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Development in Winter Wheat.

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Field and growth chamber experiments were conducted to determine chloride effects on the progress of stripe rust disease caused by Puccinia striiformis West., and to investigate turgor potential as the mechanism of the chloride effect.

Seven winter wheat (Triticum aestivum) cultivars were grown in the field in 1982 and 1983 on a Woodburn soil (Aquultic Argixeroll) at pH 5.5. Spring topdressed mixtures of $(NH_4)_2SO_4$ and NH_4Cl provided four chloride rates (0 kg/ha, 72 kg/ha, 152 kg/ha, and 304 kg/ha). Nitrogen rate was 120 kg/ha for all treatments in each experiment.

Plants were inoculated as seedlings using a composite collection of Puccinia striiformis spores from races prevalent on wheat in the Willamette Valley. Infection type, growth stage,

and foliar percent attack by stripe rust were recorded at 12 to 16 locations within each plot at weekly intervals for 5-10 weeks. Disease progress curves were plotted to compare the effect of different chloride rates on disease severity over time. A logit transformation was used to convert percent attack data from sigmoid curves into a line for each chloride treatment within cultivars. Linear regression was conducted for each cultivar with composite logit values within treatments as the dependent variable and day after inoculation as the independent variable. The slope of the logit line corresponds to the apparent infection rate of the disease. Latent period is found by solving the regression equation of the line at a given percent foliar attack (1%).

Chloride rates of 72 and 152 kg Cl/ha reduced apparent infection rates in 1983 for cultivars 'Rew' (12.4%), 'Yamhill' (7.7%) and 'Purplestraw' (10.5%). Latent period was generally lengthened by 0.5 to 2 days with added chloride. In most cases there was no significant difference in disease development among the three highest chloride rates.

Interaction of cultivar and chloride treatment at chloride rates of 72 kg/ha or higher increased the percent chloride content of leaf tissue for all cultivars. The magnitude of the increase varied by cultivar. Yamhill showed the largest increase (.27 to .73%), together with Rew (.23 to .68%), followed by OR 67-237 (.17 to .47%), Hill 81 (.20 to .50%), and Stephens (.13 to .42%) in 1982. The increases in chloride content was largest in 1983 for Purplestraw (.30 to .99%) followed by Yamhill (.26 to .86%), Rew (.28 to .82%), Hyslop (.28 to .80%), and Stephens (.18 to .49%).

Leaf water potential components were affected by cultivar rather than chloride treatment in 1982 and 1983, with a cultivar by chloride treatment interaction increasing turgor potential on May 19, May 26 and June 23 in 1982.

Chloride rates of 72 kg Cl/ha increased test weight of all cultivars in 1982 (0.64%) and 1983 (1.2%), kernel weight of all cultivars in 1982 (1.3%) and 1983 (4.3%), and grain yield of all cultivars in 1982 (6.5%) and 1983 (16.4%).

Laboratory experiments using nutrient solutions to supply chloride (3.6 meq/l) or sulfate (4.4 meq/l) treatments with equal nitrogen levels showed that chloride decreased disease incidence by 12% on 'Nugaines' in 1983 and 'Yamhill' in 1984. Added chloride decreased foliar percent attack during the primary infection cycle on all cultivars. Approximately 28 days after inoculation in 1983, foliar percent attack for the chloride-treated plants surpassed that of the sulfate-treated plants for 'Nugaines' second leaves and for 'Purplestraw' flag and second leaves. Apparent infection rate was increased for Purplestraw flag leaves and decreased for Yamhill second leaves with added chloride. A significant increase in leaf turgor potentials accompanied the increase in percent chloride in leaf tissue at the 3.6 meq/l chloride rate. Increased chloride supply slightly increased the leaf area and the apoplastic water content of cells in the leaves.

In field experiments, chloride rates of 72 and 152 kg Cl/ha (as NH_4Cl) slowed the development of Puccinia striiformis by decreasing the apparent infection rate and limiting foliar percent

attack during the reproductive growth stages of winter wheat. Chloride treatment effects on leaf chloride content corresponded to changes in disease progress only at the 72 kg/ha chloride rate. Chloride effects on disease progress were not reflected in changes in grain yield. Chloride effect on test weight, kernel weight, and grain yield in the absence of visible stripe rust symptoms may reflect: a) the impact of stripe rust infection on root growth and carbohydrate translocation of wheat plants, and b) control of take-all root rot disease of wheat. Grain yield in 1983 was 50 percent lower than in 1982 probably because of insufficient nitrogen fertilization in 1983 since oats rather than fallow preceded the wheat crop. Other possible explanations are differences in location of experimental plots in the field, different weather throughout the crop season, and possible differences in level of take-all root rot disease.

In field experiments, there were no consistent effects of added chloride on water potential components that would support growth chamber observations and confirm changes in turgor potential as a mechanism of chloride influence on stripe rust development.

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Chloride Fertilizer Effects on Stripe Rust Development in Winter Wheat

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INTRODUCTION

Epidemics of stripe rust, caused by Puccinia striiformis West., can reduce the yield of wheat (Triticum aestivum) and result in serious economic losses. According to Rapilly (1979), the disease is widely distributed throughout the world with the most severe epidemics occurring in temperate cool and wet climates. Hendrix (1964) notes that stripe rust was present in the United States of America as early as the late 1800's and was detected in the Pacific Northwest by 1915, although outbreaks were sporadic and yield losses uncertain. It is the most important cereal disease in England and northern Europe where outbreaks occur frequently and damage more than seventy five percent of a given crop (Hendrix, 1964). Mundy (1973) reminds us that wheat growers in England will long remember 1972 as the year in which 'Joss Cambier' winter wheat suffered from severe attacks of stripe rust. Coakley, et al. (1982) observed that stripe rust severly damaged susceptible wheat cultivars during 15 of the years between 1961 and 1982 in the Pacific Northwest region. Brown and Holmes (1983) note that stripe rust was first observed in Australia in 1979.

According to Shaner and Powelson (1971), epidemics of stripe rust in Oregon in 1960, 1961, and 1964 established it as a serious

disease of wheat in the Pacific Northwest. In 1961 alone, the reduction in grain yields due to the disease cost Oregon growers an estimated fifteen million dollars. Numerous studies have been conducted to characterize the modern host-pathogen interaction in Oregon and the Pacific Northwest (Shaner and Powelson, 1971; Shaner, 1969; Emge and Johnson, 1972; Emge, et al. 1975; and Young, 1977).

Puccinia striiformis requires free moisture and warm temperatures to germinate and reproduce. The environment of the Pacific Northwest - including a mild, wet climate, topography, wind direction and distribution of wheat crops - favors the year-round persistence and potentially rapid spread of stripe rust (Hendrix, 1965). Control of this disease depends primarily on breeding resistant cultivars. A supplementary method is application of fungicide timed to minimize disease development at a given stage of host maturity. Brown and Holmes (1983) developed guidelines that advise farmers in Australia to spray wheat crops with a suitable fungicide such as Bayleton when 1% of the leaf area is affected by stripe rust, provided that the predicted yield loss is greater than the cost of spraying.

Management of mineral nutrition through fertilization may limit yield loss due to stripe rust when used in observations of a chloride effect on stripe rust disease, and to evaluate the chloride response of a number of cultivars ranging from very resistant to very susceptible to the disease, a chloride treatment was superimposed on the 1981 International Winter Wheat Rust Nursery (IWWRN) at Hyslop Agronomy Farm near Corvallis, Oregon.

Results showed that "...severity of stripe rust disease was significantly ($p = 0.001$) reduced on 381 cultivars by a spring topdressing of ammonium chloride at 340 kg Cl/ha as compared to ammonium sulfate. Stripe rust infection type and rate of disease progression were not affected by chloride treatment." (Christensen, et al. 1982).

Based on these findings, field research was conducted at Hyslop Farm during the 1981-82 and 1982-3 crop seasons to observe and clarify the chloride effect. Supplemental growth chamber experiments took place in 1982-3 and 1983-4 to observe stripe rust disease development in greater detail. Cultivars representing a range of genetic resistance to stripe rust were selected from the IWWRN for field and growth chamber studies. Chloride fertilizer treatments for the field experiments included four chloride levels (the two used in the IWWRN together with two intermediates) in order to determine the relative effect of chloride level on disease. Growth chamber studies utilized nutrient solutions containing low and high levels of chloride with levels of all other nutrients held constant. The objectives were to quantify observations of a chloride effect on the development of stripe rust, to evaluate the effect of stripe rust on yield under different chloride levels, and to investigate chloride-induced osmoregulation as a possible mechanism of disease suppression.

REVIEW OF LITERATURE

Stripe rust disease

Stripe rust disease of wheat is caused by the fungus Puccinia striiformis West.. An alternate name for the disease is yellow rust, and for the pathogen is Puccinia glumarum. Although barley, rye, and approximately 75 species of grass are hosts for the disease, wheat suffers the most damage. Puccinia striiformis is an obligate parasite. It obtains its nutrition from the wheat plant and in nature grows and multiplies only on living tissue. It survives briefly as uredospores between hosts but no alternate host has been identified which would sustain the fungus in a different stage of its life cycle. Shaner (1969) investigated, on various grasses, the presence Puccinia striiformis races which infect wheat and concluded that the major source of inoculum for stripe rust epidemics on wheat is other wheat plants.

The development of Puccinia striiformis as described by Cartwright and Russell (1980), begins with germination of uredospores on the leaf surface under conditions of free moisture and warm temperatures (12-18^{c} C). Germ tubes are produced which penetrate the host through open stomata to form sub-stomatal vesicles. These vesicles generally concentrate on the distal third of adult leaves although they are almost uniformly distributed on the surface of seedling leaves. Infection hyphae develop from the side of the vesicle nearest the base of the leaf and ramify through sub-epidermal tissue of seedling leaves or through the mesophyll of

adult leaves. The hyphae branch into secondary hyphae to initiate new infections, form haustoria, and establish pustule beds from which subsequent generations of yellow uredospores develop. Most growth of Puccinia striiformis occurs in the mesophyll beneath the adaxial epidermis, and pustules therefore are formed mainly on the adaxial surface of the leaf. The size of the vascular bundle in adult leaves appears to discourage the growth of transverse infection hyphae, thus restricting the fungus to tissue between bundles so that the characteristic longitudinal striped infections develop between the veins.

The progress of stripe rust disease on wheat plants can be measured in various ways. Most obvious and extensively studied is the growth of lesions and sporulating area of leaves recorded as percent foliar attack. Emge, et al. (1975) emphasized the influence of the expanding sporulation zone (the growth of individual lesions) on stripe rust disease progress. They discussed the pronounced effect of systemic growth of the pathogen within the wheat leaf on both the period that inoculum is available to initiate new infections, and the amount of inoculum (spores) produced per day with potential to infect additional leaf surface. Hendrix, et al. (1965) noted that "stripe rust influences wheat over and above the simple destruction of photosynthetic surface". Studies by Martin and Hendrix (1967) and Hendrix and Lloyd (1970) measured the impact of disease on the roots and overall growth and development of wheat plants with ultimate effects on grain yield.

Foliar assessment of stripe rust disease includes measurement of incidence (pathogenicity) and severity (virulence). Incidence

reflects the pathogen's ability to cause disease in the host and measures whether or not disease is present. Severity measures the amount of disease present as individual lesions or percent leaf surface visibly infected. It includes chlorotic and necrotic tissue as well as visible sporulation. According to the Weber-Fechner Law (Horsfall, 1945), the human eye sees logrithmic increases in the proportion of diseased tissue present. From 0 to 50 percent attack the eye judges the visible proportion of healthy (green) tissue. From 51 to 100 percent attack the eye judges the visible proportion of diseased (yellow) tissue.

Stripe rust is a "compound interest" disease with repeating infection cycles producing secondary inoculum throughout the season. The shape of the disease progress curve (disease severity vs time) is sigmoid. A logit transformation of the disease severity data is used to convert the curve into a linear relation (Van der Plank, 1963).

1) Logit = LN(decimal percent attack/(1.0 - decimal percent attack)

The slope of the line corresponds to the apparent infection rate reflecting pooled interaction of host, pathogen, and environment.

2) Apparent infection rate = (logit B - logit A)/(time B - time A)

The Y-intercept of the line is equivalent to the length of the latent period which is the time from inoculation to initial sporulation.

Studies by Zadoks and Schein (1979) revealed that foliar infection of wheat by Puccinia striiformis reduces the translocation of photosynthate from the leaves to the roots to such an extent that the root system is undernourished or underdeveloped. This root damage hampers the uptake of water and nutrients into the plant from the soil. Differences in yield loss at comparable disease severities in dry and wet summers can be ascribed to root effects, reflecting decreased drought resistence when roots are damaged. In mist-, water-, and sand-cultures, Martin and Hendrix (1967) showed that stripe rust reduced the extent of roots and the amount of water removed from the soil. This influenced the development of subsequent leaves and their companion tillers.

Models for predicting yield loss center on severity of infection as revealed by lesions visible on leaves at a given growth stage of the wheat plant. Doling and Doodson (1968) found that 100 percent visible attack at the end of flowering would reduce yields by 30%. Additional ear (head) infection added 15% to yield loss. They defined severe infection as greater than 10% of foliage chlorotic with visible lesions. Mundy (1973) suggested a level of 5% visible infection on the top two leaves as the maximum disease severity at which using fungicide to limit yield loss is economically profitable. Measuring severity at the end of flowering, they found a loss in yield of 0.22 Mg/ha for each 1% increase in the percent visible attack by stripe rust on the flag leaf. Severe rust caused early leaf death and premature ripening of the grain.

Hendrix, et al. (1965) compared the influence of inoculation

with Puccinia striiformis vs mechanical defoliation on the development and yield of wheat plants. From primary leaf stage through flag leaf emergence, different groups of plants were inoculated with stripe rust. For the selected plants within each group, mechanical defoliation took place when visible symptoms of rust appeared, but at least 12-14 days after inoculation; the time lag corresponding to the incubation requirements of the disease. Loss of grain yield due to defoliation was less than that resulting from infection by stripe rust. Yield factors showing the greatest reduction due to inoculation were number of heads, seed weight, seed size, and test weight. These factors were reduced to a lesser extent when plants were mechanically defoliated. The more destructive single inoculations were those in which infection occurred in the fifth or flag leaf stages. This work emphasizes the relatively minor role played by the older leaves in contributing to overall kernel filling, and the benefits of evaluating the impact of disease on plants based on both foliar percent attack and yield factors.

In related studies on the effect of stripe rust on yield, comparisons were drawn between the impact of three colored rust diseases of wheat: stripe rust (yellow), leaf rust (brown), and stem rust (black). Martin, et al. (1976) found that leaf rust (Puccinia rubigovera) causes a reduction in yield primarily due to the reduced number of kernels in the spike. The kernels also are reduced in weight but not shriveled noticeably. Damage from stripe rust is similar except that kernels are shriveled. Grain shrunken as a result of stem rust (Puccinia graminis) is low in both

starch and protein because both nitrogenous and carbohydrate compounds are withdrawn from the wheat plant by the growing rust fungus.

Hendrix, et al. (1965) noted that effects of stripe rust on kernel formation and filling are probably related to an inadequate supply of nitrogen and essential hormones rather than to an inadequate supply of carbohydrates. The loss of photosynthetic area due to lesion growth can be compensated for by other metabolic pathways in the plant which normally play minimal or assisting roles in carbohydrate supply. However, the mechanisms regulating nitrogen and hormone supply to the inflorescence are also affected in some way by stripe rust and the plant is less capable of overcoming this type of stress.

In summary, the impact of stripe rust on wheat plants is most severe during the reproductive phase of growth; from flag leaf emergence through the harvest of mature grain. Before that time the loss in photosynthetic area of foliage and the damage to roots may decrease potential yield by limiting the number of tillers that head and the number of seeds formed, but yield compensation can minimize losses by filling each existing seed completely.

Control strategy

Genetic resistance is the most effective means of preventing or limiting epidemics of stripe rust. Resistance indicates that the pathogen is unable to reproduce in the host. Vertical resistance occurs when a given race of the pathogen is present and unable to reproduce in the host, while other races may be able to

cause disease. Flor's gene-for-gene hypothesis states that for every gene for resistance in the host a corresponding gene for pathogenicity must be present in the pathogen (Van der Plank, 1975). In order for disease to take place, the genes must match each other. Horizontal resistance occurs when a number of races cause low levels of disease in the host. When the races of the pathogen that are not compatible with the resistance present in a given cultivar multiply to the point where they are capable of overcoming that resistance and causing disease, new resistant cultivars must be bred. Breeding for disease resistance is an expensive and time-consuming process, the need for which is difficult to determine.

Fungicides also can limit the development of stripe rust during the crop season by inhibiting the effectiveness of secondary inoculum. The decision to apply fungicide is generally made after disease is visible in the field but before significant yield damage has occurred. The expense of this method of control is justified if applications are timed to coincide with growth stages of the host, climatic conditions favoring the disease, and disease severity is insufficient to have already affected the grain yield.

Coakley, et al. (1982) demonstrated that a model for predicting disease intensity using macrometeorological measurements can be useful at other locations in a synoptic weather region. Based on negative and positive degree days around a daily mean air temperature, together with an index of the growth stage of the plant at the time of disease assessment, they calculated stripe rust disease potential. Combining the climatological prediction

with epidemiological and management information as to the optimal growth stages and disease severity at which to attempt to control stripe rust outbreaks, accurate predictions of potential yield loss can be made.

Crop management practices can assist in limiting yield losses due to stripe rust, and may reduce the need for fungicides especially on cultivars with some resistance to the disease. Hendrix (1965) emphasized that green tissue-free periods, planting date, and fertilizer treatments can influence the potential and actual severity of the disease and its impact on grain yield. Winter wheat is occasionally sown in the spring as a cover crop to help prevent wind erosion where fields are under a fallow rotation. This practice provides a low, non-heading, dense ground cover that persists throughout the summer creating ideal conditions for harboring the wheat-attacking races of stripe rust. It is preferable to extend the period separating the maturity of one crop and the emerging seedlings of the next. The use of resistant varieties of wheat in cover crop plantings would reduce the chances of over-summering of rust in the cover crop, eliminating those sources of primary inoculum.

Early planting dates increase the exposure of seedling to infectious tissue from the preceding wheat crop. Late planted crops enter the crucial reproductive phase as disease impact is declining, and suffer less yield loss. Rapilly (1979) stressed that where weather conditions are not favorable for stripe rust development,spores are destroyed by intense sunshine and lack of humidity and dew essential to germination and spread.

According to Huber (1980), mineral fertilizers can reduce disease severity by (1) helping the plant to escape infection, (2) increasing tolerance to disease through compensation for pathogenic damage, (3) reducing pathogen virulence, or (4) enhancing physiological resistance of the plant.

