AN ABSTRACT OF THE THESIS OF

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Title: THE INFLUENCE OF SEEDING DATE, SOIL pH, NITROGEN FORM, PHOSPHORUS, AND CHLORIDE FERTILIZATION ON TAKE-ALL ROOT ROT (GAEUMANNOMYCES GRAMINIS var. TRITICI) OF WINTER WHEAT

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Winter wheat (Triticum aestivum L. var. 'Yamhill') was planted in October, 1977 in a field at the North Willamette Experiment Station where the previous wheat crop had a severe infection of take-all root rot (Gaeumannomyces graminis var. tritici). Lime treatments applied in 1969 at 0, 9, and 18 metric tons/ha produced soil pH's of 5.6, 6.0, and 6.2, respectively. The objective of this study was to determine the effect of N source, soil pH, Cl, P, and date of seeding on the severity of take-all root rot, and grain yield. Nitrogen as either NH_4Cl, $(NH_4)_2SO_4$, or $Ca(NO_3)_2$ was applied at 34 kg N/ha in the fall and 134 kg N/ha in the spring. Potassium as KCl and K_2SO_4 was applied at 37 kg K/ha and NaCl was included to give a Cl level comparable to KCl. Concentrated superphosphate was applied at 30 kg P/ha. Phosphorus and K fertilizers were all fall applied. Fall fertilizer treatments were banded with the seed at planting, while spring fertilizers were all broadcast. Root samples were taken during the spring to determine the extent of infection, and grain yields were obtained by harvesting with a plot combine in August.

Yields averaged 50% higher from the October 27 than from the

Ocotober 4 seeding, and visual observations indicated a greater presence of the typical symptoms associated with take-all (chlorotic, stunted plants with bleached white spikes) in the earlier seeded plots.

Liming increased the severity of take-all as indicated by lower grain yields. Yields from all fertilizer treatments were generally higher at pH 5.6 than at pH's 6.0 or 6.2, however, no uniform yield advantage was noted at pH 6.0 versus 6.2. The root infection data was not as consistent as the yield data; with the percent of infection often increasing with decreasing pH.

Phosphorus in combination with NH_4Cl counteracted the negative effects of alkalinity on yield, but produced no significant response when applied with $(NH_4)_2SO_4$, indicating a possible interaction between P and Cl. The P + NH_4Cl + KCl treatment gave the greatest suppression of take-all on both planting dates.

Fertilizer treatments containing NH_4-N as opposed to NO_3-N produced better control of take-all across lime treatments on both planting dates. The NH_4Cl and $(NH_4)_2SO_4$ treatments generally produced higher yields, lower percentages of infected roots, and higher test weights than the $Ca(NO_3)_2$ treatment.

Based on these same criteria (i.e., grain yield, percent root infection, and test weights), the NH_4Cl treatment produced better suppression of take-all than did the $(NH_4)_2SO_4$ treatment, indicating a response to Cl. Chloride in the form of KCl band applied at low rates, however, had no significant effect on the control of take-all.

At a site immediately adjacent to the area just described another experiment was established, October 27, on land which was in fallow the previous year following two successive wheat crops. Experimental variables were identical with those already outlined except for the absence of pH differentials. In addition, half of the plots in the fallow area were innoculated with G. graminis, and treatments containing high rates of KCl (93 kg K/ha and 186 kg K/ha) were also included.

At this site no response resulted from low rates of KCl band applied in the fall, but yields increased significantly where plants received high rates of KCl broadcast in the spring.

One additional experiment was established in Douglas County, where the unlimed soil had a pH of 5.2. Liming had the reverse effect on take-all here as opposed to the North Willamette site. In Douglas County, lime alone, and lime plus P increased the yields of the take-all infected wheat and reduced the incidence of infection. This effect can be explained by the favorable influence the liming of highly acid soils has on the availability of plant nutrients and consequent increased plant vigor. At the North Willamette Station liming encouraged the pathogen while not materially aiding the plant, a frequently observed phenomenon in cases of take-all infection.

The Influence of Seeding Date, Soil pH, Nitrogen Form, Phosphorus, and Chloride Fertilization on Take-All Root Rot (Gaeumannomyces Graminis var. Tritici) of Winter Wheat

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THE INFLUENCE OF SEEDING DATE, SOIL pH, NITROGEN FORM, PHOSPHORUS, AND CHLORIDE FERTILIZATION ON TAKE-ALL ROOT ROT (GAEUMANNOMYCES GRAMINIS var. TRITICA) OF WINTER WHEAT

INTRODUCTION

Recent increases in wheat production in Oregon's Willamette Valley[1] have produced a concomitant rise in the incidence of take-all root rot. Take-all is caused by the soil-borne pathogen Gaeumannomyces graminis var. tritici, a fungus which attacks the roots of the wheat plant, causing them to rot, and producing a blackening of the roots and basal stem (Smiley and Cooke, 1971). The most characteristic symptom of take-all is the bleached 'whiteheads' of the infected plants. Yield reductions from this disease in excess of 70% have been reported, but average losses in regions of winter wheat production are more commonly closer to 10% (Garrett, 1942; Walker, 1975).

In 1976, Drs. Powelson and Jackson obtained information from plots established at the North Willamette Experiment Station which suggested that banding certain fertilizers with the seed could effectively reduce losses from take-all (Powelson and Jackson, 1978). They observed a reduction in the incidence of infection and an increase in yields where ammonium nitrogen (NH_4-N) was applied, whereas nitrate nitrogen (NO_3-N) increased the disease incidence. This interaction between nitrogen form and take-all has been well documented by other researchers (Hornby and Goring, 1972; Huber and Watson, 1974; Smiley and Cook, 1971, 1974). However, in their plots, take-all suppression above that attributable

[1] Wheat Acreage and Production, by Oregon Counties. Compiled by Extension Economic Information Office, Oregon State University, Corvallis.

to NH_4-N occurred where chloride (Cl) was included in the fertilizer treatment, either as ammonium chloride (NH_4Cl) or potassium chloride (KCl). Such a response was unexpected, and a subsequent review of the literature revealed no reports of similar results. These workers concluded that Cl fertilization might provide a method of limiting crop damage due to take-all which could be incorporated into the normal fertilizer program of wheat growers.

Due to the innovative nature of this approach, it was decided that additional information was required in order to determine the most effective procedures for utilizing Cl in this capacity. Therefore, in the fall of 1977 a more extensive experiment was established in the same take-all infected field used by Powelson and Jackson. The objective was to measure differences which might occur in the severity of infection and in grain yields from plots which received either NH_4-N or NO_3-N, with or without Cl. To assess the effectiveness of these treatments over a range of agronomic conditions found in the Willamette Valley two planting dates, phosphorus (P) treatments, and three different soil pH's were included as additional variables. This thesis reports the results of that investigation.

LITERATURE REVIEW

The Disease and Causal Organism

The take-all disease of wheat is caused by a fungus which until 1952 was classified as Ophiobolus graminis var. graminis. That year, Arx and Oliver (1952) made the reclassification to Gaeumannomyces graminis var. graminis. The present designation of the pathogen, G. graminis (Sacc.) Arx and Oliver var. tritici Walker, was composed by Walker in 1972, after he determined that G. graminis var. graminis and the fungus causing take-all were different varieties (Walker, 1972). The separation was based upon morphological differences in the mycelial hyphopodia of the two.

Official note of take-all was first made in France in the 1840's (Mangin, 1914). Reported sitings of the disease emanated from South Australia in 1852 (McAlpine, 1904) and from England in 1884 (Smith, 1884). By 1900, most of western Europe had reported losses due to take-all (Steven, 1919). The earliest reference to a wheat disease in the United States resembling take-all was made in Oregon, by Cordley (1902), but a definite identification in this country did not come until 1920 (Kirby and Thomas, 1920). Presently, take-all is known to occur in most of the temperate wheat producing areas of the world.

