7d	0.51
13	56	-	185	-15.3	-23.3	+8.0b	0.58
14	56	-	92	-14.1	-22.7	+8.6c	0.35
15	0	-	368	-15.9	-26.6	+10.7e	0.62
16	56	204	185	-17.4	-26.7	+9.3d	0.49
17	56	-	185	-16.5	-24.9	+8.4bc	0.71

Analysis of Variance Table

Source of variation	df	Mean squares Ψ_L	π	P
Total	47			
Treatment	7	7.07	25.91	10.43
Block	5	3.84	8.78	3.25
Error	35	1.16	2.91	1.55
P-value		.0001	.0000	.0000
LSD 5%		1.26	2.00	1.46

† All plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

Table A14. Mean xylem (Ψ_L), osmotic (π), and turgor (P) potential, leaf chloride concentration and grain yield as affected by rate and source of chloride.†

Trt No.	Nutrient rates†† Fall Cl	Spring K	Spring Cl	Mean leaf water potentials Ψ_L	π	P	Chloride	Grain yield
	--- kg/ha ---						%	kg/ha
3	-	-	-	-13.8	-20.8	+6.9	0.09	5254
5	56	-	-	-13.6	-21.6	+8.0	0.16	5681
12	56	-	368	-14.6	-22.9	+8.4	0.46	6489
13	56	-	185	-14.4	-22.6	+8.2	0.55	5771
14	56	-	92	-14.3	-22.6	+8.2	0.46	6632
15	0	-	368	-15.3	-23.8	+8.5	0.54	6462
16	56	204	185	-15.7	-24.1	+8.5	0.49	6441
17	56	-	185	-15.2	-23.3	+8.1	0.58	6793

Analysis of Variance

Source of variation	df	Mean squares Ψ_L	π	P	% Cl
total	31				
treatment	7	2.1546	5.0082	1.0175	.1391
block	3	4.6512	27.9361	18.2061	.0229
error	21	.4359	.7592	.7090	.0058
P-value		.002	.003	NS	.0000
LSD (5%)		0.98	1.29	NS	0.11

† Water potentials averaged over May 12, 27, 29 and June 24, 1981.

†† All plots received 22 kg N/ha and 22 kg P/ha banded with the seed at planting, and 146 kg N/ha in the spring.

Table A15. Diurnal variations of (mean) leaf water potentials for ammonium sulfate (AS) and ammonium chloride (AC) spring-fertilized winter wheat. (June 2, 1981)

Fertilizer treatment†	Time (ave per block)	Mean leaf water potentials		
		Total leaf Ψ_L	Osmotic π_c ††	Turgor P
		bars		
AC	6:12 am	-1.8	-17.4	15.6
	7:21	-3.4	-18.2	14.8
	8:24	-3.8	-18.1	14.4
	9:22	-12.9	-22.1	9.2
	10:47	-14.7	-22.5	7.8
	12:08 pm	-16.4	-24.9	8.5
	1:35	-15.3	-25.7	10.5
	3:07	-16.2	-25.2	9.0
	3:34	-15.6	-24.3	8.7
	4:06	-14.7	-23.9	9.2
	5:07	-15.8	-23.9	8.1
	6:21	-14.6	-24.6	10.0
	7:27	-10.2	-23.2	13.0
	8:13	-8.8	-21.8	13.0
	8:59	-8.8	-22.6	13.8
	9:43 pm	-8.3	-20.9	12.6
AS	6:12 am	-4.0	-18.8	14.8
	7:21	-4.5	-19.6	15.2
	8:24	-6.4	-21.3	14.9
	9:22	-13.8	-25.5	11.8
	10:47	-17.4	-26.3	8.9
	12:08 pm	-19.0	-26.0	7.0
	1:35	-15.5	-26.0	10.5
	3:07	-20.3	-27.8	7.5
	3:34	-15.1	-23.5	8.4
	4:06	-18.6	-26.5	8.0
	5:07	-20.8	-26.3	5.6
	6:21	-19.6	-27.3	7.7
	7:27	-13.6	-23.8	10.1
	8:13	-10.9	-22.4	11.6
	8:59	-11.3	-23.3	12.0
	9:43 pm	-11.3	-23.6	12.4
P value				
5% LSD (15 df)		1.66	1.41	1.54

† AC = NH_4Cl, AS = $(NH_4)_2SO_4$ spring fertilizers. Both treatments received 22 kg P/ha plus 22 kg N/ha.

†† Osmotic potential corrected for bound water dilution.