Decreased primary inoculum levels, limited tillering before winter, and better established stands of wheat when the environment favors disease, contribute to suppression of stripe rust while limiting yield losses.

Mineral nutrition effects on disease

Management of plant nutrition through the use of inorganic fertilizers has additional potential for the suppression of plant disease. Nitrogen fertilization can help the plant to escape infection if amount and form are regulated to minimize disease and maximize plant growth. Huber and Watson (1974) noted that nitrogen form has an impact on the severity of stripe rust, with nitrates enhancing and ammonium reducing disease development, and that optimum growth of wheat occurs with the ammonium form of nitrogen as compared to the nitrate form. Huber (1980) commented on the interaction of nitrogen with other nutrients, suggesting that chloride acts through competitive inhibition of the nitrate anion to decrease uptake of nitrate while enhancing ammonium uptake. An excess of nitrogen, regardless of form, favors the growth of succulent tissue with little mechanical strength to resist infection. Abundance of nitrogen also influences the microclimate in the crop canopy by increasing plant vigor and vegetative growth

until high humidity and warm temperatures provide ideal conditions for stripe rust development.

Root damage and decreased photosynthetic supply to roots can reduce nutrient uptake from the soil. High fertility levels increase yields by stimulating growth of new roots or by improving access to and availability of nutrients when there are fewer or less efficient roots (Huber, 1980).

Russell (1978) demonstrated that stripe rust was enhanced by applications of nitrates. Chloride applications at rates of 376, 1130, or 2260 kg Cl/ha did not adversely affect the overall growth or yield in the absence of yellow rust. However, the nitrogen rates were not constant among treatments so that the detrimental effects of excess ammonium-nitrogen or interactions of chloride level and nitrogen form or amount cannot be assessed from that experiment (Russell, 1978). Huber (1980) cited the loss of resistance to cereal rusts and mildew associated with predominance of the nitrate form of nitrogen and protein degradation in the host as suggestive of a pathogen-induced mechanism to enhance the nutritional advantage of the parasite at the expense of the host. High rates of nitrate-nitrogen in the presence of excess chloride may overcome the competitive inhibition between chloride and nitrate and favor the nutrition of parasite over that of the host. The net effect would be to increase pathogen virulence. Alternately the host may produce or accumulate inhibitory compounds such as phytoalexins (Cartwright and Russell, 1981) to impede the progress of the pathogen within the plant.

Chloride effects on water relations

Russell (1975) found in England that erect leaves can allow for a threefold decrease in the number of spores retained on the leaf surface, as compared to prostrate leaves (Rapilly,1979). Christensen, et al. (1981) observed that differences in leaf habit between ammonium chloride and ammonium sulfate fertilized plants were most pronounced at midday during bright sunny weather. This suggested that increased cell turgor was responsible for the erectness of chloride fertilized plants, and that the chloride ion was affecting plant water potentials through osmoregulation. Chloride effects on leaf turgor and habit (erectness) may enhance physiological resistance of the plant to disease by reducing spore retention.

Mengel and Kirkby (1978) discuss possible roles of chloride as a micronutrient in plant metabolism including its importance in osmotic and cation neutralization, its action as a counter-ion in rapid K ion fluxes, and its contribution to turgor, replacing NO_3^- or Malate. They stress that in general a plant with high chloride uptake will have a high water content. Chloride fertilizer treatments have been shown to alter the water relations of winter wheat in the Pacific Northwest, although the mechanism has not been identified. Christensen, et al. (1981) suggested that chloride acts through osmoregulation to increase cell turgor potential. According to their results, the lower osmotic potential measured where chloride salts were spring topdressed as ammonium chloride is largely the result of increased chloride concentration in the symplasm. Osmotic potentials (corrected for apoplastic

water content) for ammonium chloride treatments were significantly lower than for ammonium sulfate treatments, and turgor potentials were significantly higher for ammonium chloride than for ammonium sulfate fertilized plants. There was no significant difference in leaf water potential between treatments. Apoplastic water content was assumed constant over the range of leaf water potentials and chloride fertilizer treatments.

Cartwright and Russell (1980) speculated that "changes in either osmotic pressure or electropotential could affect the flow of water and nutrients in and out of host cells or fungal hyphae and might consequently stress the host-parasite relationship" for stripe rust diseases. In experiments by Christensen,et al. (1982), chloride topdressed in the spring on winter wheat may have reduced the osmotic potential and increased the turgor potential in leaves while significantly reducing stripe rust severity on 381 cultivars.

Russell (1978) showed that soil applications of chloride before inoculation with stripe rust reduced the severity of disease in several winter wheat cultivars in comparison with untreated plants. He noted that a combination of sodium and potassium chloride reduced yellow rust to a greater extent than a corresponding application of sodium chloride alone. In addition he found that sodium nitrate and sodium phosphate did not inhibit stripe rust and determined it unlikely that the inhibitory effects of sodium chloride were due only to the sodium cation. Kovanci and Colakglu (1976) showed that increasing potassium as KCl decreased the severity of stripe rust and suggested that it may have been due to an increase in cell wall thickness brought about by improved

potassium supply which would decrease the penetration by the fungus. The possible impact of the chloride anion on disease progress was neither measured nor considered as an alternate explanation for the KCl effect, and the experimental design does not allow for investigation of the role of chloride using their data.

Interactions of stripe rust and water stress

Hendrix and Lloyd (1970) compared the effects of water stress and stripe rust on grain yield and root weight of wheat. In pot culture, plants inoculated with stripe rust and grown under conditions of ample moisture yielded about the same as noninoculated plants grown under moisture stress (33% less than the check treatment yield). Plants with both stripe rust and moisture stress showed a greater decrease in yield (77% less than the check treatment yield) than with either factor alone, suggesting an additive effect of the combined stresses. In mist culture, root weight showed the greatest decrease under conditions of combined stripe rust and water stress. Water stress in the absence of stripe rust decreased root weight almost as much as did the combined effect, while stripe rust in the absence of water stress caused the least decrease in root weight. There is a synergistic effect of combined water stress and stripe rust in decreasing yield, where water stress decreases root weight and stripe rust has a detrimental impact of equivalent magnitude on other aspects of plant growth and development which accentuate the root damage.

Doodson, et al. (1965) noted in work with ^{14}Carbon that the

percentage of assimilates moving to the roots in stripe rust infected plants is greatly decreased, which correlated with the observed decreases in dry weight of roots recorded in previous work by Doodson, et al. in 1964. Martin and Hendrix (1967) found that in mist culture experiments, stripe rust exerts deleterious influences on total root mass and that the extent of the influence is related to the severity of the disease. Zadoks and Schein (1979) reported that foliar infection of wheat by stripe rust reduces the translocation of nutrients and photosynthate from the leaves to the roots such that the root system is undernourished or underdeveloped. Drought resistance can be decreased when roots are damaged and the uptake of water and nutrients into the plant from the soil is hampered, causing the plant to suffer worse from water stress.

Work by Sepaskha and Boersma (1979) suggests that leaf elongation and the accompanying extension of cell walls is governed by the mechanical force of turgor pressure. Chloride induced increases in leaf area and leaf elongation (due to changes in turgor which accompany osmoregulation) might result in increases in root volume because plants maintain a nearly constant shoot-to-root ratio during vegetative development. The larger root system could result in improved nutrient and water uptake.

MATERIALS AND METHODS

Field Experiments

Experiments were conducted at Hyslop Agronomy Farm near Corvallis, Oregon in 1981-2 and 1982-3 to evaluate stripe rust development as affected by spring top-dressed chloride fertilizer treatments. Five cultivars of winter wheat were planted each year in a split plot design with cultivars as main plots and chloride treatments as sub-plots. Sub-plots were 1.53 by 10.98 meters and were replicated four times. Cultivars were selected from the IWWRN to provide different degrees of resistance to dominant races of Puccinia striiformis common in the Willamette Valley (Table 1).

Table 1. Stripe rust infection type and year planted for wheat cultivars in field experiments

Cultivar	Infection type	Year planted
Hill	resistant	1981
OR-67-237	susceptible	1981
Yamhill	seedling resistance	1981,1982
Stephens	adult resistance	1981,1982
Rew	resistant	1981,1982
Hyslop	resistant	1982
Purplestraw	susceptible	1982

Fall fertilizer was Unipel^{TM} (10-20-22) banded at planting at the rate of 224 kg/ha. Nutrient rates were 22 kg N/ha, 20 kg P/ha, 41 kg K/ha, 9 kg S/ha, and 37 kg Cl/ha. Spring fertilizer treatments supplied uniform nitrogen rates of 120 kg/ha, with varying sources of nitrogen and a range of chloride rates (Table 2).

Table 2. Nitrogen sources and chloride rates for spring fertilizer treatments, field experiments

N applied as $(NH_4)_2SO_4$	N applied as NH_4Cl	Chloride rate (kg/ha)
----------%----------		------kg/ha---------
100	0	0
75	25	72
50	50	152
0	100	304

Table 3. Crop management practices and dates for field plots

	1981-1982	1982-1983
Seeding date	23 October	3 November
Inoculation date	6 March (6 May)	31 March
Spring fertilization	16 March	15 March
Harvest date	28 July	1 August

The soil at Hyslop Farm is a Woodburn silt loam; a fine-silty,mixed mesic Aquultic Argixeroll. Soil pH was 5.4 to 5.6. Seeding rate was 100 kg/ha (90 lb/acre). Rows were spaced 0.25 meters apart to give 6 rows per plot. Benlate was applied at the recommended rate on 9 March 1982 to control Pseudocercosporella foot rot. Wheat followed fallow or oats, so that take-all root rot was not expected to be a yield limiting factor. Temperature and rainfall data was collected at the Hyslop Farm weather station throughout both crop seasons (Appendix Table 1).

Plant samples and grain yield

Leaf chloride content of a composite sample of 25 to 30 flag leaves from each plot was measured on five dates in 1982 and one date in 1983. Sampling dates for 1982 were April 27, May 11, May

25, June 7, and June 22. Sampling date for 1983 was May 27. Leaves were excised at the ligule and placed in white paper bags to dry in ovens at 53°C for at least 48 hours. Contents of each bag were chopped in a Waring blender, ground in a Wiley mill and stored in coin envelopes in a 53°C oven for at least 8 hours before being weighed. Chloride content was determined by extracting 500 mg samples for 30 minutes with 0.1 N nitric acid and then titrating with 0.2 N $AgNO_3$, using a Cl^- specific ion electrode (Orion Model 94-17A) and a specific ion meter (Orion Model 407) to detect the endpoint (Cantliffe, 1970).

Entire plot area (16.74 m^2) was harvested with a small combine and grain collected in individual bags to be weighed. Sufficient grain from each plot was cleaned to remove chaff and awns for test weight determination. Weight of five-hundred kernels from each sample was measured on a top-loading balance to calculate thousand kernel weight.

Inoculation and disease assessment

Plants were inoculated within each plot using a composite collection of Puccinia striiformis spores from races prevalent on wheat in the Willamette Valley. Preservation and rehydration of spores followed the technique of Hughes and Macer (1964) as used and amended by Shaner (1969). Spores were stored in airtight vials in liquid nitrogen until needed. The vials were heat treated at 40° C for 10 min in a beaker of water, then the vials were opened and placed on wet paper towels in another beaker and covered with plastic to hydrate under nearly 100% humidity. After 3 hours of

hydration, the spores were removed from the vial and mixed in a 1:5 ratio with sterile talc. The mixture of spores and sterile talc was shaken onto seedlings, decimal growth stage 30 (Zadoks et al.1974), from cheesecloth bags held approximately 0.25 meter above the ground. Beginning with the first visible disease symptoms on the most susceptible cultivar, infection type was recorded for each cultivar (Table 4) and observations of amount of stripe rust were made as percent leaf attack within each plot (Table 5).

Table 4. Visible symptoms related to resistance of wheat cultivars to stripe rust disease

	Observed symptoms	
Infection type	Chlorosis/necrosis	sporulation
very resistant	abundant	no or trace
resistant	moderate	trace
mod. resistant	light	light
susceptible	trace	moderate
very susceptible	no or trace	abundant

Table 5. Disease severity scale to rate foliar infection by *Puccinia striiformis* on wheat

Percent attack	Visible disease symptom
0	none
0.1	1-2 lesion in 10 meters
1.0	Up to an average of one lesion per tiller but not more than 1 percent of total leaf surface attacked
5.0	5 percent of total leaf surface attacked
10.0	10 percent of total leaf surface attacked
25.0	25 percent of total leaf surface attacked
50.0	50 percent of total leaf surface attacked
75.0	75 percent of total leaf surface attacked
90.0	90 percent of total leaf surface attacked
95.0	95 percent of total leaf surface attacked
99.0	maximum disease coverage

In 1982 and 1983, a mixture of susceptible cultivars was sown perpendicular to the planting rows at 3 locations (north end, center, and south end) in each plot to provide a standardized sites for inoculation with Puccinia striiformis spores. These plants served as line foci for assessment of stripe rust disease throughout the season. Observations of percent attack were made adjacent to each of these foci and at intermediate locations spaced 60-cm, and 120-cm toward the center of the plot form each focus for a total of 9 readings of disease severity per plot (Figure 1). Disease assessment occurred at intervals of approximately 7 days and continued until the plants reached the early dough stage (decimal growth stage 80) where stripe rust lesions were imperceptible from normal senescence.

In 1982, because there was no observed disease throughout April, sporulating plants were transplanted on May 4 from the stripe rust nursery of R.L. Powelson (O.S.U. Dept of Botany and Plant Pathology) to serve as foci for this experiment. These seedlings had been inoculated with stripe rust earlier in the season with inoculum from the same source and were from a mixture of susceptible cultivars chosen from the IWWRN. One sporulating seedling was transplanted into the center of each line foci in each plot. Assessment of percent attack was made on 5 dates (May 26, June 2, June 10, June 16, June 22) and included an observation of total estimated percent attack around each focus, bringing the number of readings of disease severity to 16 per plot on each date. In 1983 the assessment took place for a period of 10 weeks (April 19 through June 22).

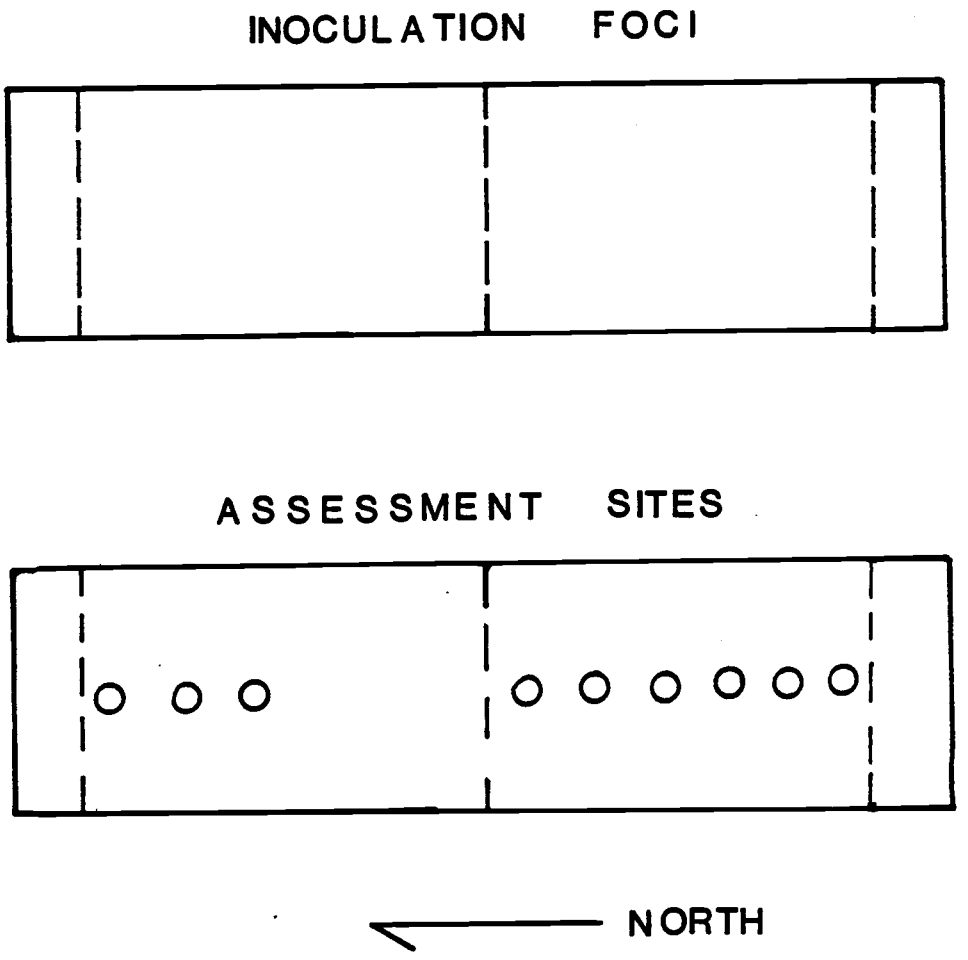

Figure 1. Locations within each field plot for inoculation with Puccinia striiformis and sites of disease assessment

Water potential components

Leaf water potentials of flag leaves were measured using the pressure chamber (Soilmoisture Model 3005) and the technique of Scholander, et al, (1964). Immediately after the reading, leaves were removed from the chamber and rolled to fit into a pre-cut 8-cm length of 9.5-mm diameter tygon tubing. Rubber stoppers sealed both ends and a removable label identified each sample. The tubes were frozen on dry (CO_2) ice and stored in a freezer until osmotic potential was determined. Total elapsed time from leaf excision just above the ligule to placing on dry ice was one minute or less.

Osmotic potentials were measured on a Wescor Vapor Pressure Osmometer (Model 5100C). Leaves were thawed at room temperature for 2 hours in their tubes, then squeezed between metal rollers to thoroughly mix apoplastic (solute-free cell wall water) and symplastic (solute laden water from inside cell) components. This necessitated later correction of measured osmotic potentials for dilution of the solute concentration by percent apoplastic water.

In 1982, leaf water potentials were measured on flag leaves at Hyslop Farm on a total of 6 dates to compare the relative effect of the 0 and 304 kg/ha chloride treatments for all five cultivars. Six leaves per treatment were sampled for each cultivar on 4 dates (May 19, June 9, June 16, and June 23), while 7 leaves were sampled on 2 dates (May 26 and June 2). Pressure-volume curves were established for two flag leaves each of Stephens and Yamhill, as measured on June 15 when the plants were at decimal growth stage 71. The

resulting apoplastic correction for osmotic potentials of all cultivars was 1.27 for May 19 through June 2, and 1.42 for June 9 through June 23.

