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Mohamed El Hadi Maatougui for the degree of Master of Science

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Title: Response of Winter Wheat (*Triticum aestivum* L. Em. Thell) to Nitrogen and Chloride Fertilization in the Presence of Take-all Root Rot (*Gaeumannomyces graminis* var. *tritici* Walker)

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Dr. Willis L. McCuistion

Response from nitrogen and chloride fertilization was measured in field experiments on winter wheat (*Triticum aestivum* L. Em. Thell. var. 'Stephens' and 'Yamhill') grown in western Oregon in an environment with a range of susceptibility to take-all root rot (*Gaumannomyces graminis* var. *tritici* Walker). Cropping sequences and expected disease severity considered in the study were: first year wheat after clover (low risk of severe take-all root rot: Nixon I experiment), second year wheat with high disease infection in the previous crop (high risk of severe take-all root rot: Keyt II experiment), second year wheat with low disease infection in the previous crop (moderate risk of severe take-all root rot: Nixon II and Coon experiment), third year wheat (high risk of severe take-all root rot: Jones experiment), fifth year wheat (high risk of severe take-all root rot: Keyt II experiment), and eighteenth year wheat (take-all decline established: the pathogen is present in the soil but does not cause damage, Evers experiment). Nitrogen treatments were applied at 0, 67, 134, and 202 kg/ha in all

experiments where wheat followed wheat and at 0, 45, 90, and 134 kg/ha in the experiment where wheat followed clover. Chloride treatments were applied at 0, 45, and 90 kg/ha in all experiments and a rate of 134 kg Cl/ha was also used on the Jones experiment. Nitrogen was predominantly supplied from urea while ammonium chloride supplied chloride and ammonium sulfate supplied the crop requirement for sulfur (about 20 kg/ha). Fertilizers were top-dressed in split application with chloride and sulfur containing fertilizers applied first (February) and urea applied later (March) in all experiments but those conducted in the Nixon farm where a single fertilizer was applied in March. Crop response was measured through the effects of N and cl treatments on dry matter production, plant nitrogen content, plant nitrogen uptake and plant percent nitrogen recovery, as well as grain yield, yield components, grain nitrogen content, grain protein content, grain nitrogen uptake, and grain percent nitrogen recovery.

The results of the study strongly indicated that take-all root rot was only a problem in the Jones, Keyt I, and Keyt II experiments and was most severe in third year wheat (Jones experiment). This also was the only experiment with significant ($p = 0.05$) response from rates of 202 kg N/ha.

Nitrogen fertilization was the main factor that greatly influenced the levels of the variables studied while chloride fertilization generally did not have a significant ($p = 0.05$) influence. 134 kg N/ha was generally the rate accounting for the best levels of each variable studied in all experiments except in the Jones experiment as precised earlier.

Crop response was also affected by a relatively long 'dry' period (April 20th to June 20th), particularly in the experiment where take-all root rot was a problem.

Levels of the variables studied accounted for by the optimum rates of N were consistently higher in the experiments where take-all root rot was not a problem than where it was a problem by the following amounts: dry matter yields-17%, plant nitrogen contents-18%, plant nitrogen uptake levels-30%, plant nitrogen recoveries-28%, grain yields-22%, grain nitrogen contents-only 4%, grain protein contents-only 2%, grain nitrogen uptake levels-26%, grain nitrogen recoveries-18%, and spikes/m^2-24%.

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Redacted for Privacy

Head of department of Crop Science

Redacted for Privacy

Dean of Graduate School

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I. INTRODUCTION

Wheat production in western Oregon (west of the Cascade Mountains) is primarily concentrated in the Willamette Valley. Yields are influenced by environmental factors such as soil reaction, rainfall, soil drainage during wet winters, and temperatures, mild but favorable, which set the environmental conditions that influence plant diseases and in which the grain yield is elaborated. Maximum yield levels are achieved with efficient and consistent cultural practices that disrupt the negative effects that can arise from the interaction of all these factors combined.

The fertilization program, especially for nitrogen, and the disease problem, especially take-all root rot, are two important factors that affect the crop yield levels and consequently the farmer's profit margin.

Minimizing the disease influence with an elaborate nitrogen fertilization program that will consistently increase and insure stable high yields was the challenge that faced both researchers and farmers. It is in this perspective that, in 1976, Dr. Jackson and Dr. Powelson set the pace towards some interesting and unique findings to deal with the situation.

Powelson and Jackson (1978) found that banding chloride (Cl) containing fertilizers with the seed at planting provided suppression of take-all. This was the first time chloride (Cl) was reported to affect take-all.