Table A16. Treatment means of winter osmotic potentials and % chloride as influenced by source and rate of N, P, K and Cl fertilizers.

Trt no.	Nutrient rate† K	Cl	December 1980†† Osmotic π	Chloride	January 1981§ Osmotic π	Chloride	March 1981¶ Osmotic π	Chloride
	kg/ha		-bars	%	-bars	%	-bars	%
1	-	-	18.73	.58	15.48	.46	18.32	.24
2	-	-	17.93	.44	14.80	.42	17.79	.18
3	-	-	18.83	.44	14.74	.36	17.74	.15
4	-	56	18.33	.65	14.82	.41	18.27	.27
5	-	56	18.91	.55	14.91	.42	17.93	.29
6	-	28	18.32	.55	14.71	.43	18.55	.24
7	-	84	18.39	.54	14.91	.41	18.21	.27
8	30	28	18.62	.49	14.91	.44	17.85	.24
9	62	56	18.39	.54	15.13	.48	18.16	.30
10	62	56	18.16	.55	15.07	.46	18.21	.28
11	123	112	18.85	.61	14.96	.51	18.43	.36
18	-	56	18.79	.52	14.85	.45	18.91	.27
19	-	56	19.13	.52	15.24	.39	18.91	.23
SEM (36df)			NS	.047	NS	0.039	NS	.020

† All treatments received 22 kg N/ha except trt 1 which received none and trt 7 which had 34 kg N/ha. P = 22 kg P/ha. Trt 19 received Cu plus Zn banded with the seed (2 and 5 kg/ha, respectively).

†† Osmotic potential sampled 12-9-80; chloride sampled 12-8-80.

§ Osmotic potential sampled 1-17-81; chloride sampled 1-13-81.

¶ Osmotic potential sampled 3-9-81; chloride sampled 3-5-81.

Table A17. Treatment means of cations and anions in winter wheat leaves sampled on January 13, 1981.

Trt No.†	Chloride	Cations				Anions			Total		
		Ca	Mg	K	Na	H_2PO_4	SO_4	Cl	Cations	Anions	C-A
	kg/ha	- - - - meq/g - - - -				- - - -meq/g - - - -			- - meq/g - - -		meq/g
1	0	.24	.13	1.07	.003	.161	.367	.130	1.44	.658	.784
2	0	.25	.12	1.01	.003	.158	.384	.118	1.38	.660	.725
3	0	.25	.12	1.11	.002	.168	.365	.102	1.48	.636	.848
4	56	.26	.12	0.98	.003	.159	.372	.116	1.36	.647	.716
5	56	.25	.11	0.96	.003	.168	.362	.119	1.33	.650	.681
6	28	.25	.12	0.97	.003	.175	.363	.121	1.35	.659	.691
7	84	.25	.12	0.98	.003	.175	.365	.115	1.35	.654	.701
8	28	.25	.13	0.99	.004	.175	.372	.125	1.37	.672	.699
9	56	.25	.12	0.98	.003	.167	.363	.135	1.35	.665	.685
10	56	.25	.12	1.06	.003	.171	.368	.129	1.43	.668	.764
11	112	.23	.12	0.99	.003	.174	.374	.145	1.35	.692	.656
18	56	.26	.12	0.98	.003	.176	.366	.128	1.37	.670	.696
19	56	.25	.12	0.95	.003	.162	.390	.111	1.32	.664	.656
P value		NS	NS	NS	NS	.002	.0814	.0545	NS	NSNS	
EMS						.00004	.00016	.0002			
SEM (36df)						.0044	.0089	.0110			

† All treatments except trt 1 and 7 received 22 kg N/ha banded with the seed at planting. Trt 7 received 34 kg n/ha, while trt 1 received none.

Table A18. Treatment means of cations and anions in winter wheat leaves sampled on March 5, 1981.