In 1983, leaf water potentials were measured on 7 flag leaves per treatment for 3 cultivars (Stephens, Yamhill, and Rew) on 27 May. Chloride treatments of 0, 72, and 304 kg/ha were sampled. Measurements were made consecutively from 10:56 A.M. through 2:28 P.M. with average time of 2 minutes per leaf. The apoplastic correction for the osmotic potentials was 1.38, based on the mean of the corrections from 1982.

Growth chamber experiments

Growth chamber experiments were conducted in 1983 and 1984 in order to quantify host-pathogen-chloride interactions for three winter wheat cultivars. Purplestraw, Nugaines, and Yamhill cultivars were grown in nutrient solutions containing either 3.6 meq/l Cl^- and 0.8 meq/l $SO_4^=$ or 0.0 meq/l Cl^- and 4.4 meq/l $SO_4^=$. The levels of other nutrients were equal for both treatments (3.6 meq/l NH_4^+; 2.0 meq/l each of K^+ and $H_2PO_4^+$; and 0.8 meq/L each of NO_3^-, Mg^{++}, and Ca^{++}) (Table 6).

Purplestraw is a soft red winter wheat that is susceptible to stripe rust. Nugaines and Yamhill are soft white winter wheats that are resistant to stripe rust, with Yamhill showing seedling resistance and adult susceptibility.

Seedlings were vernalized in October of each year according to procedures established by R.J. Metzger (O.S.U. Crop Science Dept., personal communication). Seeds were planted at the rate of 10 seeds per pot in 2 inch square plastic pots filled with coarse vermiculite soaked with tap water. Pots were stored on trays in a cold room at a constant temperature of 8°C with fluorescent lights cycling on 8 hour days for 7 weeks. During this time they were sub-irrigated with tap water previously cooled to 8°C. Seven weeks after planting, seedlings were transferred to a growth chamber with temperature set a 15°C and a combination of incandescent and fluorescent lights cycling on 12 hour days. Approximately

Table 6. Nutrient solution for growth chamber experiments

Chemical Reagent	stock g/21	nutrient solution ml/201	chloride treatment
KH_2PO_4	272	40	both
$MgSO_4 \cdot 7H_2O$	394	10	both
$CuSO_4 \cdot 5H_2O$	0.3	2	both
$MnCl_2 \cdot 4H_2O$	7.2	2	both
FeEDTA	8.0	2	both
$ZnSO_4 \cdot 7H_2O$	0.9	2	both
H_3BO_3	11.44	2	both
$H_2MoO_4 \cdot H_2O$	0.36	2	both
$Ca(NO_3)_2 \cdot 4H_2O$	189	20	SO_4
$(NH_4)_2SO_4$	476	20	SO_4
NH_4Cl	300	20	Cl
NH_4NO_3	128	20	Cl
$CaCl_2 \cdot 2H_2O$	116.8	20	Cl

eight weeks after planting, when seedlings reached the three leaf stage (decimal growth stage 13), they were transplanted into coarse vermiculite in one gallon plastic pots at the rate of 10 seedlings per pot in 1983 and 8 seedlings per pot in 1984. Initial watering was with tap water kept at ambient temperature, with lights turned off for the first two days to ease the transition. Thereafter the temperature was set at 7°C night/24°C day with lights cycling at 12 hours for the duration of the experiment. Nutrient solution treatments began at this time and the use of tap water was discontinued.

Pots were arranged in a randomized design with twelve replications, three of which were not inoculated but served as controls for measurement of chloride content and water potential. Each pot corresponded to one experimental unit. Pots were irrigated with the nutrient solutions at the rate of 150 ml per pot 3 times per week. Excess solution was allowed to drain freely.

As each cultivar reached the stage of flag leaf emergence (decimal growth stage 39), the eight plants in each pot were labelled for sampling. Plants numbered 1 through 4 were the most vigorous and at an equivalent stage of development for inoculation. Plants numbered 5 and 6 were designated for water potential measurements, and plants numbered 7 and 8 were used for leaf area determination then combined for leaf chloride analysis.

Leaf area

Leaf area was determined as a basis for calculating percent attack of foliar surfaces by stripe rust. Two plants per pot for a

total of 36 plants per treatment were used to measure leaf area of the flag and second leaf. Length and width were measured with a ruler, then each leaf was excised just above the ligule and passed through a leaf area meter (Li-Cor Models Li-3000 and 3050A). This allowed for later calculation of leaf area for inoculated leaves using the measured length and width. By the end of disease assessment, leaves with visible disease symptoms had senesced at the tips so that the leaf area meter could not give accurate area readings.

Inoculation and disease assessment

A composite collection of stripe rust spores from races prevalent in the Willamette Valley were used to inoculate the flag and second leaves of 36 plants per treatment. Spores were stored in airtight vials in liquid nitrogen until needed. The vials were heat treated at 40°C for 10 min in a beaker of water, then the vials were opened and placed on wet paper towels in another beaker and covered with plastic to hydrate under nearly 100% humidity. After 3 hours of hydration, the spores were removed from the vial and mixed in a 1:5 ratio with sterile talc. The inoculation site of each leaf was approximately one third of the way from the ligule to the tip. It was rubbed gently between the index finger and thumb of the researcher before a thin crosswise line of the spore-talc mixture was applied to the adaxial (upper) surface of the leaf with a small camels hair brush. The edge of the leaf was notched with a razor blade to mark the location of the line throughout the experiment. The inoculated plants were placed in a dew chamber at

100% humidity at 18°C for 18 hours to provide conditions suitable for germination of spores. They were returned to the growth chamber under previous conditions to await the appearance of lesions.

Disease incidence was recorded as both the number of individual lesions and the number of leaves with visible lesions. Disease severity as foliar percent attack was calculated using the individual and cumulative lesion length per treatment and cultivar on each observation date. The latent period was recorded as the time between inoculation and when lesions first appeared, after which time individual lesions were measured by length and width in centimeters and patches were measured as trapezoids. On each leaf the lesions were measured in either or both ways to determine the total area covered by lesions. The lesion area was multiplied by the estimated average width per lesion (0.1 cm) then divided by the mean leaf area for the cultivar and treatment to determine a foliar percent attack for comparing the effects of the two chloride treatments.

Leaf chloride content

The excised leaves from leaf area measurements for each cultivar and treatment were collected as were the remaining plant parts, both being bagged and oven dried for subsequent chloride analysis as described for field samples.

Water potential components

Predawn leaf water potentials were measured the day before inoculation on 72 leaves (18 flag and 18 second leaves per treatment) using the pressure chamber technique of Scholander, et al. (1964). Immediately after the reading, leaves were removed from the chamber and rolled to fit into a pre-cut 8-cm length of 9.5-mm diameter tygon tubing. Rubber stoppers sealed both ends and a removable label identified each sample. The tubes were frozen on dry (CO_2) ice and stored in a freezer until osmotic potential was determined. Total elapsed time from leaf excision just above the ligule to placing on dry ice was one minute or less.

Osmotic potentials were measured on a Wescor Vapor Pressure Osmometer (Model 5100C). Leaves were thawed at room temperature for 2 hours in their tubes, then squeezed between metal rollers to thoroughly mix apoplastic (solute-free cell wall water) and symplastic (solute laden water from inside cell) components. This necessitated later correction of measured osmotic potentials for dilution of the solute concentration by percent apoplastic water.

Pressure-volume curves were obtained at flowering on 2 leaves per treatment per cultivar according to the procedure introduced by Scholander, et al. (1964) and refined by Tyree and Hammel (1972). Plants were hydrated in their pots in the dark for 18 hours at 5 C after being thoroughly soaked and sub-irrigated with distilled water. Leaves were excised just above the ligule and immediately weighed on an analytical balance to estimate fully turgid weight.

Paired measurements of water potential and subsequent leaf weight were recorded. Expressed sap was blotted with absorbant tissue until equilibrium was reached at each pressure. Eight to ten paired readings were made per leaf up to a maximum pressure of 30-35 bars. Finally leaves were oven dried at 53 C for 24 hours, then reweighed to determine dry weight. Moisture release curves were plotted and apoplastic water content calculated (Appendix Table 2) with elastic modulus calculated where sufficient data fell within the required range. The correction for apoplastic water content was not applied to growth chamber osmotic potentials in 1983 or 1984 because chloride treatment did not significantly change the apoplastic water content.

RESULTS AND DISCUSSION

Results of field Experiments

Disease severity among cultivars

Disease progress curves in Figure 2 illustrate stripe rust severity over time using an average percent attack over all four chloride treatments for cultivars which had visible symptoms of stripe rust in 1982 and 1983. The progress of stripe rust during an epidemic is dependent upon the air temperature and humidity to provide conditions favoring germination and growth of the pathogen within the host. A comparison of disease progress curves for different cultivars in a single crop season may reveal differences in timing of onset of disease, or in disease severity at a given date or a given growth stage of the host.

In 1983, the delay in onset of stripe rust on Rew, Yamhill, and Hyslop (compared to Purplestraw) may reflect the period when the races pathogenic to those cultivars were multiplying on susceptible hosts until acting as secondary inoculum and spreading the disease across the field. At 40 days after inoculation, when flag leaves were fully emerged for all cultivars, Purplestraw had an average severity of 34% compared to Hyslop, Rew, and Yamhill which were all less than 5%. At the same day after inoculation in 1982, Rew showed 18% severity although the plants were at a later growth stage. Purplestraw severity increased from 34% to 88% between flag leaf emergence and anthesis. Over the same time period, Rew increased from 2% to 25% and Yamhill increased

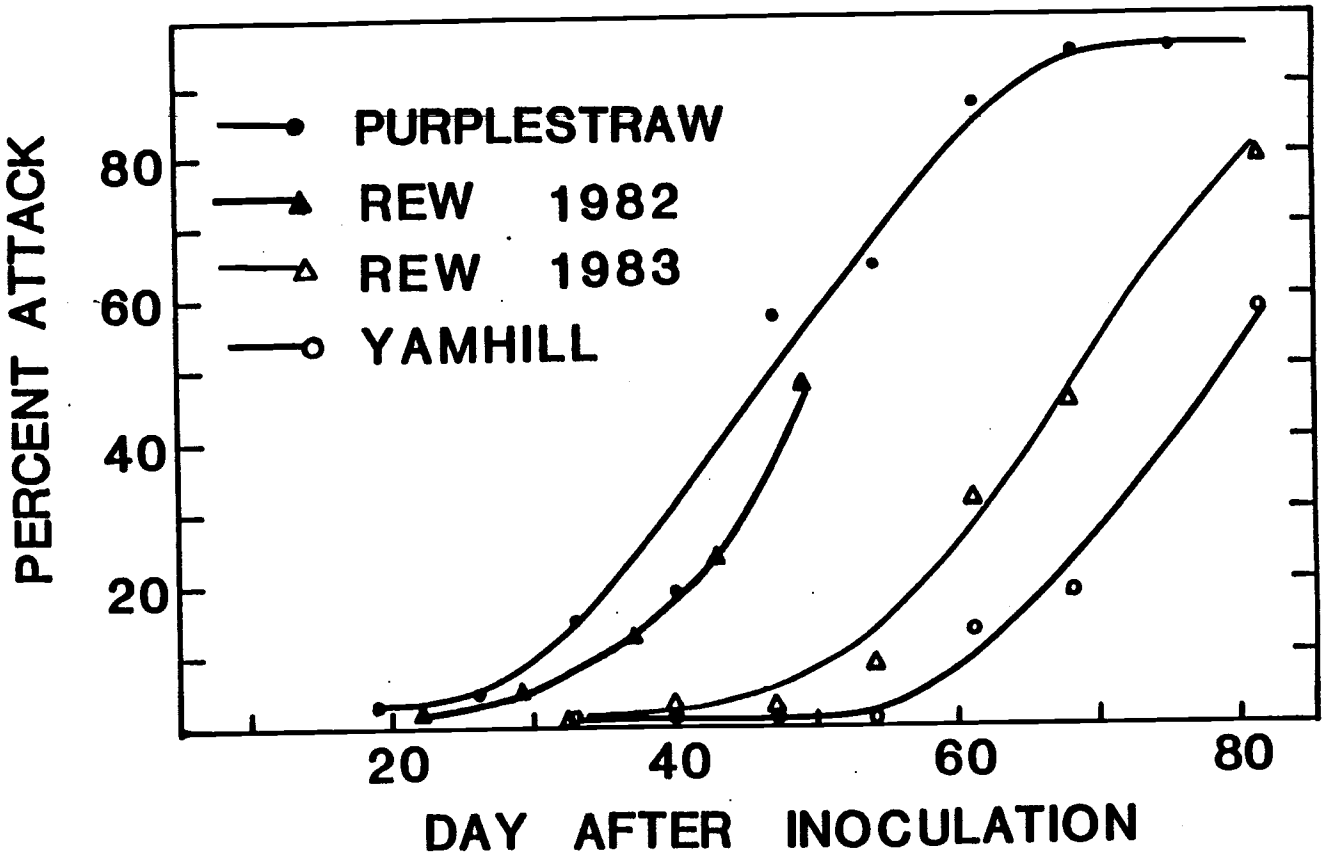

Figure 2. Disease progress curves for cultivars with visible symptoms of stripe rust, field experiments

from 1% to 9%. Hyslop did not develop an epidemic of stripe rust, possibly due to a severe Septoria spp. infection beginning about 35 days after inoculation with stripe rust.

By late spring, weather conditions generally are less favorable for germination and reproduction of Puccinia striiformis. Limited severity of stripe rust at flag leaf emergence can limit the maximum severity reached before leaves begin to senesce at the soft dough stage of host development. High disease severity during ear emergencewill limit the number of kernels formed, while high severity during grain filling will limit the size of each kernel or the number of kernels filled.

Chloride treatment effects

Disease progress within cultivars

Within cultivars, disease progress curves are useful for comparing the effect of increased chloride levels on length of latent period for primary versus secondary infection cycles, numbers of infection cycles, and disease severity at given growth stages of the host (Figures 3A through 7A).

In order to quantify the observed chloride effect on disease progress, a logit transformation was performed on percent attack data. The resulting lines (Figures 3B through 7B) accounted for percent diseased tissue relative to remaining healthy tissue for secondary infection, and allowed statistical comparison of rate of disease progress and length of latent period. The apparent infection rate is influenced by all factors which govern disease

progress such as weather, the effectiveness of secondary inoculum in causing secondary infections, the ability of the pathogen to reproduce within the host, proportion of tissue diseased versus healthy, the resistance or susceptibility of the host, and the length of primary and secondary latent periods. A decrease in apparent infection rate would reflect slower progress of an epidemic and, other factors equal, lower disease severity at a given point in time.

The latent period indicates the time from inoculation to sporulation. An increase in latent period would delay the progress of the epidemic and, other factors equal, result in fewer infection cycles and lower disease severity at a given point in time. Various combinations of changes in apparent infection rate and latent period can result in increased, decreased, or the same level of disease severity at a later date.

Linear regression was conducted for each cultivar with composite logit values within treatments as the dependent variable and day after inoculation as the independent variable. Logit lines were compared between chloride treatments within cultivars. The significant difference between chloride treatments, and the potential interactive effect of changes in apparent infection rate and latent period is illustrated for four chloride treatments for each cultivar (Figure 3B through 7B). Lines have been plotted in these figures to compare the effects of the four chloride treatments on disease progress within cultivars, given the appropriate slopes and intercepts (Table 7).

Purplestraw disease progress curves show a decrease in disease severity with increased chloride rates (Figure 3A). On each disease assessment date the 0 kg Cl/ha treatment had higher foliar percent attack than the three higher chloride rates. As estimated from the curves, added chloride decreased the number of infection cycles from 4 to 3, and increased the primary latent period from 12 to 22 days. Subsequent latent periods were approximately 14 days for all chloride treatments. Logit transformation of the percent attack observations revealed a significant decrease in apparent infection rates and minor increases in latent periods with added chloride (Figure 3B and Table 7).

Yamhill disease progress curves showed no differences in disease severity between chloride treatments until after flowering, when the 0 kg Cl/ha treatment increased in percent attack at a rate faster than that of higher chloride rates (Figure 4A). All treatments were limited to a primary infection cycle with latent periods of uniform length. A comparison of logit lines indicated a significant decrease in apparent infection rate with added chloride (Figure 4B and Table 7). Latent period increased slightly at higher chloride rates.