The take-all fungus is a poor saprophyte which maintains itself in infected wheat and grass plants or in host debris (Butler, 1961). Besides wheat, the host range includes barley, rye, bromegrass, quackgrass, and bentgrass. Of these, wheat is the most susceptible (Walker, 1973).

Take-all is especially favored by mild soil temperatures (12-18^{o}C) and wet conditions (Wiese, 1977), which accounts for its prevalence in the Pacific Northwest west of the Cascades, and in the irrigated areas of the Columbia Basin (Cook et al., 1968). Pathogenic development is also encouraged by, but not restricted to, loose, open soils (Garrett, 1934; Butler, 1961). Soil reaction is another important parameter associated with determining the ecological suitability of a soil for _G. graminis_. The fungus is reportedly placed at an increasing disadvantage with competitors in the soil microflora as the pH decreases (Smiley, 1975; Smiley and Cook, 1973). Consequently, the incidence of take-all is usually reduced under acidic conditions with lower resultant crop losses (Garrett, 1942).

The more severe symptoms of take-all infection include the blackening and rotting of roots, often resulting in a dark mycelial plate beneath the lowest leaf sheath (Wiese, 1977). Infection can also produce stunted, chlorotic plants which ripen prematurely, frequently displaying bleached, white, sterile inflorescences called whiteheads. However, it is probably more common for milder forms of infection to occur which reduce yields while going undetected in the field (Walker, 1975). Transmission of infection is normally performed by runner hyphae located on the rhizoplane of the host, or less frequently by infectious germ tubes of the ascospores (Walker, 1973). No seed transmission is thought to occur.

Control of take-all is most effectively and economically attained through crop rotation. Limiting consecutive wheat crops to no more than two in a row usually insures freedom from infestation. However, reports of take-all infection in first-year wheat, particularly following grass-legume pastures, underscores the importance of the crop sequence in the rotation. Take-all can either be increased or decreased in ensuing wheat crops depending upon which cereal, grass, or legume preceeds the wheat (Huber, 1980).

Suppression of take-all is a more serious problem where wheat is used in rotations on a long-term basis. In such instances, the diease is usually most severe in the third to fourth year of continuous wheat. Thereafter a decline phenomenon commences and take-all becomes less of a factor in each succeeding crop (Slope and Cox, 1964, 1966; Shipton, 1972). This scenario has been dubbed take-all decline (TAD), and is prevalent in many of the world's important wheat producing areas (Garrett, 1934; Slope and Cox, 1964; Baker and Cook, 1974).

A biological factor is thought to be responsible for this naturally occurring antagonism. Evidence in support of this thesis was presented by Henry (1932), Gerlagh (1968), and Shipton et al. (1973). All of these investigators demonstrated an elimination of the factor suppressive to take-all following soil sterilization. Baker and Cook (1974) make the point that in certain areas, such as the Palouse country of eastern Washington, where wheat is monocultured continuously without interruption, soils suppressive to take-all have developed to the extent that the disease is rarely encountered.

Rotation out of wheat aborts the decline phase of take-all. Cook and Rovira (1976), for example, report that TAD does not develop in the southern Australian wheat belt where wheat has been grown since the region was settled. The traditional practice in that area of rotating grass-legume pastures with wheat probably accounts for the failure of TAD to develop.

Date of Seeding

Where take-all infection is a problem, research indicates higher yields accrue from late than from early planting. Butler (1961) contends the problem with early seeding in relation to soil-borne plant diseases involves soil temperature. Higher soil temperatures, according to this researcher, favor the pathogen over the host, while the competitive edge belongs to the host under cooler conditions.

Van der Watt (1965) working in the winter rainfall region of South Africa, reported a decrease in the severity of take-all attack by delaying seeding until after the first rains occurred. It was concluded that such practices extended the saprophytic phase of G. graminis rendering the fungus more prone to attack by antagonists. Chambers (1977), in a greenhouse experiment, found greater reductions in fresh weight and increased suppression of head development the earlier in the plant's growth infection occurred. Glynne (1965) concluded that early seeding provided a higher yield potential where take-all was negligible, but that when the disease was prevalent late seeding increased yields by facilitating disease avoidance.

Soil Reaction

Soil pH has been assessed under varying experimental conditions to have a marked influence on take-all (Garrett, 1936). Most research supports the notion that the disease is favored by alkaline soil conditions, and declines in severity directly with decreasing soil pH (Brittlebank, 1919; Hartmann, 1913; Fish, 1927). Rosen and Elliott (1923), for example, noted increased take-all in field plots which received lime, while Glynne (1935) detected noticeable increases in take-all with elevation of the soil pH to only 5.9.

Garrett (1936) attributed the less propitious development of G. graminis under acidic conditions to the higher CO_2 concentration present in the soil atmosphere. This hypothesis was based upon his observation that fungal colonies of G. graminis were reduced on potato dextrose agar as the atmospheric CO_2 concentration increased. In a follow-up study (Garrett, 1937) employing a soil with a pH in the acid range, the apparent inhibitory effect of CO_2 was overcome by aeration. Ferraz (1973), operating on the premise that CO_2 does not accumulate on the root surface in amounts sufficient to be fungistatic, later refuted Garrett's theory. The removal of CO_2 from soils, he showed, had no effect upon the growth rate of G. graminis, whereas a pH increase from 5 to 8 did suppress fungal growth. The conclusion was made that the beneficial effects from aeration witnessed by Garrett could be attributed to the extreme sensitivity of the fungus to reductions in the partial pressure of O_2, as shown by Fellows (1928b).

Although most reports confirm the occurrence of decreased take-all in soils with low pH, there are accounts of extensive take-all under acidic conditions (Rosen and Elliott, 1923; Smith, 1957; Nilsson, 1969; Huber, 1980). Such cases may be an indication of the influence which pH has on nutrient availability, and consequently host resistance. Plant availability of certain macronutrients, in particular phosphorus (P), are decreased in acid soils, while toxic concentrations of micronutrients can occur (Tisdale and Nelson, 1975). In this context, Angell (1943) attributed the decreased take-all which he observed in pots containing limed soil to increased nutrient availability.

The influence of pH on the growth of *G. graminis* in pure culture is apparently more complex than its effect on take-all development in the field. Kirby (1922) found growth of *G. graminis* to be maximum on cornmeal at pH 8.2 and on potato dextrose agar to be maximum at pH 9.0. Davis (1925), using strains of the fungus from Oregon, Arkansas, and New York, found them to have different pH maxima when grown in pure culture. Overall, the optimum growth for all strains occurred in media which was slightly acidic. Webb and Fellows (1926) conducted experiments on several synthetic and non-synthetic media and concluded that the growth of *G. graminis* in pure culture was variable, and depended to a large extent on the chemical composition and physical nature of the media.

Lal (1939) investigated the possible influence of pH on the microbial antagonism of *G. graminis* in pure culture. Using samples of roots infected with take-all plated out on potato dextrose agar at different initial pH values, along with the contaminating microorganisms, he found an accentuation of growth by the competitors on the more acid agar where they tended to overgrow the *G. graminis* colonies. Being an epiphyte, and, thus, exposed to fluctuations in the biology of the rhizosphere (Smiley, 1975), it seems only reasonable that the *in vivo* growth habit of *G. graminis* should differ from its growth in pure culture.