Later, Christensen et al. (1981), Christensen et al. (1982), and Taylor et al. (1983) evaluated specific effects of seeding date, soil pH, nitrogen form, phosphorus and chloride on take-all. They established that spring top dressing of chloride with NH_4-N form increased grain yield and controlled take-all.

Management recommendations developed from this research allowed Willamette Valley wheat growers to produce wheat after wheat with reduced risk where take-all root rot has developed.

Take-all root rot is a problem in the Valley because of increased frequency of wheat in the crop rotation. Consequently, a better understanding of the effects of spring topdressings of nitrogen, chloride, and other management practices on the expected incidence of take-all root rot and subsequent wheat yields is essential for the successful production of this crop.

A study reflecting a range of expected take-all root rot situations corresponding to different wheat cropping sequences was conducted in the 1981-1982 growing season. These situations were:

- high risk of take-all (HRTA): 2nd and 3rd year wheat
- moderate risk of take-all (MRTA): 2nd year wheat with low take-all the previous year
- low risk of take-all (LRTA): 1st and 5th year wheat
- take-all decline established (TADE): longterm wheat (more than 6 years)

The objectives of the study were 1) to measure crop response as influenced by take-all root rot and the different rates of nitrogen and chloride attempting to determine the rates providing for the best yield levels in each take-all situation (redefined if necessary); 2) to determine the nitrogen uptake and nitrogen recovery in relation to the applied nitrogen and chloride rates; and 3) to assess the effect of nitrogen and chloride fertilization on the yield components, the above ground dry matter, the percent grain protein, percent nitrogen in the grain and the whole plant at the dough stage. This thesis reports on the results of this study.

II. LITERATURE REVIEW

In western Oregon, application of nitrogen to winter wheat is required to insure high yields and optimum protein content. Recently, application of chloride has proven to be beneficial to counter the take-all root rot problem and to increase grain yield.

The literature has been reviewed under the following subject headings:

a) The take-all root rot disease

b) Nitrogen and chloride ferilization and crop response

The take-all root rot disease

Take-all root rot is caused by the soil-borne fungus *Gaeumannomyces graminis* (Sacc.) Arx & Oliver var. *tritici* Walker (G.g.t), formerly referred to as *Ophiobolus graminis* (Sacc.) Sacc. (Walker, 1975).

Take-all has increased in western Oregon as the frequency of wheat in the crop rotation increased (Christensen et al., 1982). This disease was first reported in western Oregon by Cordley (1902).

Root infection results from the penetration of ascopore germ tubes into the root hairs and the epidermis in the meristematic zone leading to the plugging of the xylem and consequently, the death of roots (Weste, 1972).

The affected plants have decaying, blackened roots with infection extending to the crown and basal stem in severe cases (Wiese, 1977). Root rot can occur on plants at all growth stages.

Seedling and young plants can be killed by take-all in patches, tillering is reduced on older plants, and at maturity, infected plants show bleached heads (white heads) (White, 1947, cited by Walker, 1975).

Take-all is favored by mild soil temperatures (12 to 18 C), and wet soil conditions, prevailing in high rainfall and irrigated areas (Wiese, 1977). Cook et al. (1972) found that G.g.t grew best at highest moisture levels (-1.2 to -1.5 bars) and ceased growing at -45 to -50 bars. In this regard, soils of western Oregon are ideal habitats for G.g.t.

Saprophitic survival of G.g.t is perpetuated within the parasitically colonized plant crowns, organic debris and straw tissue returned to the soil (Walker, 1975). Viable G.g.t was found on artificially colonized stubble after 50 weeks (Butler, 1959; MacNish and Dodman, 1973). Survival was found to be dependent on soil residual N (Butler, 1959). Hosts of G.g.t, besides wheat, include barley, rye, bentgrass, quackgrass, and bromegrass (Wiese, 1977).

The pathogen has been reported capable of satisfactory growth over a wide range of soil pH: 3.2 to 9.6 (Huber and Watson, 1974), and the disease severity has been reported to increase with increasing soil pH (Cook et al., 1968). Smiley and Cook (1973) concluded the pH of the root rhizosphere was important in establishing the disease.

Yield losses caused by take-all are variable and associated with disease severity. The most serious losses occurred in high rainfall and irrigated areas (Cook et al., 1968; Cook and Papendick, 1972) where continuous wheat was produced (Shipton, 1972) before the decline of the take-all severity was established in the monoculture, or in wheat after a break of the monoculture rotation (Butler, 1961; Cook, 1981; Slope and Etheridge, 1971).