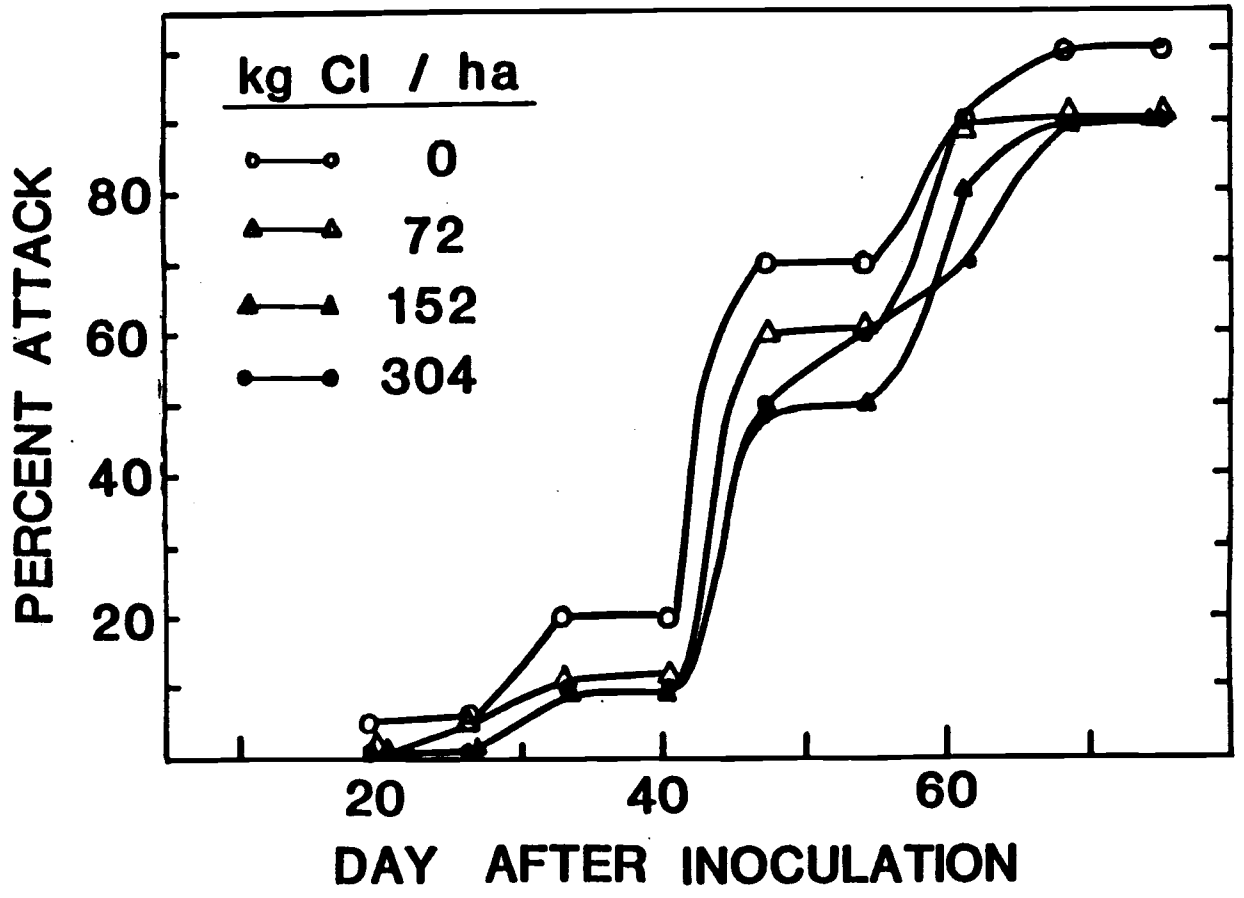

Figure 3A. Disease progress curves for Purplestraw cultivar as affected by chloride treatment

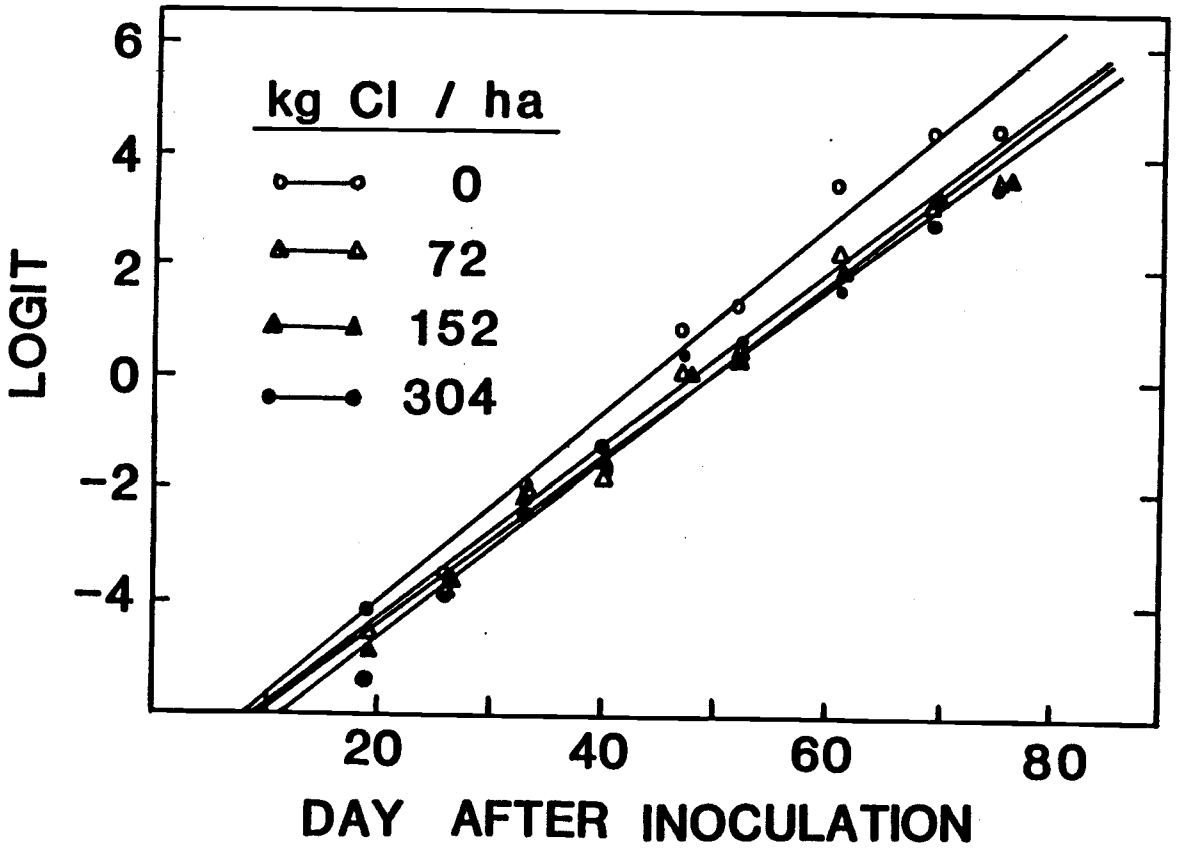

Figure 3B. Logit lines for Purplestraw cultivar comparing apparent infection rate and latent period as affected by chloride treatment

Table 7. Effect of field chloride treatment on apparent infection rate, intercept, and calculated latent period based on logit transformation of disease severity in various cultivars

Chloride Treatment	Cultivar: Rew (1982)	Rew (1983)	Purple-straw	Yamhill	Hyslop
kg/ha					
	Apparent infection rate				
0	0.1594	0.2018	0.1713	0.2160	0.0988
72	0.1736**	0.1767*	0.1533*	0.1993**	0.1204
152	0.1878*	0.1816*	0.1492*	0.1916*	0.1591*
304	0.1745	0.2078	0.1573*	0.1910*	0.1090**
	Intercept				
0	-17.44	-14.20	-7.62	-16.84	-10.44
72	-18.98	-12.75	-7.51	-15.96	-11.13
152	-20.38*	-13.31	-7.33	-15.62*	-11 99
304	-18.96	-14.56	-7.87*	-15.58*	-10.25
	calculated latent period (day where PA = 1.0)				
0	20.55++	28.57+	17.63	37.67+	40.11+
72	22.83	27.12	18.98	37.99	35.24
152	24.03	28.96	18.29	38.52	27.45
304	22.29	28.93	20.79	38.49	32.83

* significant difference from zero chloride treatment (p=.01)

** significant difference from zero chloride treatment (p=.05)

\+ subtracted 19 days to allow for production of secondary inoculum on susceptible hosts, reflecting multiplication of races pathogenic to this cultivar

++ subtracted 60 days from initial inoculation date to allow for inoculum provided through transplanting of sporulating plants.

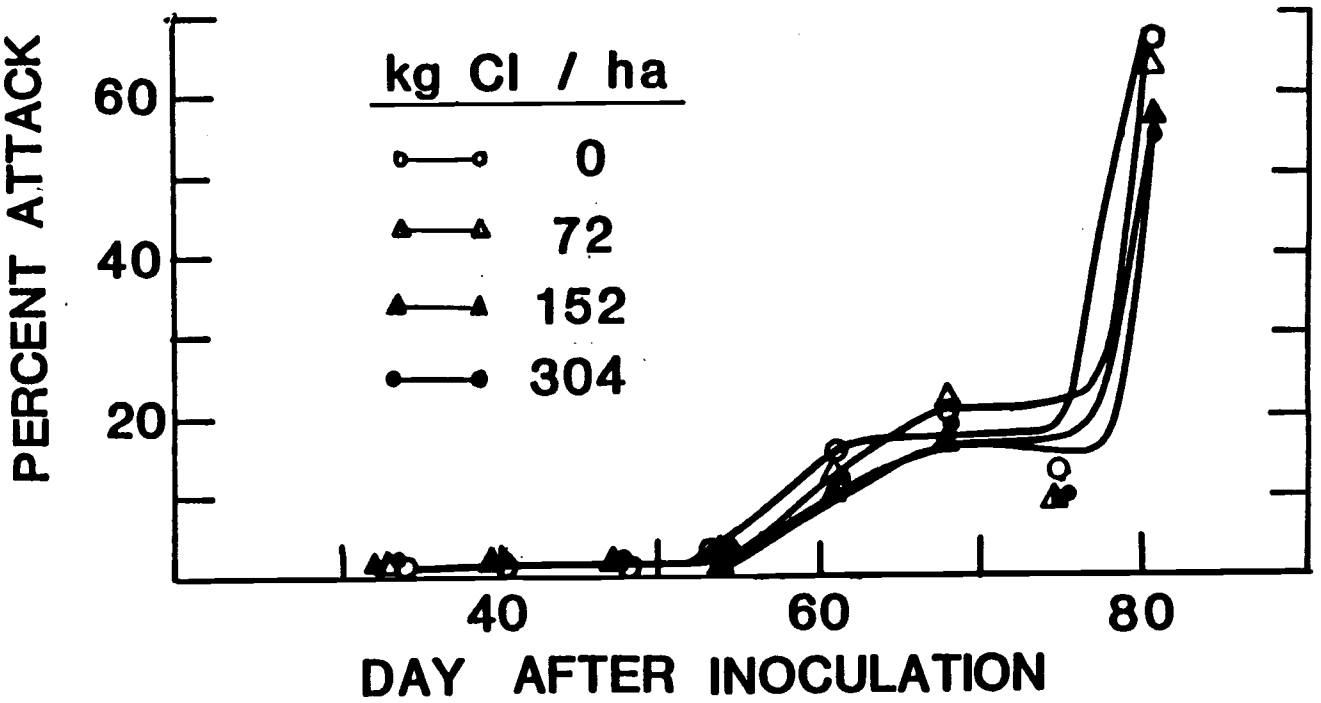

Figure 4A. Disease progress curves for Yamhill cultivar as affected by chloride treatment

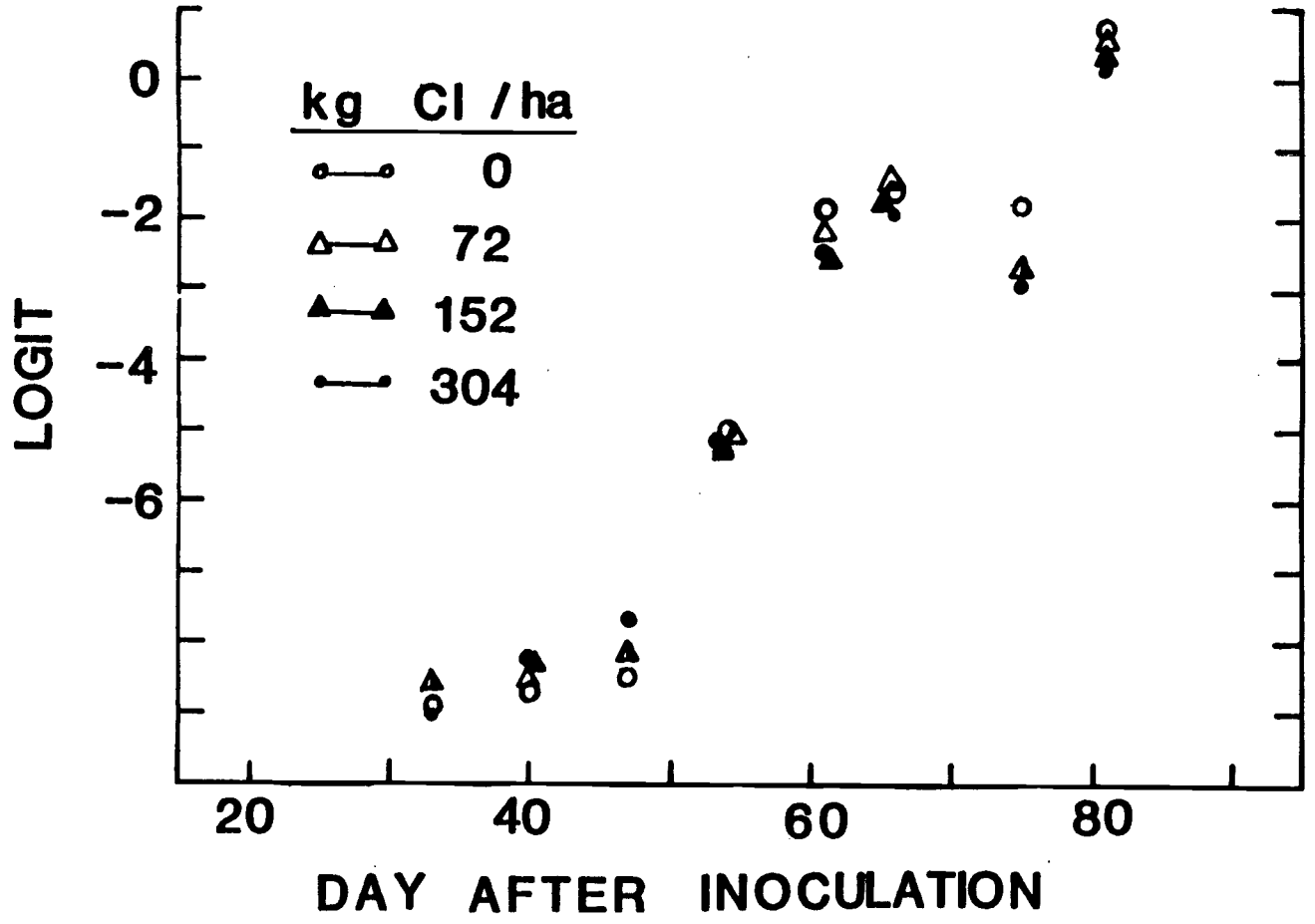

Figure 4B. Logit lines for Yamhill cultivar comparing apparent infection rate and latent period as affected by chloride treatment

In 1983, Rew disease progress curves showed higher disease severity for the 0 kg Cl/ha treatment than for intermediate chloride rates (Figure 5A). The 304 kg Cl/ha treatment reversed the trend and increased severity to the level obtained without added chloride. All treatments completed two infection cycles with latent periods of equivalent length. Increased chloride rates resulted in a significant decrease in apparent infection rate except for 304 kg Cl/ha treatment which caused no change (Figure 5B and Table 7). Latent period changed by less than a day, decreasing with addition of 72 kg Cl/ha and increasing at higher chloride rates. In 1982, Rew disease progress curves were not different in disease severity or length of latent period due to added chloride (Figure 6A). All treatments were limited to a primary infection cycle with maximum of fifty percent attack. Increased chloride rates resulted in a increased apparent infection rate and longer latent period except for 304 kg Cl/ha treatment which caused no change (Figure 6B and Table 7).

Hyslop disease progress curves were not different in disease severity or length of latent period due to added chloride (Figure 7a). All treatments were limited to a primary infection cycle with maximum of three percent attack, probably due to a severe infestation of Septoria spp. Increased chloride rates caused an increase in apparent infection rate and a decreased length of latent period (Figure 7B and Table 7).

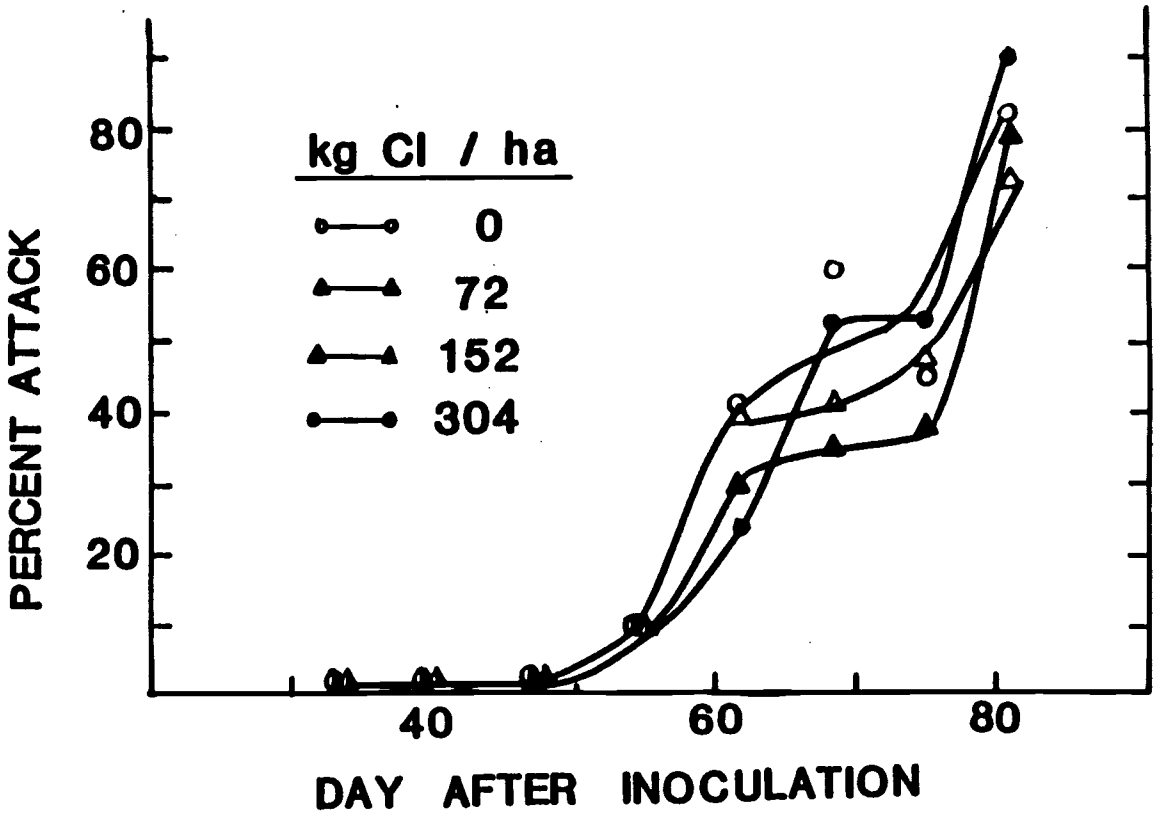

Figure 5A. Disease progress curves for Rew cultivar as affected by chloride treatment 1983