Nitrogen

Nitrogen nutrition has a modifying influence on many of those plant properties associated with susceptibility to disease. Besides being essential for the production of amino acids and nucleotides (Tisdale and Nelson, 1975), N is also involved in defining the root/shoot ratio (Casper, 1975), cell wall thickness, rate of plant maturation (Nilsson, 1969) and the carboxylate-amide ratio of plant tissue (Nowakowski and Cunningham, 1966); all causal factors in disease development. There are numberous reports of increased yields resulting from fertilizing take-all infected wheat with N (Butler, 1961; Garrett, 1942, 1948, 1956; Chambers, 1964; Huber, 1969). Since most agricultural soils require the addition of this nutrient in order to optimize wheat production, the suppression of take-all in the field by N has usually been ascribed to increased plant vigor.

The degree to which take-all is controlled by the application of N appears to be dependent upon crop management practices, time of fertilization, stage of disease development, the availability of other nutrients, and the form of N added. Salt (1957) has demonstrated a relationship between N nutrition, rate of seeding and the severity of take-all. In thickly sown plots, grain yields were found to be higher when fertilization occurred in early rather than late spring, whereas, the control of take-all was better in thinly seeded plots with a late spring application of N. It was concluded that the thickly seeded plots became nitrogen deficient sooner than did the thinly seeded plots. Huber (1972) observed an increase in the severity of take-all infection when winter wheat was fertilized in the fall with N, while spring applied N suppressed the disease. Shipton (1972) has noted an interaction between N and the level of disease development. In a long-term experiment it was shown that N fertilization had little influence on the incidence of disease when wheat plants were only mildly infected with take-all. Suppression of take-all in response to N was not recorded until infection reached its severest stage. This didn't occur until the fifth consecutive wheat crop.

There is evidence which suggests that when N is available to the plant in adequate amounts the form of N is a more important factor for determining take-all suppression in the field (Huber, 1980). Research has shown on several occasions that ammonium nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N) have a differential effect on the rate of take-all infection (Huber, 1969; Huber and Watson, 1974; Huber et al., 1977; Ebbels, 1971). Apparently, NO_3-N stimulates the pathogen causing an increase in the incidence of infection, while increasing the percentage of NH_4-N taken up by the plant is inhibitory to disease development, and materially reduces the amount of infected tissue. Because plants fed solely NH_4-N are subject to reduced vigor caused by ammonia toxicity (Reisenauer, 1978), and are thus more susceptible to attack, there is apparently an optimum ratio of NH_4-N to NO_3-N which maximizes host resistance (Hornby and Goring, 1972).

The mode of action by which these two forms of N increase the yields of take-all infected plants probably differ. It has been suggested that NH_4-N promotes higher yields through a general decrease in infection while at the same time accelerating plant growth. Nitrate nitrogen, on the other hand, is thought to stimulate the pathogen causing more extensive root infections while simultaneously alleviating yield reductions by increasing plant growth (Huber et al., 1968). Garrett (1948), who observed the phenomenon produced by NO_3-N over thirty years ago, has summarized these opposing processes very succinctly. Nitrogen, he concluded, increases the susceptibility of individual roots, but provides for disease escape, since the plant is able to produce new roots more efficiently.

The differential response to N form may in part be an indirect effect of the higher mobility of NO_3-N in soils, and its greater tendency to be leached from the root zone, envoking N deficiency (Huber and Watson, 1974). Although the amount and duration of N availability to the plant is no doubt a factor, the main stimulatory effect of NO_3-N on take-all appears to be direct. Ebbels (1971) compared the effects of soil fumigation and N on the incidence of take-all. All nitrogen-fumigant combinations controlled take-all with the single exception of soils fumigated with dichloropropene-dichloroporpane. This fumigant was the only one which raised soil NO_3 levels.

Ward and Henry (1961) found that _G. graminis_ failed to grow on synthetic medium when the N source was $(NH_4)_2SO_4$. White (1941), however, was able to successfully culture the fungus on media containing NH_4NO_3, suggesting that _G. graminis_ is unable to utilize NH_4-N as a substrate for growth.

Smiley (1974), and Smiley and Cook (1973) have interpreted the effect of N form on take-all to be an indirect expression of induced changes in rhizophere pH (pH_r). In their research, pH_r changes as large as 2.5 units occurred between plants fed predominantly NH_4-N and those given NO_3-N. These workers judged that take-all was suppressed by the downward shift in pH_r which accompanied NH_4 absorption by the roots, whereas the increase in pH_r created by NO_3 absorption encouraged the pathogen. Seemingly, these changes in pH_r were not very extensive, since the bulk soil pH (pH_b) remained unaltered.

To account for the considerable influence exercised by pH_r over take-all, Smiley and Cook (1971) have proposed a two-fold mechanism. In trials employing fumigated soils these workers found take-all infection to be inhibited below a pH_b of 5. Above this pH, plants sustained uniformly severe infection. They theorized that the effect of pH_r on infection by take-all was direct when less than 5. This probably being the lower limit at which G. graminis was able to grow. Above pH_r 5.0, the effect was concluded to be indirect; possibly operating through soil microorganisms antagonistic G. graminis.

The possible existence of antagonists to G. graminis in the soil microflora has been studied quite extensively in connection with the take-all decline phenomenon (Shipton et al., 1973; Slope et al., 1978). There is strong evidence in support of flourescent pseudomonads as one group of specific antagonists of G. graminis (Cook and Rovira, 1976). The influence of the form of N on these bacteria has been investigated by Smiley (1978). He reported that while fertilization of a soil suppressive to G. graminis with $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ had little influence upon the overall microflora, a greater percentage of antagonistic pseudomonads occurred in the NH_4-N treated soil samples than in the NO_3 treated samples. The conclusion was made that the effect of the form of N on take-all may be an increased expression of antagonism by pseudomonads spp. Consequently, the possibility exists that the control of take-all by NH_4-N is the result of a three-way interaction between the N form, pH_r, and the microbial antagonists of G. graminis.

Phosphorus and Potassium

Phosphorus has been credited in several reports with minimizing yield losses due to take-all (Butler, 1961; Stumbo et al., 1942; Garrett, 1950; Clark, 1942). The beneficial effect derived from P fertilization of take-all infected wheat has been attributed to increased host resistance derived from the more rapid replacement of damaged, non-functional roots (Garrett, 1948; Mattingly and Slope, 1977).

The effectiveness of P at suppressing take-all has been reported to vary considerably depending upon the nutritional status of the soil, and the host's requirement for P. Stumbo et al. (1942) reported P to be involved in controlling take-all when soil N was adequate, but was much less effective where N was limiting to crop growth. Syme (1966) made a similar discovery, observing that the control of take-all by P witnessed in the presence of N was not seen when N was withheld. In western Washington, Davidson and Goss (1972) reported better controls of Ophiobolus patch disease of turf with sulfur (S) than with P. Although the authors advanced no explanation for the efficacy of S in suppressing take-all, it was most likely a case of S being the limiting element for crop growth; underscoring the importance of proper nutrient balance.

Potassium (K) has also been implicated with suppressing take-all by providing for disease escape through increased crown root development (Goss, 1967). Brenchley and Jackson (1921) found no increase in root growth when K was added in conjunction with P, but they did observe that roots which received K had a noticeable thickening near the crown which caused them to stand out away from the plant when it was removed from the soil. Roots of plants receiving only P and N collapsed against each other. The frequently reported increase in host resistance to disease associated with K fertilization (Goss, 1968) may result in part from this "thickening" of cells (increased lignification), making parasitic invasion more difficult (Fellows, 1928a). The opposite effect has been observed where excess N is applied (Nilsson, 1969). Often roots will be thin and flexible and all but void of lignified cells, increasing their susceptibility to attack.