Control of take-all root rot: factors affecting G.g.t

The lack of genetic resistance and effective fungicides leaves cropping sequences and manipulation of soil management practices as the major basis for control. Important practices affecting this disease are reviewed in this section.

Crop rotation and take-all decline

Suppression of take-all of wheat with crop rotation depends on whether wheat follows wheat or another crop that is host or nonhost to G.g.t in some kind of short or long term rotation that takes into consideration the pathogen survival and the factors affecting it (Walker, 1975).

In short-term crop rotation, take-all severity was usually reported to be more manifested in intensive wheat culture or in wheat after a pathogen host crop (Walker, 1975). Increased severity was reported in wheat after subterranean clover (Butler, 1961), as well as in second year wheat after oats (Slope and Etheridge, 1967), and after beans (Slope and Cox, 1964), all nonhost crops.

Because of the resurgence of take-all severity in the second year wheat crop, the value of nonhost breaks in short term rotations was regarded as limited and more attention was given to what Slope and Cox (1964) described as take-all decline (TAD) as a means to control take-all.

TAD, a wheat monoculture phenomenon, is based on the fact that the severity of take-all increases until the third or fourth wheat crop and then starts to decrease in the fifth or sixth crop and then remains fairly steady in the decline state (Brown et al., 1973; Cook, 1981; Hornby, 1979; Shipton, 1975; Slope and Cox, 1964). If the decline phase is broken with any other crop, especially legumes, the severity cycle will start again (Hornby, 1979; Slope and Etheridge, 1971; Shipton, 1975).

TAD results from a natural form of biological control by agent(s) not fully identified (Cook, 1981; Hornby, 1979; Shipton, 1975). Hornby (1979) summarized the explanation accounting for TAD to fall into two main categories: The disease is either suppressed by determinants external to the fungus (i.e. antagonistic soil microorganisms), or by determinants within the fungus itself (i.e. loss of virulence). In either category of explanation, it is admitted that the pathogen remains present in the soil but no longer causes severe disease.

Recent investigation by Cook and Naiki (1982) showed that there was little evidence that during prolonged wheat cultivation (7 to 22 years), declining virulence in the population of G.g.t could account for the absence of take-all, suggesting that antagonistic soil microflora probably played a more important role.

Even though the mechanism of disease severity decline remains to be elucidated, TAD offers a means of disease control in regions where wheat monoculture is the dominant cropping system. In western Oregon, the take-all decline phenomenon is assumed to conform to the description given earlier (Christensen et al., 1982).

Nitrogen fertilization and take-all root rot

Within the management practices that significantly affect take-all root rot of wheat, nitrogen form has been reported to have had a decisive impact because of its influence on both host nutrition and disease severity. It is widely accepted that severity of take-all is decreased by NH^+_4 N and increased by NO^-_3-N forms (Hornby and Goring, 1972; Huber et al., 1968; Huber and Watson, 1974; Huber et al., 1980; MacNish and Speijers, 1982; Smiley, 1978a; Smiley, 1978b; Smiley and Cook, 1973; Taylor et al., 1983; Walker, 1975).

Furthermore, it is the form of N available to the host and pathogen that affects disease severity or resistance rather than the amount of nitrogen (Huber and Watson, 1974).

Huber et al. (1968), in Idaho, clearly showed this in pot and field experiments. Application of ammonium sulfate, $(NH_4)_2SO_4$, particularly in combination with nitrapyrin (a nitrification inhibitor) reduced take-all severity, while application of ammonium nitrate (NH_4-NO_3) at even lower rates increased take-all severity in both field and pot experiments. The more effective control of take-all with the NH_4-N form was attributed to the fact that slow rate of nitrification made ammonium -N more utilized by competitive or antagonistic soil microorganisms, thus affecting G.g.t populations.

In further investigations with irrigated spring wheat, Huber (1972) showed that timing of NH_4-N application was an important consideration in the control of take-all and should be regarded in relation to conditions that influence the rate of nitrification. Applying 84 kg N/ha as ammonium sulfate in the fall resulted in severe take-all, lower grain yield, and less straw than in non-fertilized plots, while spring application provided practical control of take-all, and increased grain and straw yields.

In both previous cases, evidence that nitrogen form affected wheat resistance to take-all was attributed to reduced root tissue infection and smaller lesions caused by NH_4-N compared to NO^-_3-N due to a combination of increased root growth, host resistance, and altered G.g.t pathogenicity by soil microflora.

In western Oregon, suppression of take-all with NH_4-N was shown by Christensen et al. (1982), Powelson and Jackson (1978), and Taylor et al. (1983). More emphasis was put on the fact that within NH_4-N fertilizers, NH_4Cl (ammonium chloride) provided better take-all control than $(NH_4)_2SO_4$ (ammonium sulfate) because of the role of chloride (Taylor et al., 1983).