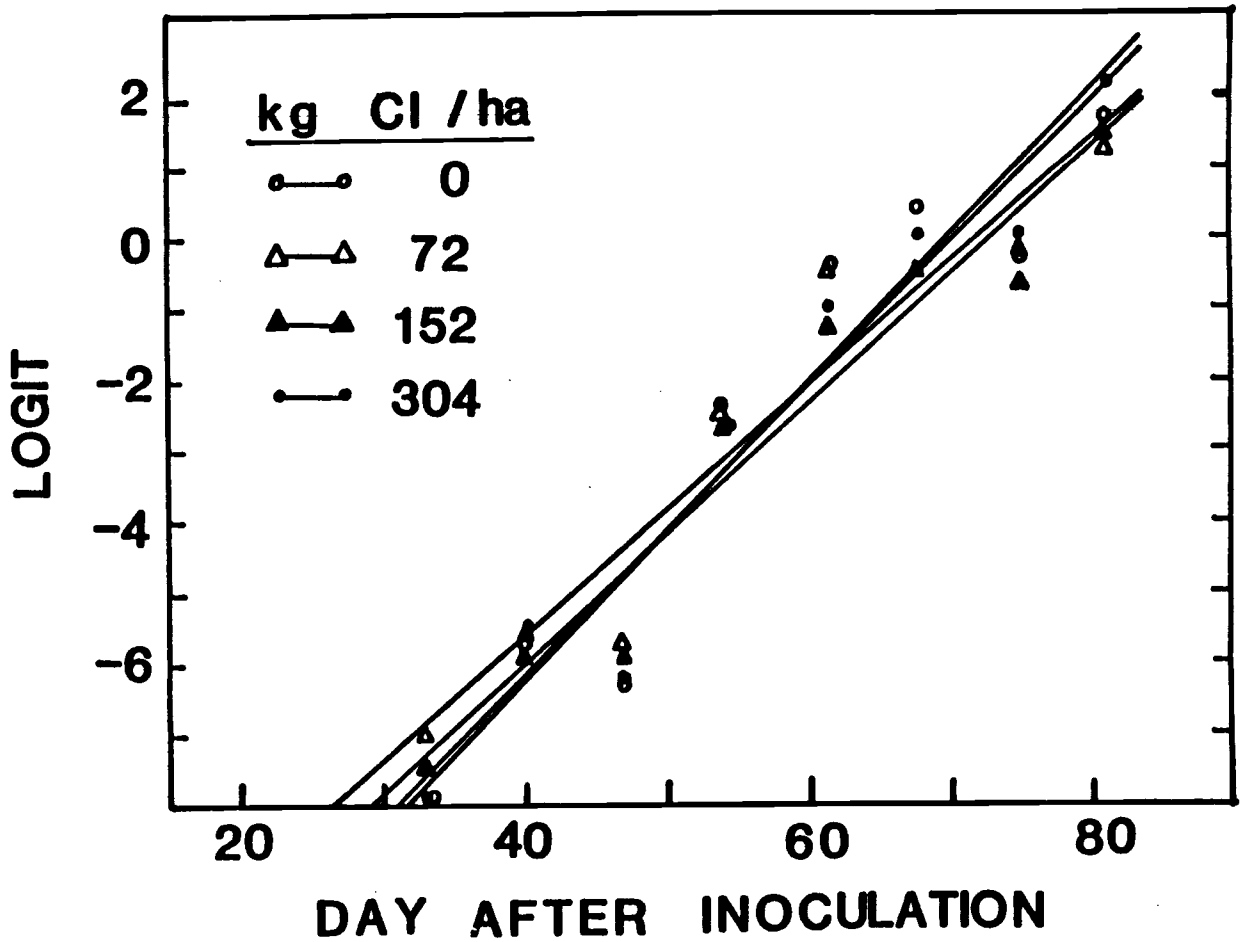

Figure 5B. Logit lines for Rew cultivar comparing apparent infection rate and latent period as affected by chloride treatment 1983

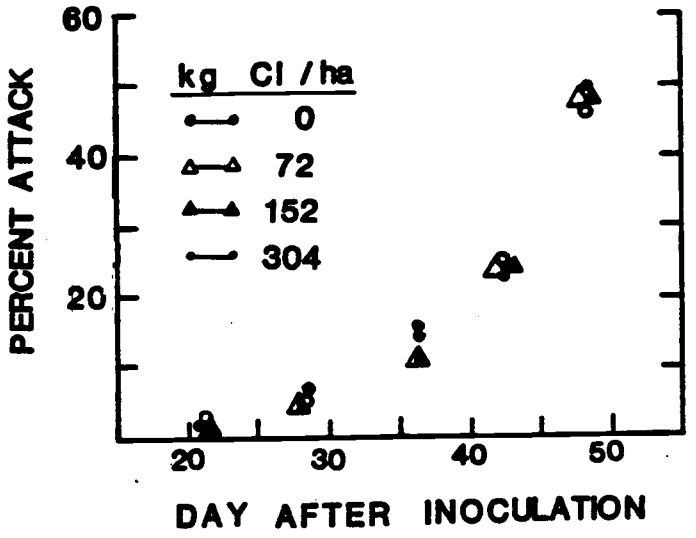

Figure 6A. Disease progress curves for Rew cultivar as affected by chloride treatment, 1982

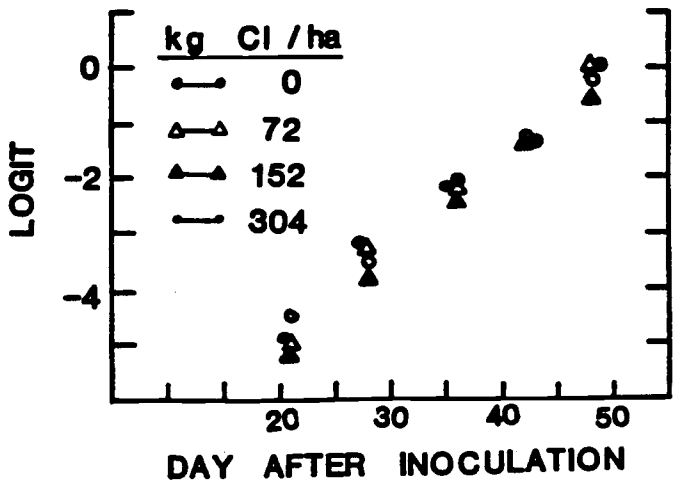

Figure 6B. Logit lines for Rew cultivar comparing apparent infection rate and latent period as affected by chloride treatment, 1982

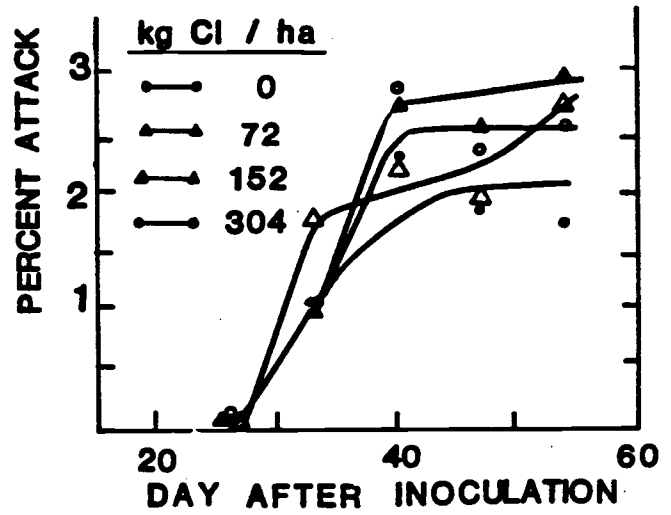

Figure 7A. Disease progress curves for Hyslop cultivar as affected by chloride treatment, 1982

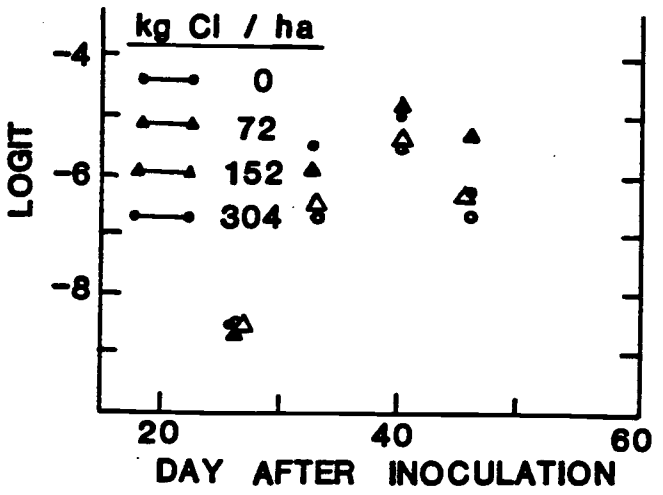

Figure 7B. Logit lines for Hyslop cultivar comparing apparent infection rate and latent period as affected by chloride treatment, 1982

For Purplestraw, Yamhill, and Rew cultivars in 1983, the significant decrease in apparent infection rate with chloride rates of 72 kg Cl/ha or 152 kg Cl/ha resulted in lower foliar percent attack by stripe rust through the ear emergence period of host development (Appendix Tables 4 through 8). This difference was maintained at a lesser magnitude throughout the season. This decrease may reflect slower lesion growth, reduced sporulation by lesions, limited germination of subsequent generations of spores, or decreased virulence of secondary and tertiary inoculum. Observations of percent attack as used in field experiments do not permit direct investigation of these factors.

Although latent periods (as observed visually) were not significantly different for the chloride treatments, there was a three day delay of onset of the stripe rust epidemic at the higher chloride rates for Purplestraw and for Rew in 1982. In a geographic area such as Oregon where climate limits germination of spores after June, this small difference in date of onset can have a large effect on disease progress by limiting the epidemic to three infection cycles instead of four as occurred with Purplestraw. In addition to chloride related lengthening of latent period, delay of onset of epidemics can be caused by climatic conditions unsuitable for germination of spores, or when the races of stripe rust pathogenic to a given cultivar are present as a small proportion of the primary inoculum. The delay reflects the need for the pathogenic races to multiply before disease becomes visible. In these experiments all cultivars were inoculated together so that climatic conditions were similar.

Yield

Analysis of variance for 1982 and 1983 grain yields showed significant differences between cultivars and chloride treatments but no significant cultivar by chloride treatment interaction (Table 8 and 9). In general, the yields followed expected ranking for the cultivars under growing conditions in the Willamette Valley. In 1982, Hill 81 had the highest yield, followed in order by Stephens and Yamhill, with no statistical significant difference between them. OR 67-237 ranked next and was significantly lower in yield than Hill 81, but not statistically different from Stephens or Yamhill. Rew yield was significantly lower than the other cultivars in 1982. Yields were significantly increased with chloride additions at the rate of 72 kg Cl/ha as compared to the zero chloride rate. As chloride rates increased from 72 to 304 kg Cl/ha, yields were reduced to the level of the check treatment recieving no chloride.

1983 grain yield was significantly highest for Rew, followed by Hyslop and Stephens which were not significantly different from each other. Yamhill was significantly lower in yield than the previous three cultivars, and Purplestraw had the lowest yield by a wide margin. Yields were increased significantly by the application of 72 kg Cl/ha, but showed no change as the chloride rate was increased from 72 to 304 kg Cl/ha. Grain yields in 1983 were 50 % less than 1982 largely due to insufficient nitrogen fertilization to replenish that used by oats growing in the plots instead of a fallow period.

Table 8. Effect of chloride treatment on grain yield among cultivars, field experiments 1982

Chloride Treatment	Cultivar					trt mean
	Rew	OR 67-237	Stephens	Hill 81	Yamhill	
	kg/ha					
0	6350	6879	7217	7753	7316	7103
72	6550	7469	7836	8018	7951	7565
152	6452	7511	7559	7815	7357	7339
304	6203	6760	7588	7682	7616	7170
cult mean	6388	7154	7549	7816	7560	----

LSD (.05) cultivar mean 478
LSD (.05) chloride treatment mean 242
LSD (.05) cultivar by chloride treatment 543

Analysis of Variance

Source	df	MSE	F	significance
Main plot				
Cultivar	4		8.65	.0016
Error a	12	577384		
Sub-plot				
Chloride trt	3		5.84	.0019
Cult by Cltrt	12		.91	.5358
Error b	45	145194		
Block	3			
Total	79			

Table 9. Effect of chloride treatment on grain yield among cultivars, field experiments 1983

Chloride Treatment	Cultivar					trt mean
	Purple-straw	Hyslop	Yamhill	Stephens	Rew	
	kg/ha					
0	2330	3504	2797	3134	4274	3208
72	2862	4105	3363	3835	4502	3733
152	2980	4087	3497	4288	4489	3868
304	2938	4067	3555	4119	4666	3869
cult mean	2777	3940	3302	3844	4483	----

LSD (.05) cultivar mean 458
LSD (.05) chloride treatment mean 243
LSD (.05) cultivar by chloride treatment 544

Analysis of Variance

Source	df	MSE	F	significance
Main plot				
Cultivar	4		12.83	.0003
Error a	12	528767		
Sub-plot				
Chloride trt	3		13.53	.0000
Cult by Cltrt	12		.59	.8317
Error b	45	145939		
Block	3			
Total	79			

Analysis of variance for yield components showed head counts significantly different by cultivar in both years (Table 10 and 11). Stephens and Hill 81 had the highest head counts in 1982, followed by Yamhill, then OR 67-237 and Rew. In 1983 Purplestraw had the highest head counts by far, followed by significantly lower counts for Stephens and Rew, then Yamhill. Hyslop had the lowest counts in 1983.

Kernel weights were significantly different by cultivar and chloride treatment in 1982, and by the interaction of cultivar and chloride treatment in 1983 (Tables 10 and 11). Corresponding test weights showed significant cultivar and chloride treatment effects in both years with no interaction. Stephens had the highest kernel weights followed by Rew and Hill 81 in 1982. Significantly lower kernel weights were measured for OR 67-237 and Yamhill in 1982. Chloride additions of 72 kg Cl/ha in 1983 significantly increased kernel weight with no further increase at higher chloride rates and no significant difference between higher chloride rates. The ranking for kernel weights in 1983 in descending order was Stephens, Rew, Yamhill, Hyslop, and Purplestraw.

Table 10. Head counts, kernel weight, and test weight as influenced by cultivar and chloride treatment, 1982

Main effect	Head count	Kernel weight	Test weight
Cultivar	#/2 m row	mg	kg/hl
Rew	114	45.4	79.7
OR 67-237	108	43.0	76.9
Stephens	154	52.7	78.3
Yamhill	143	38.8	79.3
Hill 81	157	44.9	76.7
LSD (.05)	11.5	0.68	0.49
Chloride trt			
---kg/ha---			
0	133	44.4	77.9
72	137	45.0	78.4
152	135	45.3	78.3
304	135	45.4	78.3
LSD (.05)	10.5	0.68	0.35

ANOVA

Source	df	P value	P value	P value
Cultivar	4	.0000	.0000	.0000
Chloride trt	3	.9374	.0275	.0301
Cult by cltrt	12	.9837	.5887	.6416
MSE cult	12	224.7	1.634	0.4075
MSE cltrt	45	346.82	1.152	0.3053

Table 11. Head counts, kernel weight, and test weight as influenced by cultivar and chloride treatment, 1983

Main effect	Head count	Kernel weight	Test weight
Cultivar	#/2 m row	mg	kg/hl
Purplestraw	154	35.9	74.6
Hyslop	89	37.7	74.0
Yamhill	101	41.0	72.7
Stephens	110	47.5	75.5
Rew	117	41.9	75.8
LSD (.05)	9.77	0.058	0.984
Chloride trt			
---kg/ha---			
0	110	39.4	73.8
72	118	41.1	74.7
152	115	42.2	74.8
304	113	41.5	74.8
LSD (.05)	9.36	1.14	0.41

ANOVA

Source	df	P value	P value	P value
Cultivar	4	.0000	.0000	.0007
Chloride trt	3	.5251	.0021	.0000
Cult by cltrt	12	.8686	.0280	.1438
MSE cult	12	240.490	2.7158	2.439
MSE cltrt	45	310.699	3.2168	0.4150

Leaf chloride content

In 1982, leaf chloride content was measured on 5 dates throughout the season (Figure 8). Using the mean leaf chloride content across all five cultivars, the ammonium sulfate treatment resulted in significantly lower leaf chloride content than the three ammonium chloride treatments for each date. There was a significant difference among the ammonium chloride treatments for each date with the 304 kg/ha chloride rate showing highest leaf chloride content followed in order by the 152 kg/ha and 72 kg/ha rates. The two week period encompassing flag leaf emergence (April 27 to May 11) showed an increase in chloride content for the ammonium sulfate while the ammonium chloride treatments decreased chloride content. There was no significant change in chloride content within treatment after the flag leaves emerged for the 0 kg/ha or the 304 kg Cl/ha treatments, but the 72 and 152 kg/ha chloride rates showed significant decreases in leaf chloride content between the last two measurement dates (June 7 to June 22).

During the field experiment of 1982, the ammonium chloride treatments showed an initial decrease in percent chloride in leaves during flag leaf emergence, then maintained the lower level throughout the season. The decrease may be due to a noninteractive dilution effect (Jarrell and Beverly, 1981) where the concentration of a nutrient decreases due to continuation of plant growth after uptake. The chloride was applied at spring fertilization as a single application when plants were tillering, followed 8 weeks later by flag leaf emergence. In contrast, the ammonium sulfate treatment initially increased in percent chloride

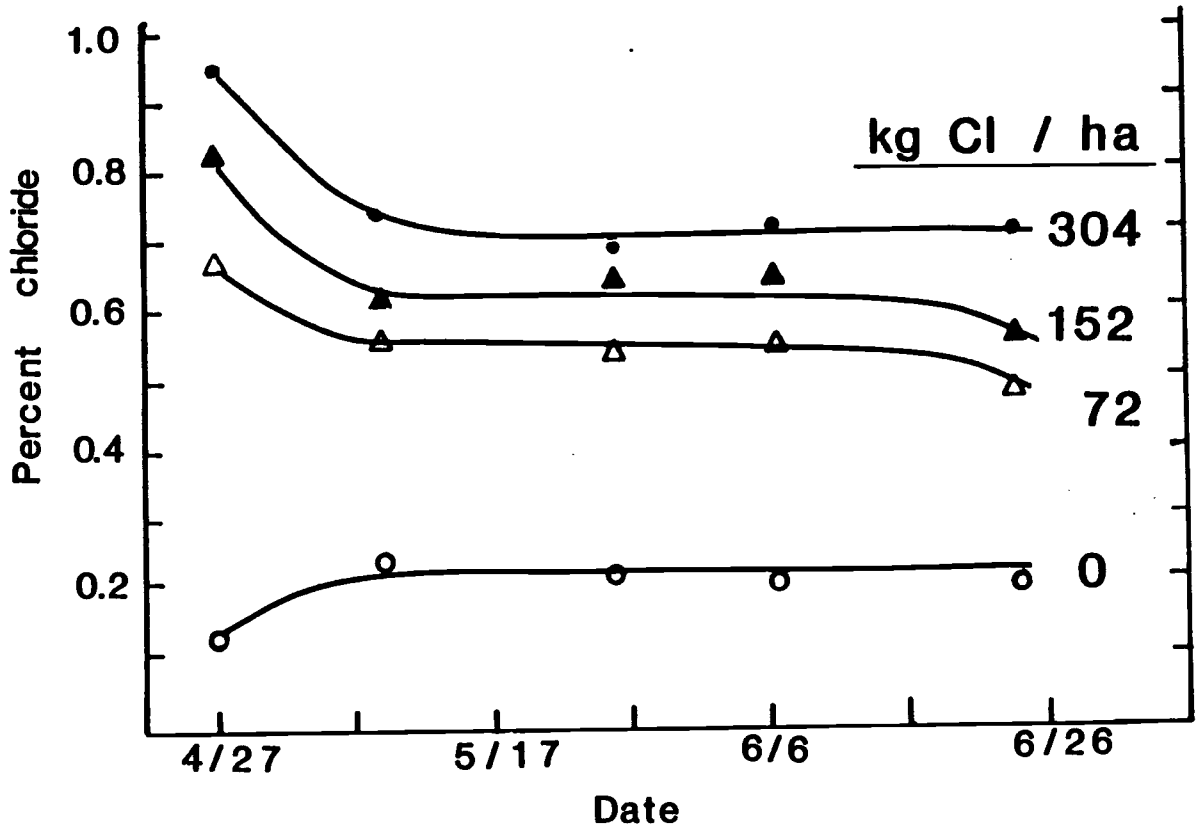

Figure 8. Leaf chloride content as affected by chloride treatment over five dates in 1982, data averaged across cultivars

in leaves, then maintained a level significantly below that of the ammonium chloride treatments for the remainder of the season. The initial increase in chloride content for the 0 kg/ha treatment may reflect increased uptake of residual chloride from soil as the root system developed and explored a larger rooting volume. In both years, a background level of 0.13 to 0.30 percent chloride was present in the 0 kg/ha treatment for all cultivars, reflecting fall fertilization with 9 kg/ha chloride, and chloride in the soil.