Trt No.†	Chloride	Cations				Anions			Total		
		Ca	Mg	K	Na	H_2PO_4	SO_4	Cl	Cations	Anions	C-A
	kg/ha	- - - - meq/g - - - -				- - - -meq/g - - - -			- - meq/g - - -		meq/g
1	0	.21	.10	0.70	.004	.117	.324	.069	1.01	.509	.503
2	0	.22	.09	0.73	.004	.113	.335	.051	1.04	.500	.541
3	0	.22	.09	0.69	.004	.116	.300	.042	1.00	.457	.546
4	56	.23	.09	0.74	.004	.120	.350	.077	1.06	.546	.514
5	56	.23	.09	0.71	.005	.116	.326	.081	1.02	.522	.500
6	28	.22	.10	0.73	.004	.122	.310	.067	1.05	.499	.552
7	84	.23	.09	0.74	.004	.114	.359	.075	1.06	.548	.516
8	28	.22	.09	0.75	.004	.119	.326	.067	1.07	.512	.556
9	56	.22	.09	0.73	.004	.122	.318	.083	1.04	.523	.522
10	56	.21	.09	0.76	.004	.123	.310	.079	1.06	.512	.549
11	112	.21	.09	0.80	.004	.123	.314	.103	1.10	.539	.562
18	56	.23	.10	0.76	.004	.124	.354	.076	1.09	.554	.535
19	56	.22	.09	0.71	.005	.109	.339	.066	1.02	.514	.507
P value		NS	NS	.0171	NS	.0579	.0275	.0000	NS	.003	NS
EMS				.0013		.00004	.0006	.00006		.0006	
SEM (36df)				.0258		.0046	.0172	.0056		.0175	

† All treatments except trt 1 and 7 received 22 kg N/ha banded with the seed at planting. Trt 7 received 34 kg N/ha, while trt 1 received none.

Table A19. Treatment means of cations and anions in winter wheat leaves sampled on April 30, 1981.

Trt No.†	Nutrient rates				Milliequivalents of ions per gram of leaf tissue									
	Fall		Spring		Cations				Anions			Total Cation	Total Anion	Organic Anion C-A
	K	Cl	K	Cl	Ca	Mg	K	Na	H_2PO_4	SO_4	Cl			
	- - - kg/ha - - -				- - - - - meq/g - - - -				- - - meq/g - - -			- - - - - meq/g - - - - -		
1	-	-	-	-	.10	.08	.56	.001	.099	.245	.078	.740	.419	.321
2	-	-	-	-	.20	.10	.62	.001	.101	.505	.033	.920	.639	.281
3	-	-	-	-	.22	.10	.55	.001	.101	.528	.037	.862	.708	.154
4	-	56	-	-	.19	.09	.56	.001	.105	.532	.044	.837	.681	.156
5	-	56	-	-	.19	.09	.57	.001	.107	.511	.049	.852	.667	.185
6	-	28	-	-	.21	.10	.54	.001	.102	.539	.052	.839	.693	.147
15	-	-	-	368	.19	.08	.57	.001	.104	.294	.190	.839	.588	.251
12	-	56	-	368	.20	.08	.54	.001	.099	.293	.193	.822	.586	.237
13	-	56	-	185	.19	.08	.56	.001	.104	.374	.187	.832	.666	.167
14	-	56	-	92	.21	.09	.54	.002	.104	.386	.150	.836	.640	.196
16	-	56	204	185	.19	.09	.59	.001	.103	.430	.184	.875	.717	.159
17	-	56	-	185	.22	.09	.55	.001	.105	.405	.188	.859	.697	.162
7	-	84	-	-	.20	.09	.55	.001	.102	.539	.052	.839	.693	.147
18	-	56	-	368	.22	.08	.56	.002	.106	.326	.215	.859	.646	.212
19	-	56	-	368	.19	.08	.57	.001	.101	.313	.198	.838	.612	.226
20	-	56	-	368	.22	.08	.53	.001	.107	.377	.196	.833	.679	.153

Continued

Table A19. Treatment means of cations and anions in winter wheat leaves sampled on April 30, 1981. (Continued)

Trt No.†	Nutrient rates Fall K	Fall Cl	Spring K	Spring Cl	Milliequivalents of ions per gram of leaf tissue: Cations Ca	Mg	K	Na	Anions H_2PO_4	SO_4	Cl	Total Cation	Total Anion	Organic Anion C-A
	- - - kg/ha - - -				- - - - - meq/g - - - - -				- - - meq/g - - -			- - - - - meq/g - - - - -		
8	30	28	-	-	.22	.10	.56	.001	.109	.561	.041	.879	.711	.168
9	62	56	-	-	.21	.09	.58	.001	.104	.574	.051	.873	.730	.143
10	62	56	-	-	.19	.10	.58	.001	.103	.494	.056	.868	.653	.214
11	123	112	-	-	.20	.09	.59	.001	.107	.548	.071	.885	.726	.158
P value					.0000	.0001	.0037	NS	NS	.0000	.0000	.0000	.0000	.0000
EMS					.004	.0001	.0007			.0016	.0006	.0008	.0023	.0026
SEM (57 df)					.0140	.0055	.0192			.0280	.0170	.0200	.0338	.0361
n per trt (4)														

† All treatments received a total of 168 kg N/ha except trt 1 which received no fertilizer, and trt 20 which received 224 kg N/ha. All treatments with P received 22 kg P/ha except trt 18 which received 45 kg P/ha.