Because both P and K are involved in counteracting the rapid proliferation of immature tissue caused by high levels of N, the proper balance between these nutrients is especially crucial where disease is a factor. A report by Garrett (1941) illustrates this point. In a greenhouse experiment, take-all infected plants yielded the highest when fed adequate amounts of N, P, and K. Reduction of K to one-third the adequate amount resulted in the most severe infection, while plants which received one-third adequate N had the mildest infection, but reduced yields. The lowest yields were recorded where plants had been given, N, K, and one-third P. Nutrient suppression of take-all, therefore, can only accurately be assessed in the context of the total plant available nutrients, and their interactions as mediated through increased plant vigor.

Chloride

A careful review of the literature produced no evidence pertaining to the suppression of take-all by Cl. There are, however, reported cases of K suppression of the disease where the source of K was KCl (Garrett, 1948; Goss and Gould, 1967). Unfortunately, no attempt was made to separate the possible influence of Cl on take-all from that of K.

Chloride does seem to affect the development of some other plant diseases. Younts and Musgrave (1958) noted a decrease in the severity of stalk rot of corn, caused by Gibberella zeae and Gibberella fujikuroi with increased KCl applications, but not with K_2SO_4 or KPO_3. Similar observations were made by Warren et al. (1975) in their research concerning the influence of nitrification inhibition on stalk rot. Hegde and Karande (1978) found that pretreatment of seeds in NaCl solution decreased the incidence of downy mildew (Sclerophthora macrospora) in Pennisetum typhoides (pearl millet), while Russell (1978) has shown that yellow rust of wheat caused by Puccinia striiformis, is decreased significantly by both KCl and NaCl. Nitrogen source comparisons, conducted in eastern Washington, indicated a reduction in the severity of selenophoma leaf spot of winter wheat with NH_4Cl, but no suppression of the disease when the N source was NH_4NO_3, $(NH_4)_2SO_4$, or $CO(NH_2)_2$ (personal communication from O. A. Vogel and F. Koehler, 1979). The latter was the only reported suppression of a disease specifically involving NH_4Cl.

MATERIALS AND METHODS

North Willamette Experiment Station

Plots of winter wheat (*Triticum aestivum* L. var 'Yamhill') were established on a Willamette silt loam at the North Willamette Experiment Station during the fall of 1977. This land had a cropping history for the previous four years of wheat-summer fallow-wheat-wheat, and displayed a uniform infection of take-all in the 1976-77 wheat crop. Lime was applied to the field in 1969 at rates of 0, 9, and 18 metric tons/ha on plots measuring 6 x 61 m. By the time the present experiment was established, all the calcium carbonate had reacted, so that differences associated with lime treatments could be attributed to variations in soil pH and not to pockets of reacting calcium carbonate. Plowing direction was alternated each year to minimize movement of topsoil between plots. In 1977, the pH values of the no, low, and high lime plots were 5.6, 6.0, and 6.2, respectively (averaged over four replications). Soil analysis for pH was performed on 1:2 soil to solution mixtures. Plots measuring 1.5 x 6.0 m were assigned to take advantage of these pH variables. All fertilizer treatments encompassed both low and high limed areas, while a few selected treatments were established on the unlimed plots only. Each fertilizer and lime combination constituted separate treatments which were replicated three times in a randomized complete block design.

Two seeding dates, October 4 and October 27, were selected in order to measure the effect of early versus late planting on the severity of take-all. The wheat was seeded with a double-disc drill on a 23 cm row spacing at the rate of 150 kg seed/ha. Nitrogen fertilizer, either as NH_4Cl, $(NH_4)_2SO_4$, or $Ca(NO_3)_2$ was applied at the time of planting at the rate of 34 kg N/ha followed by a spring application of 134 kg N/ha, and NaCl was applied to provide a Cl level comparable to that of KCl. Concentrated superphosphate was applied at 30 kg P/ha. Fall N, P, and K fertilizer treatments were banded with the seed at planting, while spring N and K were broadcast by hand. To avoid S deficiency, gypsum ($CaSO_4$) was hand broadcast two weeks after planting at 35 kg sulfur/ha on all plots except those which received $(NH_4)_2SO_4$.

Plots were sprayed in mid-November with Hoelon (diclofop-methyl) at 1.1 kg ai/ha for control of ryegrass and other annual weeds. Signs of Pseudocercosporella trichoides (eyespot) in the October 4 seeded plot area necessitated a spray application of Benlate (benomyl) at 1.1 kg ai/ha in late March. The late seeded plots were not sprayed with Benlate.

Root samples were taken during the spring (May 24) to determine the extent of infection. Plants were dug from the ground, the soil washed from the roots, and the percent of roots showing symptoms (blackening) was estimated. Plant samples were taken during the last week in July to measure shoot and head weights. Two 60 cm sections of a single row were randomly selected from each plot sampled. Plots were harvested in early August, and the grain was cleaned by passing it once through a fan cleaner before yields and test weights were determined.

At a site located immediately adjacent to the area just described another experiment was established on land which had been in fallow the previous year following two successive wheat crops. The plots were seeded on the same day as the late planting of the take-all infested area (Oct. 27). The method of planting, fertilizer rates, and weed control practices were the same as those already outlined with the following exceptions:

(1) No pH differentials were present in the fallow area. The soil pH for the entire field was approximately 5.6.

(2) Seed used to plant half the rows (3) of each plot was artificially innoculated with G. graminis var. tritici just prior to planting. The innoculum was produced by culturing isolates of the fungus on unhulled oats, and was mixed with the seed in the field.

(3) Treatments containing high rates of KCl (93 kg K/ha) were added in combination with band applications of either NH_4Cl or $(NH_4)_2SO_4$. The KCl was broadcast applied in either the fall, the spring, or at a double rate (186 kg K/ha) with half in the fall and half in the spring.

Visual inspection of roots and plant characteristics at the time of harvest failed to show the presence of take-all infection resulting from the innoculation, so no attempt was made to harvest the innoculated and the uninnoculated rows separately. Rather, entire plots were harvested the same day as the take-all infested areas. The grain was cleaned with a fan blown cleaner prior to making yield and test weight determinations.

Douglas County Oregon

An experiment was established on the Richey farm, located approximately five miles north of Sutherlin, Oregon, on a Nonpariel clay loam. This land had been in wheat for the previous two years, and prior to that in grass - subclover (Trifolium subterraneum) pasture.

Plots measuring 3 x 12 m were seeded on October 11 with eight different wheat varieties. The experimental design employed was a split, split plot arrangement with varieties as main plots, lime as a subplot, and P as a sub-subplot. All plots received N as $(NH_4)_2SO_4$ at 22 kg N/ha banded with the seed and 134 kg N/ha spring broadcast. Phosphorus was applied at 30 kg P/ha as concentrated superphosphate also in a band with the seed. Lime was applied to the field during the late summer of 1976, and analysis of soil samples taken prior to planting revealed pH values of 6.4 and 5.2 on the limed and unlimed areas, respectively.

Entire plots were harvested the first week in August with a plot combine. At harvest, the severity of take-all infection was assessed based upon the percentage of bleached, white, empty spikes (whiteheads) per plot. Before yields were determined the grain was passed once through a fan cleaner.

Statistical Analysis

Analysis of variance was conducted on the grain yield, test weight, infection, and head weight data from the North Willamette Experiment Station and from Douglas County. All computations were performed using the interactive statistical program (SIPS) available on the CYBER 70/73 computer at Oregon State University. Values for the standard error of a mean difference (SEM), and the corresponding degrees of freedom are presented in tables in the discussion section along with the treatment means. It is left to the reader to perform the least significant difference calculation ($LSD_n = t_n$ X SEM) at the desired level of significance (n).