Analysis of variance for percent chloride content showed significant interaction between cultivar and chloride treatment in 1982 and 1983 (Table 12 and 13). In both years, all cultivars showed the largest increase in percent chloride with addition of chloride at the rate of 72 kg Cl/ha. Stephens contained the lowest percent chloride at each chloride rate, ranging from 0.13 percent at zero chloride to 0.52 percent maximum at 304 kg Cl/ha. There was no significant difference in chloride content between intermediate chloride rates. OR 67-237 ranked second lowest in percent chloride and was comparable to Hill 81 in the magnitude of the significant increase in chloride levels at each rate, reaching maxima of 0.61 and 0.67 percent chloride, respectively. Rew ranged from 0.23 to 0.94 percent chloride with significant increases at each chloride rate and surpassing the Stephens maximum at a chloride rate of only 72 kg Cl/ha. Yamhill had the highest leaf chloride concentration (from 0.27 to 1.06 percent chloride) with significant increases accompanying each added increment of chloride. At 72 kg Cl/ha, Yamhill flag leaves contained 0.73% chloride which was higher than the chloride content of Stephens,

Table 12. Effect of field chloride treatment (1982) on leaf chloride content among cultivars, mean of five dates

Chloride Treatment	Cultivar				
	Rew	OR 67-237	Stephens	Hill 81	Yamhill
---kg/ha--	----------percent----------				
0	.23	.17	.13	.20	.27
72	.68	.47	.42	.50	.73
152	.85	.54	.42	.59	.88
304	.94	.61	.52	.67	1.06

LSD (.05) cultivar by chloride treatment .047

----------Analysis of Variance----------

Source	df	MSE	F	significance
Cultivar	4	1.857	283.4	.0000
Chloride trt	3	5.936	1038.9	.0000
Cult by Cltrt	12	0.134	22.8	.0000
Date	4	0.257	18.1	.0001
MSE cult	60	.00655		
MSE Chloride trt	225	.00571		

Table 13. Effect of field chloride treatment (1983) on leaf chloride content among cultivars

Chloride Treatment	Cultivar				
	Stephens	Rew	Purple-straw	Yamhill	Hyslop
---kg/ha--	----------percent----------				
0	.18	.28	.30	.26	.28
72	.49	.82	.99	.86	.80
152	.59	.94	1.18	1.03	.73
304	.56	.94	1.19	1.08	1.01

LSD (.05) cultivar by chloride treatment .151

----------Analysis of Variance----------

Source	df	MSE	F	significance
Main plot				
Cultivar	4	.4635	58.09	.0000
Error a	12	.00798		
Sub-plot				
Chloride trt	3	2.017	164.45	.0000
Cult by Cltrt	12	.0433	3.53	.0010
Error b	45	.0122		
Block	3	.0227		
Total	79			

OR 67-237, and Hill 81 wheats receiving 304 kg Cl/ha.

In 1983, Yamhill, Rew, and Stephens ranked in descending order for percent chloride content, which agreed with results from 1982. Purplestraw leaves had the highest percent chloride at each chloride rate with a range from 0.30 at 0 kg Cl/ha to 1.19 at 304 kg Cl/ha. Hyslop ranked between Yamhill and Rew in percent chloride and was the only cultivar that showed a significant increase in percent chloride with added chloride from the 152 kg Cl/ha rate to the 304 kg Cl/ha rate. Stephens had the lowest percent chloride at each rate, with 0.49 percent at 72 kg Cl/ha rate compared to 0.80 percent or above for the other four cultivars at the same chloride rate.

Water potential

Analysis of variance for leaf water potential (Psi leaf) in 1982 showed the cultivar effect significant on all dates except June 9 (Table 14). Chloride treatment effect was significant on May 19 and June 9. The interaction of cultivar and chloride treatment was not significant on any of the six dates. The leaf water potential became more negative as the season progressed although the cultivars were not consistent in their ranking from lowest to highest potential (Table 15). Generally, OR 67-237 had the most negative potential with Rew, Yamhill, and Hill 81 at intermediate levels. Stephens had the highest leaf water potentials. Increased chloride rates from zero to 304 kg Cl/ha resulted in more negative leaf water potentials on each date (Table 16).

Table 14. Analysis of Variance for leaf water potential of field experiment, 1982

Source	df	Psi Leaf P value	Psi osmotic P value	Psi turgor P value
May 19				
Cultivar	4	.0243	.0021	.2201
Chloride trt	1	.0116	.0009	.0456
Cult by cltrt	4	.2634	.3104	.0662
Block (time)	5			
Total	59			
MSE	45	1.0010	2.2133	1.6756
May 26				
Cultivar	4	.0000	.0000	.0000
Chloride trt	1	.2451	.0640	.3069
Cult by cltrt	4	.6700	.1812	.0020
MSE	54	2.7522	2.9224	1.6398
June 2				
Cultivar	4	.0278	.0016	.0724
Chloride trt	1	.1366	.4715	.5463
Cult by cltrt	4	.9685	.9980	.9646
MSE	54	2.5031	4.0377	2.3620
June 9				
Cultivar	4	.2628	.0001	.0001
Chloride trt	1	.0351	.0287	.4878
Cult by cltrt	4	.2717	.2738	.4446
MSE	45	2.5742	4.0468	2.2984
June 16				
Cultivar	4	.0163	.0001	.0001
Chloride trt	1	.2025	.7988	.7039
Cult by cltrt	4	.4121	.7567	.6859
MSE	45	1.7099	9.1083	5.8004
June 23				
Cultivar	4	.0277	.4946	.0241
Chloride trt	1	.5875	.2607	.3628
Cult by cltrt	4	.5317	.0394	.0107
MSE	45	3.5731	13.4632	11.7185

Table 15. Effect of cultivar on leaf water potential, 1982 field experiment

Cultivar	Psi Leaf	Psi Osmotic	Psi Turgor
-----kg/ha-----	----------bars----------		
May 19 : Flag leaf emerged			
Rew	-15.07	-29.15	14.08
OR 67-237	-15.58	-30.31	14.72
Stephens	-14.53	-28.17	13.63
Hill 81	-14.66	-28.67	14.00
Yamhill	-15.64	-30.27	14.63
LSD (.05) cult mean	0.82	1.22	0.89
May 26			
Rew	-17.59	-31.16	13.57
OR 67-237	-18.61	-34.34	15.73
Stephens	-15.80	-31.32	15.51
Hill 81	-17.61	-33.80	16.19
Yamhill	-15.78	-32.32	16.53
LSD (.05) cult mean	1.26	1.30	0.97
June 2			
Rew	-16.93	-27.58	10.65
OR 67-237	-17.98	-30.21	12.23
Stephens	-16.02	-27.20	11.17
Hill 81	-16.94	-28.86	11.92
Yamhill	-16.47	-27.94	11.47
LSD (.05) cult mean	1.20	1.52	1.17
June 9 : Flowering			
Rew	-20.72	-31.74	11.02
OR 67-237	-21.93	-35.68	13.75
Stephens	-20.72	-32.83	12.11
Hill 81	-21.60	-33.57	11.96
Yamhill	-21.40	-31.93	10.52
LSD (.05) cult mean	1.10	1.65	1.25
June 16			
Rew	-19.92	-31.96	12.03
OR 67-237	-21.40	-37.18	15.78
Stephens	-19.55	-32.86	13.31
Hill 81	-20.19	-33.66	13.47
Yamhill	-20.10	-30.84	10.74
LSD (.05) cult mean	1.08	2.48	1.98
June 23			
Rew	-25.29	-35.28	9.99
OR 67-237	-23.31	-36.86	13.54
Stephens	-24.93	-35.07	10.14
Hill 81	-25.77	-34.82	9.05
Yamhill	-25.30	-36.80	11.50
LSD (.05) cult mean	1.55	4.27	2.82

Table 16. Effect of chloride treatment on leaf water potential of 1982 field experiment. Data averaged across cultivars.

Chloride treatment	Psi Leaf	Psi Osmotic	Psi Turgor
-----kg/ha-----	----------bars----------		
May 19 : Flag leaf emerged			
0	-14.7	-28.63	13.87
304	-15.4	-30.00	14.56
LSD (.05)	0.5	0.77	0.67
significance	.012	.001	.046
May 26			
0	-16.85	-32.20	15.35
304	-17.31	-32.98	15.67
LSD (.05)	0.79	0.82	0.61
significance	NS	NS	NS
June 2			
0	-16.59	-28.19	11.60
304	-17.16	-28.54	11.38
LSD (.05)	0.76	0.96	0.74
significance	NS	NS	NS
June 9 : Flowering			
0	-20.83	-32.57	11.74
304	-21.73	-33.74	12.01
LSD (.05)	0.83	1.05	0.79
significance	.035	.029	NS
June 16			
0	-20.02	-33.20	13.19
304	-20.45	-33.40	12.95
LSD (.05)	0.68	1.56	1.25
significance	NS	NS	NS
June 23			
0	-24.79	-35.23	10.44
304	-25.06	-36.31	11.25
LSD (.05)	0.98	1.90	1.77
significance	NS	NS	NS

Analysis of variance for leaf osmotic potential (Psi osmotic) in 1982 showed the cultivar effect significant on all dates except June 23 (Table 14). Chloride treatment effect was significant on May 19 and June 9. The interaction was significant only on June 23. Osmotic potentials became more negative as the season progressed with the exception of June 2 when potentials approximated those of May 19 before decreasing again the next week. OR 67-237 consistently measured most negative in Psi osmotic, followed by Yamhill, Hyslop, and Stephens with Rew generally highest (Table 15). Increased chloride rates resulted in more negative osmotic potentials on each date (Table 16).

Analysis of variance for leaf turgor potential (Psi turgor) in 1982 showed the cultivar effect significant except on may 19 and June 2 (Table 14). Chloride treatment effect was significant on May 19. The interaction was significant on May 26 and June 23. Turgor potentials showed no pattern of increase or decrease as the season progressed. OR 67-237 generally measured most positive in Psi turgor, followed by Stephens, Yamhill, and Hyslop at intermediate potentials and with Rew generally lowest (Table 15). Increased chloride rates resulted in more positive turgor potentials on each date except June 2 and June 16 although the differences were not significant (Table 16).

In 1983 a single sampling date compared the effects of the 0 kg/ha, 72 kg/ha and 304 kg/ha chloride rates on water potential components. Analysis of variance and a protected LSD test (Fischer (1935) as detailed in Snedecor and Cochran, 1980) showed a

significant interaction between cultivar and chloride treatment for leaf water potential (Table 17). Stephens had the lowest potentials, with a significant increase in potentials at 72 kg Cl/ha and a non-significant decrease at the rate of 304 kg Cl/ha compared to the zero chloride treatment. Yamhill had intermediate potentials and Rew had the highest potentials, both with a non-significant decrease in potentials at 72 kg Cl/ha and a non-significant increase at the rate of 304 kg Cl/ha compared to the zero chloride treatment.

Analysis of variance of osmotic and turgor potentials in 1983 showed cultivar effect significant but no chloride treatment or interaction effects (Table 18 and 19). Yamhill osmotic potentials were significantly more negative than those of Rew or Stephens which were not significantly different from each other. Stephens turgor potentials were significantly more positive than those of Rew or Yamhill, and Yamhill was significantly most negative.

Table 17. Interaction of cultivar and chloride treatment on leaf water potential among cultivars, field 1983

	Cultivars		
Chloride treatment	Yamhill	Stephens	Rew
-----kg/ha-----	----------bars----------		
0	-19.61	-21.85	-18.00
72	-20.68	-19.42	-19.88
304	-19.70	-20.91	-19.12
cultivar mean	-20.00	-20.73	-19.00

LSD (.05) interaction 2.56

----------Analysis of variance----------

Source	df	MSE	variance ratio	P value
Cultivar	2	15.8068	4.7027	.0136
Chloride trt	2	0.1630	0.04855	.9527
Cult by cltrt	4	9.5575	2.8435	.0340
Block (time)	6	2.6468		
Error	48	3.3612		
Total	62			

Table 18. Effect of field chloride treatment (1983) on leaf osmotic potential

Chloride treatment	Cultivar		
	Yamhill	Stephens	Rew
-----kg/ha-----	----------bars----------		
0	-32.42	-29.74	-28.09
72	-33.88	-27.42	-30.26
304	-34.01	-28.90	-29.38
cultivar mean	-33.44	-28.69	-29.24
LSD (.05) cult mean	1.07		

----------Analysis of variance----------

Source	df	MSE	variance ratio	P value
Cultivar	2	91.534	107.82	.0000
Chloride trt	2	0.882	1.04	.3613
Cult by cltrt	4	1.489	1.75	.1535
Block (time)	6	2.585		
Error	48	0.848		
Total	62			

Table 19. Effect of field chloride treatment (1983) on leaf turgor potential

Chloride treatment	Cultivar		
	Yamhill	Stephens	Rew
-----kg/ha-----	----------bars----------		
0	12.80	7.88	10.09
72	13.19	7.99	10.37
304	14.31	7.99	10.25
cultivar mean	13.44	7.95	10.24
LSD (.05) cult mean	0.04		

----------Analysis of variance----------

Source	df	MSE	variance ratio	P value
Cultivar	2	159.930	149.02	.0000
Chloride trt	2	1.846	1.72	.1886
Cult by cltrt	4	1.311	1.22	.3119
Block (time)	6	3.797		
Error	48	1.069		
Total	62			

Discussion of field experiments

Relationship of disease progress and yield

The cultivar and chloride effects on grain yield occurred in 1982 and 1983 on all cultivars whether or not they developed stripe rust epidemics. This suggests that the increased yields were due to chloride influence on other aspects of stress for the plants. It has been shown that chloride can decrease the severity of take-all root rot on wheat, which may have been a factor in these experiments despite the fallow or oats immediately preceding the wheat crops.

Relationship of disease progress and leaf percent chloride

In general, chloride treatment effects on disease progress are consistent with chloride treatment effects on leaf percent chloride. The significant decrease in disease occurred with addition of 72 to 152 kg Cl/ha which corresponded to significant increases in leaf percent chloride for all cultivars. The interaction of chloride content and disease progress among the higher chloride rates varies within and between cultivars.

Purplestraw cultivar responded to increased leaf percent chloride with lower apparent infection rates, although the 152 kg Cl/ha rate had a greater effect than the other chloride rates. Again, no significant increase in percent chloride occurred with the added chloride above 152 kg Cl/ha although that increment increased the latent period above that of the zero chloride rate

and again above that shared by the intermediate chloride rates. The net effect of increased percent chloride in Purplestraw appears to be slower disease progress and lower disease severity in two stages. It occurs initially with chloride rates of 72 kg Cl/ha and 152 kg Cl/ha, then further at the 304 kg Cl/ha rate. It is not clear how the highest chloride rate decreases disease without a significant increase in percent chloride in the leaves.

Yamhill cultivar was one of the highest accumulators of percent chloride in both years but only suffered from a stripe rust epidemic in 1983. In that year the largest decrease in apparent infection rate corresponded to the largest increase in percent chloride at the 72 kg Cl/ha rate. Smaller and insignificant increases in percent chloride occurred with additional increments of chloride added, with no additional decreases in the apparent infection rate. The two highest chloride rates significantly increased the latent period above that of zero and 72 kg Cl/ha rates with no significant difference between themselves. The increases obtained in percent chloride in this cultivar at chloride rates of 72 kg Cl/ha and 152 kg Cl/ha appeared to correlate with slower disease progress and lower disease severity. Where no further significant increase in percent chloride was obtained at the highest chloride rate of 304 kg Cl/ha, disease progress and severity did not change from previous levels.

In 1982, Rew cultivar showed significant increases in leaf percent chloride content with each added increment of chloride fertilizer. The magnitude of the increase was greatest at the 72 kg Cl/ha rate, yet the 152 kg Cl/ha rate was more significant in

increasing the apparent infection rate and increasing the length of the calculated latent period above that of the zero chloride treatment. The 304 kg Cl/ha rate caused both factors to decrease again with a high level of variation so that they were not significantly different from the zero chloride treatment. In 1983, Rew showed greater increases in percent chloride at 72 kg Cl/ha, reaching the 1982 maximum level of 0.94 with only 152 kg Cl/ha and maintaining that level despite increased chloride rate to 304 kg Cl/ha. The effect of increased leaf percent chloride was reversed from the previous year as apparent infection rates decreased with added chloride. Latent periods decreased with the initial added chloride then decreased with no significant difference overall. Again, the highest chloride rate showed apparent infection rate and latent period closest to that of the zero chloride treatment.

Hyslop cultivar showed percent chloride not significantly different between intermediate chloride rates, although significant increases occurred at 72 kg Cl/ha and again at 304 kg Cl/ha. Apparent infection rate did not significantly increase until the 152 kg Cl/ha rate, and percent chloride was slightly lower at that rate than it was at 72 kg Cl/ha. The final increment of chloride added decreased the apparent infection rate but retained the significant increase above the zero chloride rate. Latent period decreased with added chloride with no significant difference between the four treatment effects. However, 152 kg Cl/ha showed the greatest decrease in latent period compared to that of the zero chloride rate. The effect of increased percent chloride on Hyslop,

though of doubtful significance due to variation, appears to be faster disease progress and higher levels of disease severity.

Relationship of disease progress and leaf water potential

There was no consistent chloride effect on leaf water potential components in both years despite differences in disease progress. In 1982, the interaction of cultivar and chloride treatment on leaf water potential, osmotic potential, and turgor potential was not significant (Table 20). Rew and Yamhill followed the trends expected due to osmoregulation; leaf water potentials decreased with added chloride while osmotic potentials showed a larger decrease, resulting in an increase in turgor. OR 67-237 showed no change in leaf water potential but followed the expected trends in osmotic and turgor potentials. Stephens and Hill 81 did not change in osmotic potential so that decreases in leaf water potential resulted in decreases in turgor potential. In 1983 (Tables 17 through 19), Rew and Yamhill again followed the expected trends and Stephens increased leaf water potential and osmotic potential and turgor was constant. Purplestraw and Hyslop were not measured in 1983, nor was the 152 kg/ha chloride rate sampled for chloride effects on leaf water potential. The response of Rew and Yamhill suggests that chloride additions can affect turgor potential to a small degree, but the impact of turgor on stripe rust disease progress was not established.