Table A20. Cations and anions in winter wheat flag leaves sampled on four datest in 1981.

Date	Trt no.	Ca	Mg	K	Na x 10^{-2}	H_2PO_4	SO_4	Cl	Total cations	Total anions	Organic C-A
		- - - - - - - - - - - - meq/g - - - - - - - - - - - -									
May 12	3	.21	.10	.437	.0	.064	.41	.037	.78	.513	.266
	5	.20	.08	.47	.0	.065	.50	.046	.75	.611	.136
	12	.25	.08	.52	.0	.072	.26	.158	.85	.486	.368
	13	.21	.08	.45	.0	.072	.33	.139	.74	.542	.195
	14	.24	.10	.49	.0	.072	.36	.190	.83	.620	.210
	15	.26	.07	.53	.0	.072	.23	.176	.85	.478	.374
	16	.23	.08	.37	.09	.072	.40	.170	.69	.640	.463
	17	.24	.08	.50	.09	.072	.37	.169	.82	.607	.212
May 27	3	.34	.12	.38	.22	.062	.62	.019	.84	.706	.135
	5	.36	.12	.43	.30	.066	.52	.042	.91	.625	.282
	12	.43	.10	.45	.22	.074	.29	.113	.98	.477	.504
	13	.40	.10	.46	.13	.070	.41	.185	.96	.661	.298
	14	.42	.12	.46	.22	.072	.44	.107	.99	.618	.374
	15	.41	.10	.39	.22	.072	.27	.124	.90	.467	.437
	16	.34	.10	.52	.22	.070	.50	.125	.96	.695	.261
	17	.45	.10	.43	.30	.072	.50	.152	.99	.720	.265
May 29	3	.45	.13	.43	.22	.066	.81	.020	1.01	.895	.117
	5	.38	.12	.48	.30	.065	.52	.044	.98	.631	.347
	12	.49	.12	.45	.30	.070	.29	.107	1.05	.470	.582
	13	.41	.12	.49	.22	.073	.36	.134	1.02	.564	.454

Continued

Table A20. (Continued)

Date	Trt no.	Ca	Mg	K	Na x 10^{-2}	H_2PO_4	SO_4	Cl	Total cations	Total anions	Organic C-A
		meq/g									
May 29 (cont.)	14	.36	.12	.50	.39	.073	.38	.123	.98	.575	.404
	15	.45	.10	.45	.30	.072	.25	.135	1.00	.457	.544
	16	.37	.08	.52	.22	.073	.46	.118	.97	.651	.319
	17	.45	.12	.44	.22	.073	.40	.129	1.01	.599	.407
June	3	.45	.12	.37	.30	.044	.55	.023	.94	.618	.318
	5	.39	.12	.41	.22	.054	.59	.047	.92	.689	.227
	12	.46	.12	.48	.22	.047	.29	.145	1.06	.483	.574
	13	.46	.13	.47	.22	.047	.28	.163	1.06	.489	.569
	14	.46	.15	.42	.22	.046	.33	.098	1.03	.473	.561
	15	.59	.12	.36	.30	.045	.23	.174	1.07	.453	.617
	16	.48	.12	.49	.30	.047	.36	.137	1.09	.547	.541
	17	.54	.13	.46	.22	.045	.38	.200	1.13	.627	.506
Averaged over the 4 dates	3	.36	.12	.41	.18	.059	.60	.025	.89	.683	.209
	5	.33	.11	.45	.21	.063	.53	.045	.89	.639	.248
	12	.41	.10	.47	.18	.066	.28	.131	.99	.479	.507
	13	.37	.11	.47	.14	.065	.34	.155	.94	.564	.379
	14	.37	.12	.47	.21	.066	.38	.130	.96	.571	.387
	15	.43	.09	.43	.21	.065	.25	.152	.96	.464	.493
	16	.35	.09	.47	.21	.065	.43	.138	.93	.633	.292
	17	.42	.11	.46	.21	.065	.41	.162	.99	.638	.348
SEM (21 df)		.0243	.0064	NS	NS	.0020	.0442	.0151	.0339	.0498	.0575

† Plant analysis data for each of the 4 dates was not replicated. Each treatment number represents only 1 sampling on that date.