RESULTS AND DISCUSSION

Planting Date

The most dramatic decrease in the severity of take-all, measured as a function of grain yield, resulted from differences in planting date. The overall average from treatments planted October 4 was 3.04 metric tons/ha, compared to 4.33 metric tons/ha for the October 27 planting. Visual observations were even more striking. Plants from the early seeding displayed the classic symptoms of take-all infection. Short statured plants of uneven height with a high percentage of white-heads were common throughout these plots. Conversely, plants in the October 27 plots showed a conspicuous absence of such symptoms.

Planting later in the season, when soil temperatures were lower, probably slowed pathogenic activity and delayed the onset of root infection and epidemic development, thus allowing for disease escape by the plants. It should be noted, however, that while late planting may reduce losses due to take-all, fall rains in the Willamette Valley limit how long a grower can wait before fields become too wet to plant. There is also a reduced yield potential with late seeding and an increased risk of winter and herbicide damage.

Soil pH

There was an overall trend towards reduced yields as the soil pH increased. The yields for lime treatments averaged across the NH_4Cl, $(NH_4)_2SO_4$, and $Ca(NO_3)_2$ fertilizer treatments, with and without KCl, were 3.18, 3.04, and 2.61 for soil pH values of 5.6, 6.0, and 6.2, respectively, on the October 4 planting, and 4.53, 4.22, and 3.88, respectively, for the same pH sequence on the October 27 planting. This is consistent with observations by other workers who have characterized take-all as being less severe in acid soils (Garrett, 1936; Walker, 1975). Table 1 shows that except for the October 4 seeded $(NH_4)_2SO_4$ treatment yields were consistently higher at pH 5.6 than at 6.0. However, a comparison of treatments at soil pH 6.0 versus 6.2 reveals that the yield advantage vacillated between these two pH levels across fertilizer treatments. This probably reflects an absence of influence by pH on disease development over this range.

Yields from treatments containing either KCl, K_2SO_4, or NaCl in combination with $(NH_4)_2SO_4$ or NH_4Cl are presented in Table 2. With the exception of all but one of the P treatments and the October 4 NH_4Cl + NaCl treatment yields were higher at pH 6.0 than at 6.2 (treatments containing K_2SO_4 and NaCl at pH 5.6 were not included in this experiment). It is interesting that except for the October 27 $(NH_4)_2SO_4$ + KCl + P treatment, P either maintained or increased yields as the pH increased, nullifying the negative effects of alkalinity.

In the present experiment, the effect of liming on the yield of take-all infected wheat does not appear to have been caused by alterations in plant vigor, since the change in pH was within the optimum range for wheat production. It's more probable that the downward shift in pH had a direct physiological effect on the fungus, or acted indirectly through stimulation of antagonistic organisms in the soil microflora. However, this premise is complicated by the occurrence of severe take-all infection on acid soils (Huber and Watson, 1974). Just such a

TABLE 1. Effects of nitrogen source, seeding date, and soil pH on the yield of wheat infected with take-all root rot. North Willamette Exp. Sta., 1978.

Fertilizer Treatment					Seeded October 4				Seeded October 27			
	Fall		Spring		Soil pH				Soil pH			
Source	N	Cl	N	Cl	5.6	6.0	6.2	Avg[3]	5.6	6.0	6.2	Avg[3]
	kg/ha				metric tons/ha							
Check	0	0	0	0	0.89	0.86	0.64	0.80	1.84	1.38	0.84	1.37
NH_4Cl	34	86	134	342	3.74	3.06	3.12	3.31	5.82	4.51	4.43	4.92
$(NH_4)_2SO_4$	34	0	134	0	2.85	3.31	2.32	2.83	4.27	3.94	4.17	4.13
$Ca(NO_3)_2$	34	0	134	0	3.14	2.94	2.42	2.83	4.18	3.72	3.13	3.68
P						**				**		
df[1]						(54)				(50)		
SEM[2]						(0.95)				(0.45)		

** highly significant (p = 0.01)

[1] Degrees of freedom

[2] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

[3] Analysis of variance for mean averages were not made due to the absence of a complete factorial between fertilizer treatments and soil pH differentials.

TABLE 2. Yield response by take-all infected wheat in response to seeding date, and different nitrogen sources in combination with phosphorus, potassium chloride, potassium sulfate, and sodium chloride. North Willamette Exp. Sta., 1978.

	Fertilizer Treatment								Seeded October 4			Seeded October 27		
	Fall				Spring				Soil pH			Soil pH		
Source	N	K	P	Cl	N	K	P	Cl	6.0	6.2	Avg[3]	6.0	6.2	Avg[3]
	kg/ha								metric tons/ha					
NH_4Cl, KCl	34	37	0	126	134	0	0	342	4.24	2.44	3.34	5.58	4.33	4.96
NH_4Cl, K_2SO_4	34	37	0	86	134	0	0	342	2.90	4.00	3.45	--	--	--
NH_4Cl, NaCl	34	0	0	126	134	0	0	342	3.67	3.90	3.78	5.07	4.89	4.98
NH_4Cl, KCl, P	34	37	30	126	134	0	0	342	4.90	4.92	4.91	5.41	5.64	5.52
$(NH_4)_2SO_4$, KCl	34	37	0	40	134	0	0	0	3.19	2.27	2.73	4.12	4.07	4.10
$(NH_4)_2SO_4$, K_2SO_4	34	37	0	0	134	0	0	0	3.24	2.37	2.80	4.41	4.01	4.21
$(NH_4)_2SO_4$, NaCl	34	0	0	40	134	0	0	0	3.67	2.72	3.20	4.98	4.45	4.72
$(NH_4)_2SO_4$, KCl, P	34	37	30	40	134	0	0	0	2.49	2.89	2.69	4.58	4.19	4.38
P									**			**		
df[1]									(54)			(50)		
SEM[2]									(0.95)			(0.45)		

** highly significant (p = 0.01)

[1] Degrees of freedom

[2] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

[3] Analysis of variance for mean averages were not made due to the absence of a complete factorial between fertilizer treatments and soil pH differentials.

situation occurred at the experimental site in Douglas County. On P deficient, acid soils 80 to 90 percent of the wheat, representing eight different cultivars, displayed whiteheads and yields averaged 1.10 metric tons/ha on plots which received no lime or P (Table 3). Liming, the addition of P, or a combination of lime plus P reduced the average percent of whiteheads to 20 percent, and increased the yields to 3.0, 3.74, and 4.83 metric tons/ha with P alone, lime alone, and lime plus P, respectively. In this situation, where the soil pH averaged 5.2 on the unlimed plots, raising the pH probably increased the plant available P, while staving off the possible toxic effects from Mn and Al. (A comparison of soil analysis values for the two sites are contained in Table 4). Thus, there exists a very intimate relation between the physiological effects on the plant, e.g., increased host resistance, caused by changes in the soil environment due to liming or the addition of plant nutrients, and the direct consequences of such changes upon the pathogen. Where possible, these two contesting influences should be assessed separately.

Form of Nitrogen

Ammonium -N fertilized plots produced higher yields (Table 1) and had plants with a lower percentage of infected roots (Figure 1) than did plots receiving NO_3-N. The average yield for both planting dates for NH_4Cl and $(NH_4)_2SO_4$ fertilization was 3.80 metric tons/ha compared to 3.26 metric tons/ha for $Ca(NO_3)_2$. Most of these yield differences, upon analysis, proved to be statistically insignificant, even though F-test values for overall treatment differences were significant at the 0.01

TABLE 3. The effects of lime and phosphorus treatments on yield and severity of take-all root rot infection of eight winter wheat varieties. Douglas County, 1978.