Table 20. Effect of interaction of chloride treatment and cultivar on leaf water potential, data averaged over time for each cultivar, field 1982

Cultivar and Chloride treatment	Psi Leaf	Psi Osmotic	Psi Turgor
-----kg/ha-----	----------bars----------		
Rew			
0	-18.96	-30.40	11.44
304	-19.55	-31.89	12.34
LSD (.05)+	1.42	2.20	1.82
significance	NS	NS	NS
OR 67-237			
0	-19.84	-33.45	13.61
304	-19.77	-34.74	14.97
significance	NS	NS	NS
Stephens			
0	-18.22	-31.32	13.09
304	-18.96	-31.16	12.20
significance	NS	NS	NS
Hill 81			
0	-19.19	-32.14	12.94
304	-19.74	-32.32	12.59
significance	NS	NS	NS
Yamhill			
0	-18.64	-31.04	12.31
304	-19.59	-32.33	12.70
significance	NS	NS	NS

+ LSD averaged over 6 dates

Growth Chamber Experiments Results

Disease incidence

Disease incidence is a measure of the number of leaves that exhibit visual symptoms of disease as a compared to the total number of leaves inoculated or exposed to inoculum. In each experiment, 72 leaves were inoculated with stripe rust spores. In 1983, Nugaines showed slightly higher disease incidence for sulfate treatment than for chloride treatment while in 1984 Nugaines showed significantly higher disease incidence for chloride treatments than for sulfate. Purplestraw showed no significant difference between treatments in 1983 and no visible disease was observed for 1984. No disease was present in 1983 on Yamhill. In 1984 Yamhill, sulfate treatment was slightly higher in disease incidence than the chloride treatment (Table 21).

Table 21. Growth chamber disease incidence among cultivars based on number of leaves visibly diseased out of 72 leaves inoculated per treatment

Cultivar	Chloride trt	Sulfate trt
	----------% diseased----------	
Purplestraw (1983)	33.3	29.2
Nugaines (1983)	16.7	29.2
Nugaines (1984)	73.6	47.2
Yamhill (1984)	20.8	33.3

Disease severity

Analysis of variance showed that leaf area was not significantly influenced by chloride treatment and barely significant by leaf position within cultivars (Table 22). Percent attack values were corrected for mean leaf area per cultivar, leaf,

Table 22. Effect of 1984 growth chamber chloride treatment, cultivar, and leaf position on leaf area calculated from measured leaf length and width at inoculation

Chloride Treatment	Cultivar and leaf position					
	Purplestraw		Yamhill		Nugaines	
	Flag	Second	Flag	Second	Flag	Second
	cm^2					
Chloride	62.61	54.82	36.46	37.95	28.51	21.13
Sulfate	59.52	46.74	30.69	34.25	28.24	18.42

Analysis of Variance

Source	df	MSE	variance ratio	P value
Cultivar	2		328.54	.0030
Chloride trt	1		14.55	.0624
Cult by Cltrt	2		1.46	.4062
Leaf	1		27.92	.0340
Cult by leaf	2		15.16	.0619
Cltrt by leaf	1		0.749	.4780
Error	2	3.195		
Total	11			

and treatment. Flag and second leaves were separated for disease assessment within each treatment.

Percent attack based on the sum of lesion lengths per leaf was higher for sulfate treatments than for chloride treatments on flag leaves of Nugaines in 1983 and 1984 and for Yamhill in 1984 at any given growth stage (Figure 10 - 12). Purplestraw showed the same trend initially although the chloride treatment later surpassed the sulfate in lesion area (Figure 9). Second leaves were less consistent in showing chloride effects, with smaller differences in percent attack between treatments.

The results in these experiments agree with those of Emge, et. al.(1975) who found that sporulation zones showed a definite and continual linear increase in area over time, ranging from 8.8 to 18.8 mm^2 per day. In their experiments, the number of spores produced and capable of reinfection increased significantly in the absence of new infections. They found that sporulation occurred on the entire lesion area until the lesions coalesced or reached the extremity of the leaf, or until the leaf senesced.

Due to the fact that environmental conditions in the growth chamber limited germination of spores, no secondary infection was observed. The characteristic sigmoid shape of the disease progress curve for stripe rust was replaced by an inverted J curve indicative of a simple interest disease. In both experiments the percent attack was higher for the sulfate treatment at the approximate end of the initial latent period (12-20 days). This would provide higher inoculum levels when environmental conditions are favorable for secondary infection in field plots.

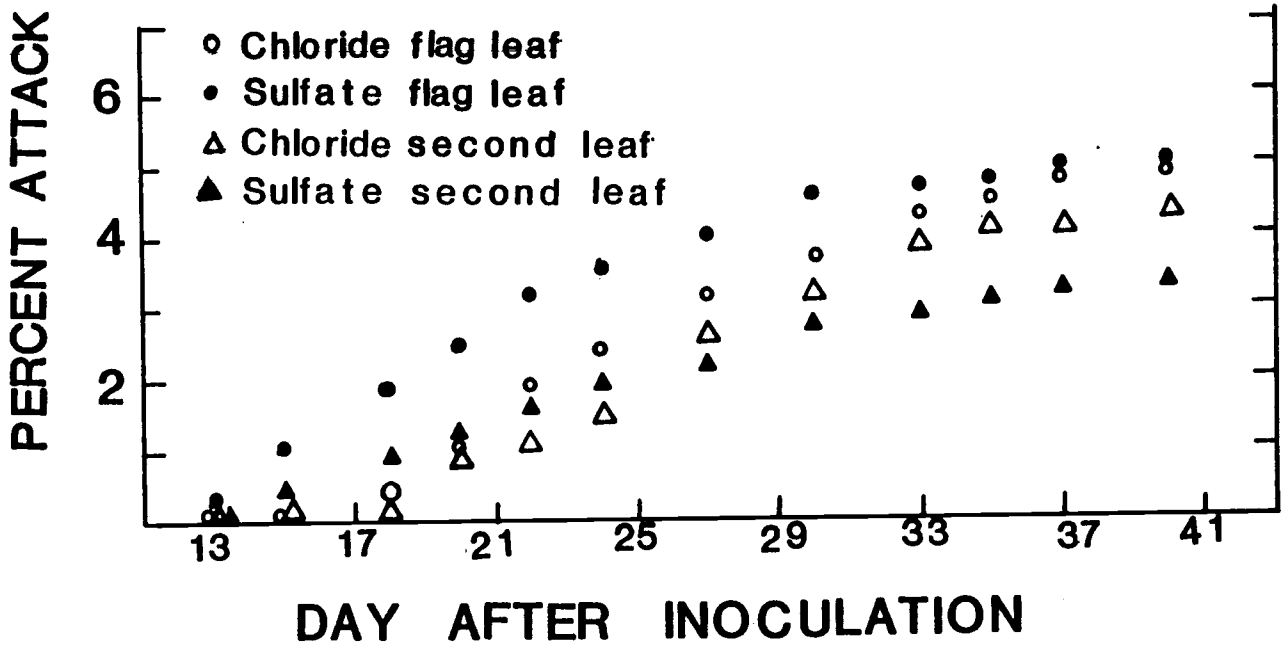

Figure 9. Disease progress curves for Nugaines cultivar corrected for leaf area and averaged within treatment, growth chamber 1983. Percent attack = (measured lesion area/calculated leaf area)

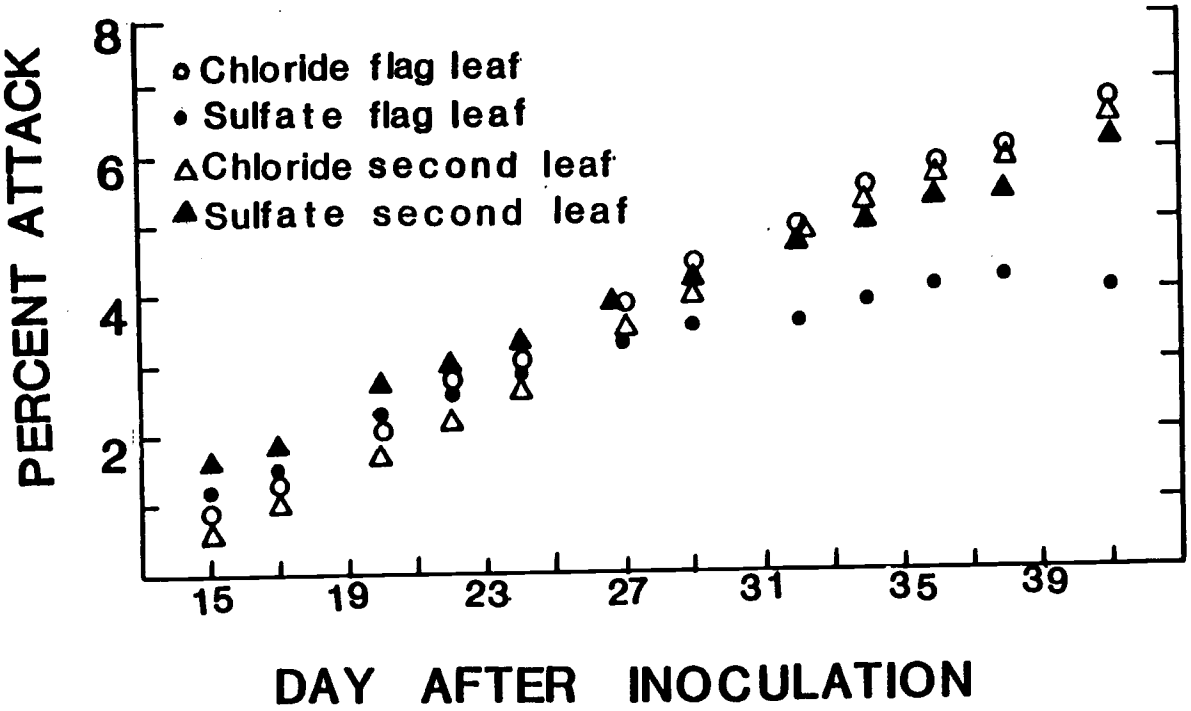

Figure 10. Disease progress curves for Purplestraw cultivar corrected for leaf area and averaged within treatment, growth chamber 1983. Percent attack = (measured lesion area/calculated leaf area)

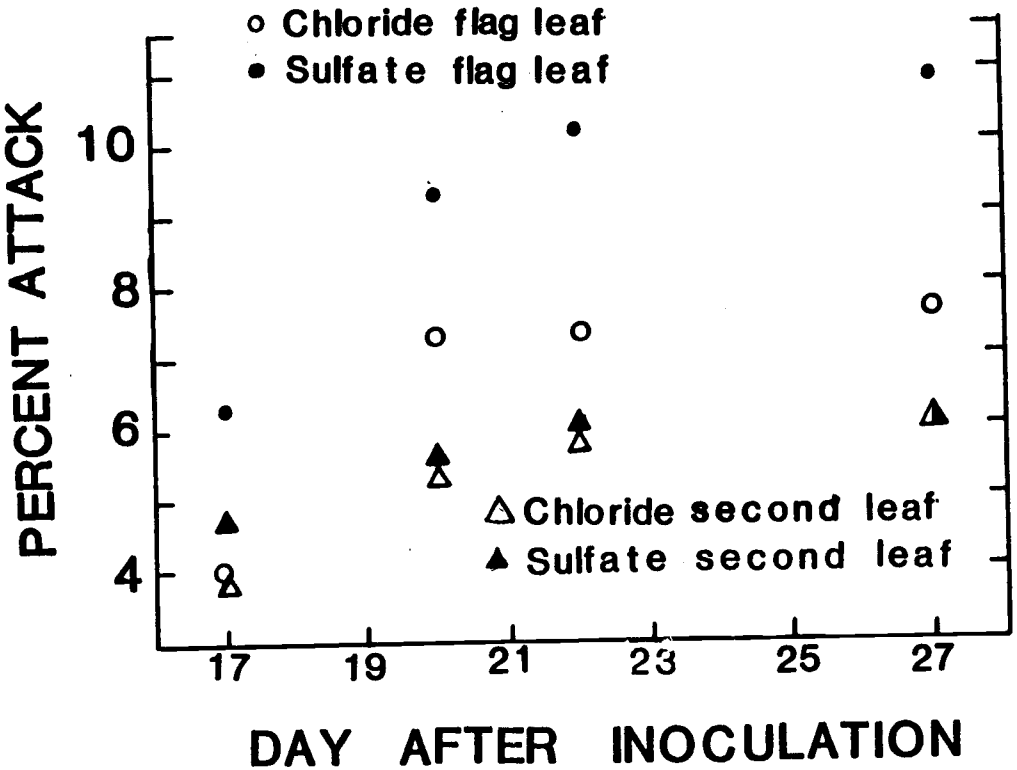

Figure 11. Disease progress curves for Nugaines cultivar corrected for leaf area and averaged within treatment, growth chamber 1984. Percent attack = (measured lesion area/calculated leaf area)

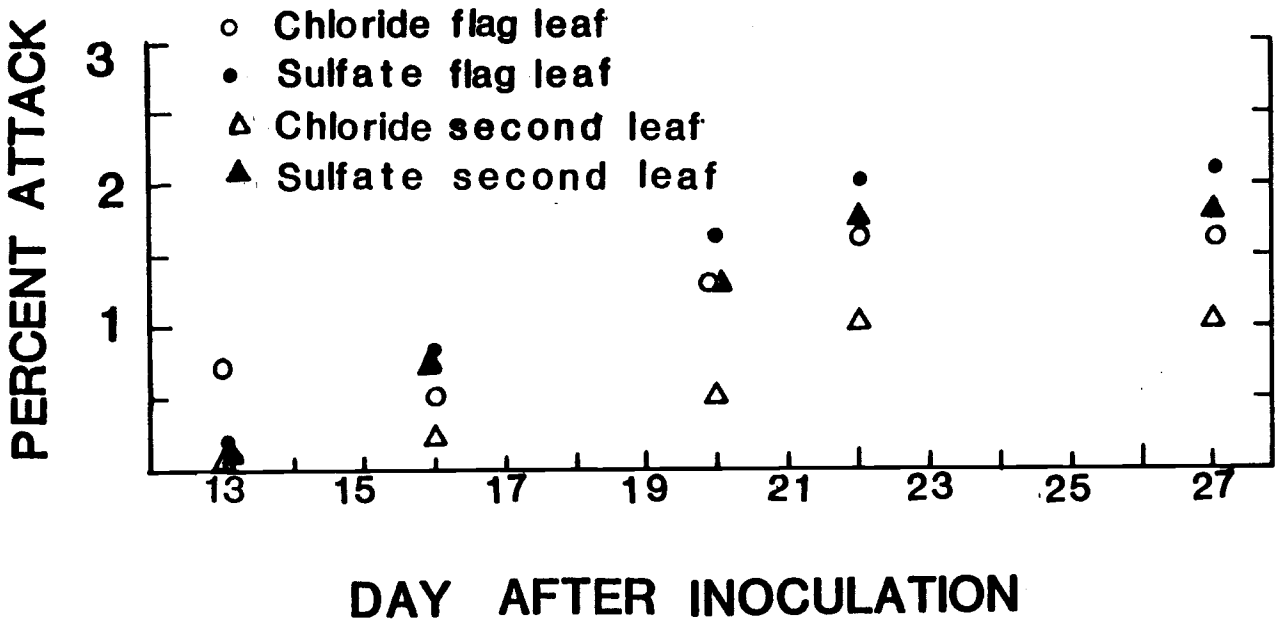

Figure 12. Disease progress curves for Yamhill cultivar corrected for leaf area and averaged within treatment, growth chamber 1984. Percent attack = (measured lesion area/calculated leaf area)

Leaf chloride content

Percent chloride content in the flag and second leaves of chloride treated plants was greater than that in the stem and lower leaves, while for sulfate treatments there was no significant difference (Table 24). Yamhill had the highest percent chloride in both leaves and lower plant, followed by Nugaines and finally Purplestraw, except that for the chloride treatment Nugaines had higher percent chloride than in the lower plant parts of Yamhill.

Table 24. Effect of growth chamber chloride treatment (1984) on chloride content of leaf and lower plant parts among cultivars

Chloride Treatment	Cultivar and plant part					
	Purplestraw		Yamhill		Nugaines	
	Leaf	Plant	Leaf	Plant	Leaf	Plant
	----------%					
Chloride	0.96	0.49	2.30	1.28	2.09	1.61
Sulfate	0.02	0.06	0.04	0.12	0.02	0.11

Differences in leaf percent chloride in the growth chamber support the field results, with percent chloride content in leaves of plants under chloride treatments exceeding 2.0 %. The additional chloride accumulated in the leaves of chloride treatments surpassed that in the lower plant parts. The sulfate treatment showed no significant difference in chloride accumulation by location in the plant as chloride was present in minimal amounts to meet micronutrient needs.

Leaf water potential

Apoplastic water content was measured for vernalized adult winter wheat leaves in the growth chamber on cultivars Nugaines, Yamhill, and Purplestraw. Moisture release curves were plotted and elastic modulus calculated where sufficient data fell within the required range. Apoplastic water content varied greatest between cultivars, and between leaf positions for Nugaines (Table 25). Minor differences betweeen treatments showed chloride increasing the water content. Elastic modulus did not vary significantly between treatments of Yamhill flag leaves (chloride = 202, sulfate = 194).

Table 25. Effect of growth chamber chloride treatment (1984) on apoplastic water content

	Cultivar and leaf position					
Chloride	Yamhill		Nugaines		Purplestraw	
Treatment	Flag	Second	Flag	Second	Flag	Second
	----------% apoplastic water----------					
Chloride	.55	.55	.37	.52	.22	---
Sulfate	.49	.52	.36	.55	---	---

Predawn leaf water potential was significantly different for the interaction of chloride treatment and cultivar (Table 26). Osmotic potentials were significantly more negative for the higher chloride rate, with significant differences between cultivars and chloride treatments but no interaction between cultivar and chloride treatment (Table 27). Nugaines and Purplestraw had lower osmotic potentials than did Yamhill. Turgor potentials were significantly higher for the chloride treatment than for the

sulfate treatment. Predawn turgor potentials decreased with cultivars ranking in descending order of Nugaines, Purplestraw, and Yamhill but there was no interaction between cultivar and chloride treatment (Table 28).