Variety	Treatments Lime	P	Yield	Whiteheads
	metric tons /ha	-kg/ha-	metric tons/ha	-%-
Hyslop	0	0	1.05	90.8
	0	30	2.50	62.5
	4.5	0	3.96	7.5
	4.5	30	4.15	7.5
McDermid	0	0	1.18	69.8
	0	30	2.94	33.8
	4.5	0	3.61	15.0
	4.5	30	4.47	12.5
Daws	0	0	0.75	96.8
	0	30	3.04	73.8
	4.5	0	4.04	17.5
	4.5	30	6.17	12.5
Stephens	0	0	0.53	96.5
	0	30	1.63	82.5
	4.5	0	4.21	22.5
	4.5	30	4.56	16.2
R9401	0	0	1.34	57.5
	0	30	3.28	28.8
	4.5	0	3.95	6.2
	4.5	30	4.83	5.0
IM6 Ymh/Hys	0	0	1.15	77.2
	0	30	3.54	36.2
	4.5	0	3.14	20.0
	4.5	30	4.94	15.0
2M6 Ymh/Hys	0	0	1.47	66.2
	0	30	4.04	23.8
	4.5	0	3.74	18.8
	4.5	30	5.52	5.0
Entry 6 Nu Gaines	0	0	1.30	72.5
	0	30	2.99	38.8
	4.5	0	3.24	18.8
	4.5	30	3.98	16.2
P			**	**
df[1]			(93)	(93)
SEM[2]			(0.52)	(11.3)

** Highly significant (p = 0.01)

[1] Degrees of freedom

[2] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

TABLE 4. Soil analysis values.[1] North Willamette Exp. Sta. and Douglas County, 1977.

Location	Soil Series	Lime	pH	P[4]	K[5]
		-mT/ha-		--- ppm	---
North Willamette Exp. Sta.	Willamette[2]	L_0	5.6	126	201
		L_9	6.0	128	216
		L_{18}	6.2	122	196
Douglas County	Non Pareil[3]	L_0	5.2	12	467
		L_2	6.4	10	458

[1] Averaged over four replications

[2] Pachic Ultic Argixerolls, fine, silty, mixed, mesic

[3] Dystric Xerochrepts, fine, loamy, mixed, mesic, shallow

[4] Determined by Bray 1 method

[5] Determined by ammonium acetate method

probability level. The failure to obtain significance between most of the N-form comparisons can be attributed, in part, to a large experimental error caused to some extent by the presence of other pathogens besides take-all in our test plots. Infection from yellow dwarf virus, Septoria tritici, and Pseudocercosporilla herpotrichoides appeared unevenly throughout the field causing yield reductions. One indication that an increase in the experimental error occurred due to the random nature of these infections is reflected in the coefficient of variation (CV) values for the two dates. For the October 4 data the CV was 38.1%, more than five times the value of 7.0% for the October 27 data. This coincided with a more severe attack by the extraneous pathogens in the earlier planting.

Research has demonstrated the presence of an interaction between the form of N, soil pH, and the severity of take-all infection. Smiley and Cook (1971, 1973) investigated this association under greenhouse conditions and obtained a significant correlation between the incidence of take-all infection and rhizophere pH (pH_r), whereas no discernible relationship between bulk soil pH and disease incidence was detected. In their experiments, both pH_r and disease rating were reduced when the plant absorbed increased amounts of NH_4-N, while pH_r and the incidence of take-all increased when NO_3-N was predominantly taken up by the plant.

Huber and Watson (1974) have argued that such a change in pH is too transitory to account for the level of control of take-all achieved with NH_4-N in the field. In their opinion, the effect of the NH_4-N on the pathogen is probably mediated through some alteration in the host's physiology leading to increased resistance. Acidity would act indirectly in this case by delaying the conversion of NH_4-N to NO_3-N through a reduction in the rate of nitrification.

In either case, NO_3-N is credited with increasing take-all infection. In accordance with theory, the $Ca(NO_3)_2$ plots produced the most extensive root infection (Figure 1), and the lowest overall yields (Table 1). It could not be determined to what extent leaching losses of NO_3 may have accounted for this increase in disease, since rates of N in excess of those normally recommended for this area were not included. However, other researchers have demonstrated increased take-all infection with increasing rates of NO_3-N (Weste and Thrower, 1971).

Chloride

Ammonium chloride plots produced higher grain yields than plots which received $(NH_4)_2SO_4$ on both planting dates (Table 1). Grain yield from NH_4Cl fertilization averaged 3.31 metric tons/ha and 4.92 metric tons/ha on the early and late plantings, respectively, whereas the average yields for $(NH_4)_2SO_4$ for these plantings were 2.83 and 4.13 metric tons/ha. Plants which received NH_4Cl also had a lower percentage of infected roots than did those from the $(NH_4)_2SO_4$ plots (Figure 1). This 'Cl effect' tended to dissipate as the pH increased. At pH 5.6 the yield increase from NH_4Cl over $(NH_4)_2SO_4$ was 1.22 metric tons/ha (averaged for the two planting dates), while the difference was only 0.53 metric tons/ha where the soil pH was 6.2. This decrease in the efficacy of Cl can probably be attributed to increased activity by the pathogen at the higher pH.

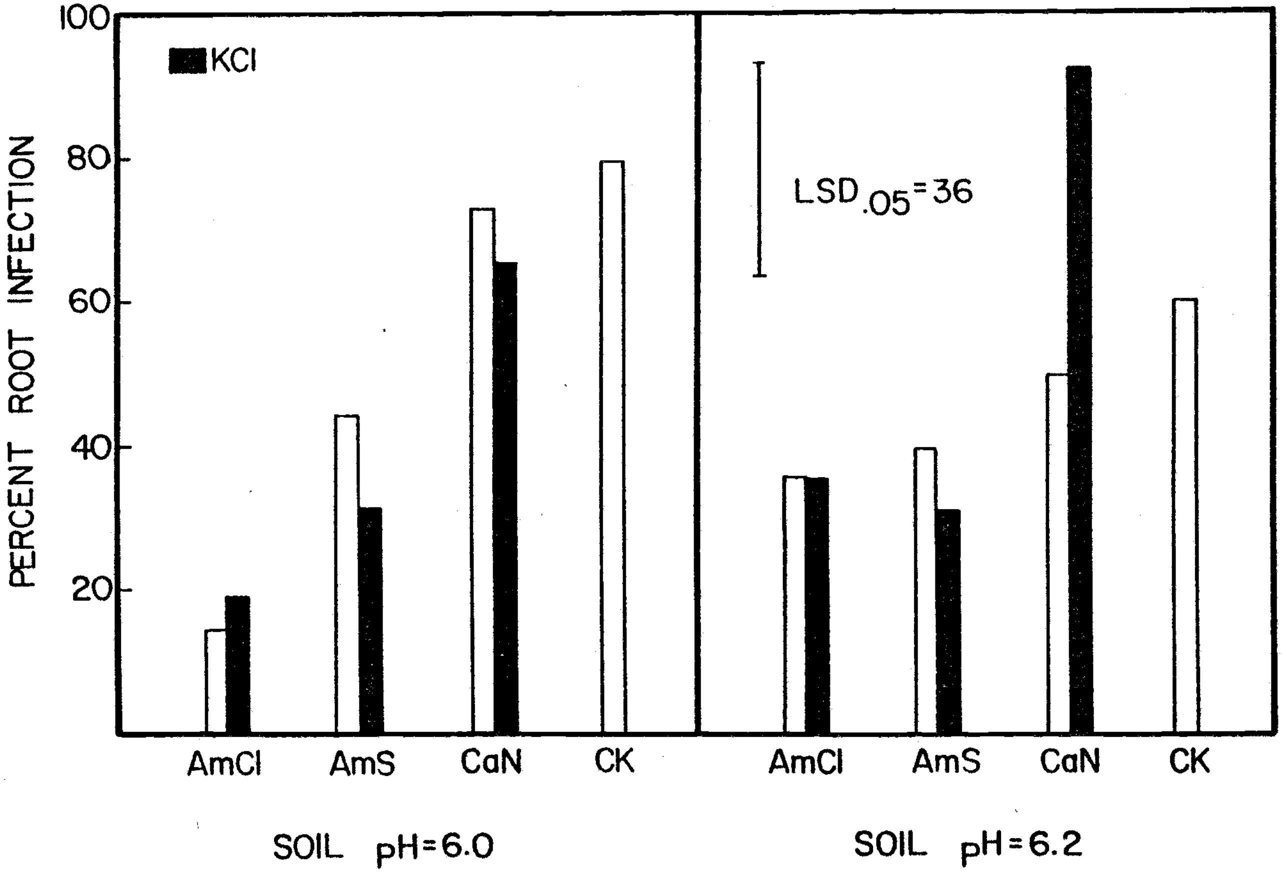

Figure 1. The effect of soil pH and different sources of nitrogen fertilizers with and without potassium chloride on the incidence of root infection by take-all. North Willamette Exp. Sta., 1978.

In order to evaluate the effect of Cl from other sources, yields from plots which received banded fall applications of KCl, K_2SO_4, and NaCl in addition to N fertilization were compared. Treatments containing NaCl and K_2SO_4 were not applied to plots with soil pH's of 5.6. Therefore, Table 2 contains yield means from plots with soil pH's of 6.0 and 6.2, only. Sodium chloride produced consistently, but not signficantly, higher yields, while KCl and K_2SO_4 rated about the same. The fact that yields resulting from NaCl fertilization were higher than either K_2SO_4 or KCl argues against a response to K. Even though Na can substitute in the plant for K, it does so poorly (Mengel and Kirkby, 1978). On the other hand, no significant advantage was demonstrated by KCl over K_2SO_4. Root symptom data pertaining to KCl was likewise difficult to interpret (Figure 1). Banding KCl with either $(NH_4)_2SO_4$, or $Ca(NO_3)_2$ reduced infection where the soil pH was 6.0 but no consistent advantage was noted at 6.2.

Suppression of take-all by KCl was more uniform in the preliminary study conducted in 1976-77 (Powelson and Jackson, 1978). That season, KCl when banded with either NH_4Cl, $CO(NH_2)_2$, NH_4NO_3, or $Ca(NO_3)_2$ acted to limit disease on both limed and unlimed plots. It could be that differences in the soil moisture regimes over the two growing seasons contributed to the reduced effectiveness of KCl in 1977. The fall and winter of 1976 were among the driest on record for the Willamette Valley, with 31.6 cm precipitation being recorded at the North Willamette Experiment Station between October 1 and March 1, as compared to 76.7 cm for the same period in 1977-78 (Climatological Data, Oregon, 1976-77, National Climatic Center, Asheville, N.C.). Chloride, a highly mobile anion, was more subject to be leached from the seedling root zone by the two-fold increase in precipitation in 1977, whereas the movement of Cl during 1976 was probably restricted due to the less favorable leaching conditions.

Support for the thesis, that a relationship existed between the persistence of Cl in the soil and reduction in the severity of attack by take-all, is enhanced when the amount of Cl contained in the various 1977 fertilizer treatments and their method of application are examined. The NH_4Cl + KCl treatment totalled 463 kg Cl/ha compared to 35 kg Cl/ha for the $(NH_4)_2SO_4$ + KCl and $Ca(NO_3)_2$ + KCl treatments. Besides differences in soil Cl concentration due to the larger amounts applied in the spring, there were probably other factors favorable to Cl retention by soils connected with the spring applications. Broadcasting the Cl over a large area, as contrasted with banding it, would promote the retention of Cl by taking better advantage of the soil's limited anion exchange capacity. It is possible that plant absorption of Cl might also be facilitated by broadcasting. In their work, Younts and Musgrave (1958) reported a higher tissue concentration of Cl in maize from broadcast than from banded applications of KCl. Additionally, the spring applied Cl avoided much of the leaching loss due to heavy winter precipitation.

In the plots established immediately adjacent to the take-all infected field at the North Willamette Experiment Station significant yield advantages were obtained from KCl fertilization. On land which was in fallow the previous year, plants revealed no above ground symptoms of take-all, and roots displayed only a moderate infection. However, since half the seed was innoculated artificially with G. graminis at planting, a low level of infection probably existed. Table 5 compares the grain yields from those plots which received high rates of KCl + $(NH_4)_2SO_4$ to those fertilized with NH_4Cl alone or $(NH_4)_2SO_4$ alone. The KCl at 93 and 186 kg K/ha contained 100 and 200 kg Cl/ha, respectively, which was broadcast applied in either fall or spring. Fertilizing with KCl in the fall did not increase yields significantly above those plots which received $(NH_4)_2SO_4$ alone, while spring application of KCl produced significant yield increases. It would be difficult to explain these results in terms of a response to K, particularly yield increases on soils with native K values of over 200 ppm (100 ppm soil K has been established as the critical level for wheat in the Willamette Valley).

All fertilizer treatments in this area of limited take-all infection yielded better than similar treatments in the more heavily infected plots (Tables 2 and 5). The check plot, for example, yielded 341% and 80% more grain than wheat from the infected plots planted October 4 and October 27, respectively. These data indicate that only a low level of take-all infection existed in the fallow plots, and that yield increases due to Cl probably resulted from increased plant vigor. It would also seem plausible that the lack of response to KCl in the infected plots was due to the low rate of Cl employed, as well as the method and time of application.

Both head weights and test weights were higher when plants were fertilized with NH_4Cl. This was another indication of take-all suppression by Cl, since a characteristic symptom of this disease is its inhibition of spike development due to moisture stress. When heads were harvested at the hard-dough stage, and the weight per head calculated,

TABLE 5. Yield response to rate and time of potassium chloride application on wheat with mild take-all infection. North Willamette Exp. Sta., 1978.

	Fertilizer Treatment[1]						
	Fall			Spring			
Source	N	K	Cl	N	K	Cl	Yield
	kg/ha						metric tons/ha
Check	0	0	0	0	0	0	3.60
NH_4Cl	34	0	86	134	0	342	6.04
NH_4Cl, KCl	34	37	126	134	0	342	6.08
$(NH_4)_2SO_4$	34	0	0	134	0	0	5.20
$(NH_4)_2SO_4$, KCl	34	37	40	134	0	0	5.16
$(NH_4)_2SO_4$, KCl	34	93 (BR)	100	134	0	0	5.36
$(NH_4)_2SO_4$, KCl	34	0	0	134	93	100	5.90
$(NH_4)_2SO_4$, KCl	34	186 (BR)	200	134	0	0	5.24
$(NH_4)_2SO_4$, KCl	34	0	0	134	186	200	5.80
P							**
df[2]							(24)
SEM[3]							(0.25)

** = Highly Significant (p = 0.01)

[1] All fall fertilizer banded with the seed except where indicated by Br = broadcast. All spring fertilizer broadcast applied.

[2] Degrees of freedom

[3] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

the NH_4Cl and NH_4Cl + KCl treatments displayed greater head weights (Table 6). Test weights made on the grain harvested in August indicated that the NH_4Cl treatment produced higher but not significantly different test weights than either $(NH_4)_2SO_4$ or $Ca(NO_3)_2$ when averaged over lime differences (Table 7).