Table 26. Interaction of cultivar and chloride treatment on leaf water potential, growth chamber 1984

Chloride Treatment	Cultivar		
	Nugaines	Purplestraw	Yamhill
	(bars)		
Chloride	-3.25	-3.77	-3.48
Sulfate	-2.91	-3.84	-4.17

LSD (.05) cultivar by chloride treatment 0.365

Analysis of Variance

Source	df	MSE	F	significance
Cultivar	2	13.0606	20.87	.0000
Chloride trt	1	1.0696	1.71	.1925
Cult by Cltrt	2	4.8168	7.697	.0006
Error	210	0.6257		
Total	215			

Table 27. Effect of cultivar and chloride treatment on leaf osmotic potential, growth chamber 1984

Chloride Treatment	Cultivar			trt mean
	Nugaines	Purplestraw	Yamhill	
	bars			
Chloride	-10.83	-11.16	-10.61	-10.86
Sulfate	-12.42*	-11.95*	-11.33*	-11.89
cult mean	-11.62	-11.55	-10.96	----

LSD (.05) cultivar mean 0.48
LSD (.05) chloride treatment mean 0.39

Analysis of Variance

Source	df	MSE	F	significance
Cultivar	2	9.3835	4.324	.0144
Chloride trt	1	57.6187	26.554	.0000
Cult by Cltrt	2	4.2201	1.944	.1456
Error	210	2.1698		
Total	215			

* significant difference (p=.05) between chloride treatments

Table 28. Effect of cultivar and chloride treatment on leaf turgor potential, growth chamber 1984

Chloride Treatment	Cultivar			trt mean
	Nugaines	Purplestraw	Yamhill	
--meq/L---	----------bars----------			
Chloride	7.92	7.31	6.44	7.22
Sulfate	9.17*	8.18*	7.84*	8.39*
cult mean	8.54	7.74	7.13	----

LSD (.05) cultivar mean 0.306
LSD (.05) chloride treatment mean 0.453

----------Analysis of Variance----------

Source	df	MSE	F	significance
Cultivar	2	35.7634	12.42	.0000
Chloride trt	1	74.3893	25.83	.0000
Cult by Cltrt	2	1.3896	0.48	.6178
Error	210	2.8793		
Total	215			

* significant difference (p=.05) between chloride treatments

Growth Chamber Experiments Discussion

Disease progress

Purplestraw flag leaves showed significant increase in 1983 in apparent infection rate with added chloride, which is based in part on length of latent period. Latent periods appeared to increase with added chloride for Purplestraw cultivar in 1983, and for Nugaines cultivar in both years. Yamhill second leaves showed significant decrease in apparent infection rate for chloride treated plants which resulted in lower foliar percent attack during the primary infection cycle.

As noted by Van der Plank (1975), conflicts can arise between active vegetative growth and the initiation of reproductive activity in fungi. The pathogen has two alternatives:

1) a shorter latent period, produce more, shorter lesions faster with fewer spores produced per lesion, or

2) a longer latent period but produce fewer, longer lesions with more spores produced per lesion.

The second alternative allows the fungal hyphae to be better nourished before expending the energy for reproduction, thus favoring the production of spores with optimum ability to infect tissue. However, under favorable environmental conditions earlier spore release allows for more infection cycles within the lifetime of the plant or the duration of climatological suitability for germination of subsequent generations of spores. Epidemics emphasizing early lesion growth may complete four infection cycles

while those focussing on later lesion growth barely reach the third infection cycle before senescence or harvest. Due to the logarithmic increase in infectious tissue and greater potential damage with each infection cycle, the shorter latency will be more detrimental to the plant.

The distinction between latent and incubation periods is essential when comparing field and growth chamber experiments. In measuring latency one must determine the time of onset of sporulation whereas incubation ends with the simpler visual recognition of discoloration in the leaf. As the percent attack measures necrotic or chlorotic leaf area, it does not distinguish between sporulating (infectious) and non-sporulating (infected) leaf area. In growth chamber experiments it is difficult to discern visually whether lesions are sporulating or to quantify the infectious area at a given time. Eventually the spore production by both treatments may be equal although the percent attack is not. It is also possible that one treatment has a lower percent attack masking a higher percentage of infectious tissue which enables it to complete a secondary infection cycle sooner if environmental conditions permit. This could be tested in the future by providing an environment conducive to germination of secondary inoculum.

This research suggests that the initial growth chamber lesion lengths during the primary infection cycle (up to day 24 after inoculation) are lower for chloride treated flag leaves for Purplestraw and Yamhill. The added chloride helps to signal for fungi to adopt the second alternative of Van der Plank as stated

earlier, which favors vegetative growth of hyphae over rapid spore production. This does not alter the length of incubation period but manifests longer latent period, the significance of which would be revealed in the delay of secondary infection. Sporulation of the sulfate-treated plants thus precedes that of chloride by nearly one incubation period although the visible infection and the apparent infection rate are greater for chloride-treated plants during primary infection cycle. Chloride treatment may delay sporulation with or without a greater loss of photosynthetic tissue in the primary infection cycle as a way to protect the plant from later infection. The spread and severity of stripe rust increases slower for chloride treatments as longer latent periods decrease apparent infection rate within the primary infection cycle.

Cartwright and Russell (1980) suggest a mechanism of chloride effect on hyphal growth of Puccinia striiformis. They cite a secondary type of durable resistance where a single slow growing and non-branching hyphae reveals a subtle arrest of fungal development. The natural incidence of this type of resistance was increased with treatments of KCl or sucrose. This would support the second alternative of Van der Plank and is in agreement with the growth chamber results presented in this paper. Cartwright and Russell (1980) also suggest that an antifungal toxin may be produced by mesophyll cells of resistant cultivars receiving chloride treatments, which aids in the slowing of fungal infection. Mesophyll cells with higher turgor potential may require higher energy expenditure by the fungus in the course of nutrient

extraction. The additional energy is then unavailable for hyphal growth and development. Chloride may reduce the amount or forms of nutrients in the cells that can be used by the fungus, requiring the hyphae to conquer more cells before the fungus is nourished sufficiently. In this case, excess chloride anions reduce the osmotic potential of the cell through osmoregulation. The solute concentration increases within the cell as chloride anions accumulate in the symplasm, triggering the cell to take in water which increases the turgor potential and maintains the total water potential of the cell.

The chloride might also replace essential nutrients in the cell solution through competitive inhibition of Malate or nitrate, or reduce their concentrations below minimal fungal requirements. The overall energy balance between fungal development and cell survival is altered by the presence of chloride in quantities above the micronutrient level. Care must be taken not to increase the chloride concentration to toxic levels or to the point where it limits plant access to other nutrients important to plant growth and optimal economic value of grain yield.

Turgor as a mechanism of disease control

Measurements of predawn leaf water potential in the growth chamber in 1984 show chloride decreases osmotic and increases turgor potentials. The lack of statistically significant chloride effect as measured in the field experiments may be due to the time of day when measurements were made (10 A.M. to 2 P.M.). Due to

the warm temperature, the midday period showed lower turgor potentials and more variation in water content of the leaves than for predawn water potentials as measured in the growth chamber.

Campbell, et al. (1979) found apoplastic water fraction in Nugaines wheat constant throughout the season at about 0.3 while Scholander, et al. (1964) cited 0.2 as an average figure. This project measured apoplastic water content at a single growth stage - flowering (decimal growth stage 60) - so conclusions on seasonal variation are inappropriate although the results suggest that apoplastic water content varies between cultivars. Corrections of osmotic potential should use apoplastic water content estimated from the same or similar cultivars and environmental conditions. This will require measuring pressure - volume components along with water potential at least until a store of data on the subject is compiled.

Differences in apoplastic water content between chloride and sulfate treatments allow for more precise calculation of turgor potentials. Decreased (more negative) osmotic potentials for chloride treatments, and lowered osmotic potentials for sulfate treatments due to correction for apoplastic water content may be sufficient to reveal statistically significant differences in turgor potential where work previously showed only trends. The correction factor used for field osmotic potentials was based on apoplastic water measured for two cultivars (Stephens and Yamhill) using plants which were rehydrated overnight, possibly not reflecting the true water status of varying treatments and cultivars in a daily cycle.

The small number of replicates (2) and the diseased state of some of the plants due to an unintentional infestation of powdery mildew in the growth chamber leave the results interesting but not conclusive as to the impact of chloride fertilization on apoplastic water content. The results from this study indicate that leaf position is more of a factor in determining apoplastic water content than is chloride treatment. Additionally within leaf position there appears to be little difference in apoplastic water content or elastic modulus due to chloride treatment. Apoplastic water content was considered constant within cultivars.

Melkonian, et al. (1982) showed elastic modulus independent of turgor between 0.0 and 0.8 MPa (0 to 8 bars) which was the range tested here. One difficulty was that leaves were hydrated as intact plants in their pots rather than as cut stems. This kept initial water potential readings near -6 bars instead of the optimal -2 bars for most of the leaves, reducing the number and accuracy of readings within the range needed to calculate elastic modulus.

CONCLUSION

For the major part of the growing season and through the growth stages of kernel formation and grain filling, chloride-treated plants showed lower foliar percent attack by stripe rust. They endured less biological stress due to stripe rust at these crucial reproductive stages and show higher grain yields at harvest. The signal recognized by the fungus for choosing between the alternative reproductive patterns has not been identified, but is suspected to involve fungal nutrition and factors influencing spore vigor and survival.

Although growth chamber experiments showed correlation between leaf chloride content, increased turgor potentials, and decreased disease severity; field data did not suggest that turgor was a primary factor in the chloride effect on stripe rust disease progress. Yield results from field experiments indicate that chloride suppression of take-all root rot disease may have occurred in the stripe rust plots. The recent work of Christensen and Brett (1985) shows that chloride influences nitrification, which may be a primary mechanism through which the chloride slows the progress of stripe rust. Further research is needed to define interactions of chloride, nitrogen form and availability, and stripe rust disease progress.

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APPENDIX

Table 1. Temperature and rainfall data during Hyslop Farm field experiments, 1982

date	air temp max	air temp min	precip.	minimum relative humidity
	----deg F----		.01 inch	---percent-----
03/06/82	52	32	0	49
03/07/82	56	30	0	53
03/08/82	58	33	4	47
03/09/82	55	43	21	86
03/10/82	63	45	NA	68
03/11/82	58	37	22	73
03/12/82	48	33	NA	45
03/13/82	52	38	NA	57
03/14/82	50	40	28	89
03/15/82	47	31	4	60
03/16/82	50	33	NA	41
03/17/82	53	29	0	45
03/18/82	56	30	0	33
03/19/82	56	31	NA	42
03/20/82	55	35	NA	32
03/21/82	51	34	0	33
03/22/82	58	30	0	32
03/23/82	60	31	0	39
03/24/82	64	38	0	33
03/25/82	65	35	0	38
03/26/82	60	40	NA	46
03/27/82	56	39	22	52
03/28/82	56	38	23	49
03/29/82	46	33	24	71
03/30/82	55	37	11	31
03/31/82	46	35	47	69
04/01/82	48	31	5	61
04/02/82	51	36	26	51
04/03/82	49	37	55	63
04/04/82	48	36	26	70
04/05/82	47	34	15	80
04/06/82	51	33	3	50
04/07/82	52	33	2	51
04/08/82	58	36	NA	35
04/09/82	60	33	0	27
04/10/82	64	33	0	17
04/11/82	55	41	66	55
04/12/82	59	43	14	71
04/13/82	55	41	66	55
04/14/82	50	35	81	79
04/15/82	48	34	63	69
04/16/82	52	32	4	51
04/17/82	57	36	NA	NA
04/18/82	51	29	5	52
04/19/82	51	35	6	53
04/20/82	60	40	0	31

NA trace precipitation or missing relative humidity

Table 1. Temperature and rainfall data during Hyslop Farm field experiment, 1982 continued

date	air temp max	air temp min	precip.	minimum relative humidity
	----deg F----		.01 inch	---percent-----
04/21/82	71	45	0	21
04/22/82	79	39	0	13
04/23/82	80	36	0	25
04/24/82	64	37	0	47
04/25/82	60	36	0	36
04/26/82	26	33	0	27
04/27/82	65	42	0	34
04/28/82	62	45	8	43
04/29/82	57	31	NA	44
04/30/82	61	39	0	31
05/01/82	68	43	0	37
05/02/82	66	39	0	32
05/03/82	59	45	4	51
05/03/82	59	45	4	31
05/04/82	59	33	4	31
05/05/82	60	40	0	35
05/06/82	70	41	0	26
05/07/82	77	42	0	31
05/08/82	60	40	NA	45
05/09/82	56	39	12	61
05/10/82	57	44	NA	58
05/11/82	58	41	0	53
05/12/82	68	43	0	NA
05/13/82	68	43	0	39
05/14/82	69	41	0	29
05/15/82	71	40	0	NA
95/16/82	72	46	0	32
05/17/82	73	48	29	33
05/18/82	62	42	NA	38
05/19/82	61	39	NA	NA
05/20/82	69	42	0	NA
05/21/82	75	44	0	35
05/22/82	76	40	0	NA
05/23/82	69	47	0	39
95/24/82	76	50	0	80
05/25/82	86	51	0	30
05/26/82	72	35	0	26
05/27/82	59	39	NA	41
05/28/82	65	40	NA	43
05/29/82	73	47	0	NA
05/30/82	78	48	0	20
05/31/82	80	49	0	22
06/01/82	63	50	NA	61
06/02/82	60	47	0	45
06/03/82	63	44	NA	39

Table 2. Apoplastic correction for growth chamber osmotic potentials by cultivar, leaf position, and chloride treatment, 1984 pressure-volume data.

Nugaines			
flag leaf chloride			
Pressure -bars	leaf weight mg	Pressure -bars	leaf weight mg
5	778.2	4.8	755.1
9	760.5	9	745.7
16	726.2	12	728.6
15	831.2	15	999.2
20	797.5	18	979.0
25	767.6	24	937.8
30	723.2	28	906.8
33	688.8	32	879.9
initial weight	952.3		1120.9
oven dry weight	134.5		181.0
second leaf chloride			
8	785.2	5.8	833.7
11	775.9	9	818.5
15	742.1	12	790.1
18	710.4	16	759.6
21	683.2	20	722.8
25	660.5	25	684.8
30	635.8	28	641.4
		29	622.6
initial weight	851.4		906.5
oven dry weight	127.1		142.5

Table 2. Apoplastic correction for growth chamber osmotic potentials by cultivar, leaf position, and chloride treatment, 1984 pressure-volume data. continued

	Yamhill	
Pressure	Flag chloride	Flag sulfate
-bars	------leaf weight (mg)----------	
3	899.0	1436.2
6	890.8	1422.8
9	874.8	1390.5
12	851.1	1360.6
15	819.4	1334.2
18	792.0	1275.1
21	761.7	1209.6
25		1156.1
29	697.4	
30		1058.1
33	649.5	
initial weight	959.3	1556.0
oven dry weight	149.0	227.7
3	1464.0	1237.5
6		1227.2
7	1431.7	
9	1411.8	1211.9
12	1385.8	1192.9
15	1350.4	1153.6
18	1305.1	1101.9
21	1258.2	1039.6
25	1215.7	987.9
30	1186.0	945.5
34	1134.2	840.3
initial weight	1512.3	1361.9
oven dry weight	200.3	275.0

Table 2. Apoplastic correction for growth chamber osmotic potentials by cultivar, leaf position, and chloride treatment, 1984 pressure-volume data. continued

Yamhill			
Second leaf chloride		Second leaf sulfate	
Pressure	leaf weight	Pressure	leaf weight
-bars	mg	-bars	mg
6.2	899.6	5	1078.3
9	884.0	9	1061.1
12	857.7	13	1020.1
15	831.2	15	999.2
20	797.5	18	979.0
25	767.6	24	937.8
30	723.2	28	906.8
33	688.8	32	879.9
initial weight	952.3		1120.9
oven dry weight	134.5		181.0
8	785.2	5.8	833.7
11	775.9	9	818.5
15	742.1	12	790.1
18	710.4	16	759.6
21	683.2	20	722.8
25	660.5	25	684.8
30	635.8	28	641.4
		29	622.6
initial weight	851.4		906.5
oven dry weight	127.1		142.5

Table 3. Field chloride treatment effect (1983) on stripe rust disease severity on Purplestraw cultivar, average within treatment

Day after inoculation	Chloride rate (kg/ha) 0	72	152	304
	---------percent attack---------			
19	7.1	3.6	3.2	1.1
26	5.3	4.5	3.8	4.1
33	18.4	16.4	13.9	12.3
40	26.6	15.4	19.3	16.9
47	70.5	52.0	52.0	59.1
54	76.9	61.5	58.0	65.4
61	96.0	89.8	86.2	81.2
68	98.5	94.5	94.5	93.0
75	98.8	96.2	96.0	96.1

Table 4. Field chloride treatment effect (1983) on stripe rust disease severity on Yamhill cultivar, average within treatment

Day after inoculation	Chloride rate (kg/ha) 0	72	152	304
	---------percent attack---------			
33	0.01	0.11	0.06	0.01
40	0.04	0.05	0.21	0.13
47	0.07	0.11	0.09	0.13
54	1.3	1.4	0.86	1.4
61	14.8	12.1	9.9	10.1
68	19.0	21.3	17.5	18.3
75	18.3	8.5	8.5	8.4
81	65.9	62.9	55.5	54.1

Table 5. Field chloride treatment effect (1983) on stripe rust disease severity on Rew cultivar, average within treatment

Day after inoculation	Chloride rate (kg/ha) 0	72	152	304
	---------percent attack--------			
33	0.07	0.13	0.09	0.05
40	0.81	3.1	0.76	0.65
47	0.59	0.63	0.61	0.63
54	12.5	8.6	8.2	7.6
61	40.1	38.4	22.5	28.7
68	58.7	39.5	33.8	51.3
75	43.4	45.8	36.3	51.8
81	80.8	71.5	78.1	88.6

Table 6. Field chloride treatment effect (1982) on stripe rust disease severity on Rew cultivar, average within treatment

Day after inoculation+	Chloride rate (kg/ha) 0	72	152	304
	---------percent attack--------			
21	2.1	1.4	1.5	1.8
28	5.0	5.2	4.3	6.1
36	15.6	10.2	11.2	14.9
42	25.4	23.4	24.7	23.4
48	46.0	47.9	49.3	49.1

+ based on inoculation using sporulating seedlings

Table 7. Field chloride treatment effect (1983) on stripe rust disease severity on Hyslop cultivar, average within treatment

Day after inoculation	Chloride rate (kg/ha) 0	72	152	304
	---------percent attack--------			
26	0.03	0.02	0.02	0.07
33	1.08	1.83	1.06	1.33
40	3.18	2.48	2.81	2.36
47	2.98	1.99	2.55	1.90