Exactly how Cl inhibits the development of take-all is uncertain, but it may be related to the effect this ion has on the form of N absorbed by the plant. It has been demonstrated experimentally that Cl absorption by plants inhibits NO_3 uptake (Mengel and Kirby, 1978). This would result in a higher percentage of the N being taken up as NH_4-N, the N form suppressive to take-all. Research conducted by Warren et al. (1975) supports this contention. They reported a decrease in the severity of corn stalk rot when KCl but not K_2SO_4 was used in combination with anhydrous ammonia. Since stalk rot is apparently stimulated by NO_3-N, these workers concluded that it was an increase in NH_4 absorption, promoted by Cl, which inhibited the disease.

The synergistic relationship between Cl and NH_4 may also result from an increase in the amount of plant available NH_4 in the presence of Cl. Ghosh and his associates (1956) have shown that a slower initial conversion of NH_4 to NO_3 occurs with NH_4Cl than with $(NH_4)_2SO_4$. In their trials, 70% of the NH_4 from $(NH_4)_2SO_4$ was converted to NO_3 during the first twelve days of incubation, while only 35% of the NH_4Cl underwent conversion. After thirty days, the percentages were 83% and 93%, respectively.

The greater availability of NH_4 for plant uptake due to a slower nitrification rate, and the increased absorption of NH_4 over NO_3, both

TABLE 6. Effect of various nitrogen fertilizers, potassium chloride, and soil pH on the weight per head of take-all infected wheat planted October 27. North Willamette Exp. Sta., 1978.

Fertilizer Treatment	Soil pH 5.6	Soil pH 6.0	Avg.
	------ gm ------		
NH_4Cl	1.75	1.79	1.77
NH_4Cl, KCl	1.97	1.54	1.76
$(NH_4)_2SO_4$	1.60	1.62	1.61
$(NH_4)_2SO_4$, KCl	1.71	1.61	1.66
$Ca(NO_3)_2$	1.62	1.48	1.55
$Ca(NO_3)_2$, KCl	1.43	1.39	1.41
P	*		NS
df[1]	(22)		
SEM[2]	(0.036)		

NS = Not Significant

* = Significant (p = 0.05)

[1] Degrees of freedom

[2] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

TABLE 7. Test weights of grain from wheat infected with take-all, comparing the effects of seeding date, ammonium chloride, ammonium sulfate, calcium nitrate, and soil pH. North Willamette Exp. Sta., 1978.

Fertilizer Treatment	Seeded October 4				Seeded October 27			
	Soil pH				Soil pH			
	5.6	6.0	6.2	Avg.	5.6	6.0	6.2	Avg.
	kg/hl							
NH_4Cl	70.8	70.2	70.7	70.6	68.9	67.7	68.0	68.2
$(NH_4)_2SO_4$	70.2	70.2	69.6	70.0	66.9	65.4	65.8	66.0
$Ca(NO_3)_2$	69.1	68.7	68.8	68.9	66.8	64.8	63.8	65.1
(P)		NS		NS		**		**
df[1]						(16)		(4)
SEM[2]						(1.4)		(0.9)

NS = Not Significant

** = Highly Significant

[1] Degrees of freedom

[2] Standard error of a mean difference (least significant difference (LSD) = t x SEM)

mediated by Cl, would have the effect of increasing the NH_4/NO_3 ratio in the plant. Thus, the inhibitory effect of Cl on take-all might be accomplished through that ion's influence on nitrogen assimilation by the host.

Phosphorus

The combination of NH_4Cl + KCl + P produced significantly higher yields than did the NH_4Cl + KCl treatment (Table 2). Phosphorus fertilization has frequently been reported as having a role in take-all suppression (Garrett, 1942; Huber and Watson, 1974). Though no mechanism has been proposed, the involvement of P in root growth and development has been suggested as a contributing factor (Miller and Ohlrogge, 1958).

It is interesting to note that the $(NH_4)_2SO_4$ + KCl + P treatment did not produce yields significantly greater than the $(NH_4)_2SO_4$ + KCl treatment (Tabel 2), suggesting that a possible synergistic relationship between Cl and P was responsible for the yield increases obtained with the NH_4Cl + KCl + P treatment. Large amounts of Cl seem to be required to cause this effect, since the $(NH_4)_2SO_4$ + KCl + P treatment contained a small amount (40 kg) of fall banded Cl. It is doubtful, however, that Cl caused an increase in P uptake, since most research has demonstrated the existence of an antagonism between Cl and P (Shestakov and Shvuindenkov, 1934; Leonce and Miller, 1966; James et al., 1970). It is more plausible that the yield advantages realized by additions of fertilizer P to treatments containing high rates of Cl were a response to the amelioration of Cl inhibited P uptake.

CONCLUSIONS

The foregoing discussion has delineated the results obtained in an investigation of the effects of planting date, soil pH, N form, P, and Cl on take-all root rot. It was shown that the best suppression of take-all resulted from late seeding, but that as a control measure this practice may be of limited benefit in western Oregon. The main disadvantages associated with delayed seeding include the possibility that early fall rains may leave fields too wet to work, an increased risk of herbicide damage, and a reduction in yield potential.

Among the fertilizer treatments, P in combination with NH_4Cl produced the best control of take-all, whereas P + $(NH_4)_2SO_4$ + KCl was no more effective against take-all than the $(NH_4)_2SO_4$ + KCl treatment. This was interpreted as indicating a possible interaction between Cl and P.

Chloride when applied at a high rate in the form of NH_4Cl provided better suppression of take-all than the corresponding treatments of either $Ca(NO_3)_2$ or $(NH_4)_2SO_4$. However, low rates of Cl, as KCl, banded with the seed, failed to produce any significant reduction in disease. In a separate set of plots, where the wheat plants were only mildly infected with take-all, broadcasting KCl at high rates in the spring, but not in the fall, increased grain yields significantly. From these results it was concluded that Cl was probably acting to increase plant vigor, and consequently host resistance. The failure of the banded KCl to reduce take-all infection was attributed to the low rates applied and its proneness to be leached from the root zone by winter precipitation.

Certain results reinforced the observations of other researchers. For example, infection was lessened where NH_4 was the N source, whether as NH_4Cl or $(NH_4)_2SO_4$, as compared to NO_3-N. This response was first recognized by Huber et al. (1968), and later confirmed by Smiley and Cook (1971). The often reported increase in severity of take-all as a function of increasing pH was also observed at the North Willamette Experiment Station. However, at the Douglas County site disease severity decreased following liming. The latter response was attributed to the promotion of increased host resistance at the higher soil pH induced by a lower concentration of toxic micronutrients, whereas at North Willamette where micronutrient toxicity was not a factor limiting plant growth, liming was interpreted as providing a more favorable ecological niche for the pathogen.

The general conclusion can be made that Cl does exert an inhibitory effect on take-all, and, furthermore, that the degree to which it suppresses the disease is markedly influenced by the other variables considered in this study. Chloride was most effective at low soil pH in combination with K, and especially P. This, in spite of adequate levels of these nutrients as established by soil analysis. The availability to the plant, therefore, of a balanced array of nutrients is of decidedly greater importance where take-all is a problem.

In terms of benefits which might accrue to growers, Cl fertilization could aid in reducing the monetary losses caused by the primary root disease of wheat in the high rainfall and irrigated areas of the Pacific Northwest. Extra precautions could be taken, for example, to insure that fields with a high probability of developing take-all infection receive a balanced compliment of macronutrients in the fall. If symptoms of take-all appear later during the course of the growing season, spring fertilizers containing high rates of Cl, possibly as KCl, could be included to check infection.

No definite conclusions were decided upon as to the mechanism(s) by which Cl inhibits take-all. It was suggested that its influence on N assimilation by plants might be involved, but other possibilities exist. The answer to this question, therefore, must await future investigations.

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