Garrett (1948), Horby and Goring (1972), Nilsson (1969), and Smiley and Cook (1979) reported that a high NH^+_4-N : NO^-_3-N ratio was desirable to reduce take-all and that use of (nitrapyrin) 2-chloro-6-(trichloromethyl) pyridine helped maintain a high ratio especially for fall applied NH_4-N fertilizers. None of these workers reported ammonia toxicity to have occurred to roots.

In eastern Washington, Smiley and Cook (1973) attributed the controlling influence of NH_4-N form and lack of control of NO^-_3-N to be correlated with the root rhizoshpere pH (pHr). The pHr was found to drop with uptake of NH_4-N, to increase with uptake of NO_3-N, and to remain generally unchanged with no added N fertilizer. Poor correlation was found between soil bulk pH (pHb) and disease severity.

In acid soil situations (Puyallup fine sand loam, pHb = 5.6), using 'Nugaines' winter wheat and broadcasting 90 kg N/ha as $Ca(NO_3)_2$ and $(NH_4)_2SO_4$ + nitrapyrin before planting, they found that the pHr was consistently below 5.0 where take-all was controlled, and above 6.0 where take-all was not controlled. Furthermore, because the disease severity was uniform at pHr above 5.0 in fumigated plots, they concluded that control operated directly on the fungus at pHr below 5.0 and probably through the aid of antagonistic microorganisms at pHr between 5.0 and 6.6.

Nitrogen form influences the root rhizoplane and rhizosphere microflora. Various fungi, streptomyces, and bacteria have been recognized as antagonists of G.g.t (Smiley and Cook, 1973; Smiley, 1978a and 1978b; Walker, 1975).

Smiley (1978a) showed that apparent populations of bacteria and streptomyces were similar in rhizoplanes of wheat grown in NH^+_4-N vs. NO^-_3-N treated soils, but that shifts did occur in the proportions of Pseudomonas and Streptomyces spp. that were antagonistic in vitro towards G.g.t.

In a further study, in vivo, Smiley (1978b) found that hyphal growth (lineal extension) rates of G.g.t were lower in soils treated with NH^+_4-N vs. NO^-_3-N treated soils and that the Pseudomonas spp. consistantly appeared more suppressive in NH^+_4-N treatments than the general bacterial flora, Bacillus spp. spores, streptomycetes, and fungi.

Considering the many aspects influenced by nitrogen fertilization in terms of take-all control and considering the impact of N on wheat grain yield, it is apparent that good management of N fertilization is a key factor to wheat production in regions where take-all is a problem.

Chloride fertilization and take-all root rot

Reports from the literature claiming reduction of take-all or other diseases with chloride (Cl) are scarce, probably because Cl has been almost always associated with potassium (K) as KCl fertilizer and because K has been regarded as a more important plant nutrient compared to Cl in terms of requirements for adequate plant growth and development.

There are, however, reports of Cl controlling diseases of some major crops. Younts and Musgrave (1958) reported decreased severity of corn stalk rot (caused by Giberella zeal and G. fujikuroi) with increased KCl application.

Hedge and Karande (1978) reported that pretreatment of seeds with NaCl solution decreased the incidence of downy mildew (Sclerophtora macrospora) of pearl millet.

Christensen et al. (1982) and Russell (1978) reported significant severity reduction of yellow or stripe rust (Puccinia striiformis) of wheat with application of NH_4Cl as compared to $(NH_4)_2SO_4$ and with KCl and NaCl fertilizers.

Most of the literature reports on control of take-all with chloride fertilization originated in western Oregon. Initial claims were made by Powelson and Jackson (1978) who reported that banded chloride (as NH_4Cl or KCl) with the seed provided additional take-all suppression on winter wheat. The rates of chloride were about 90 kg Cl/ha.

Taylor et al. (1983) confirmed the effect of chloride on take-all suppression with banded NH_4Cl (at 86 and 126 kg Cl/ha) with the seed and topdressed NH_4Cl (at about 342 kg Cl/ha) in early spring. They reported that rates of about 40 kg Cl/ha (as KCl) banded with the seed did not have any significant effect on take-all. It was also reported that, based on grain yield, percent root infection and test weights, the NH_4Cl treatments produced better suppression of take-all than the $(NH_4)_2SO_4$ treatments, indicating a response to chloride. $Ca(NO_3^-)_2$ treatments produced lower performances than the two previous fertilizer treatments. It was concluded that Cl exerted an inhibitory effect on the take-all disease and that the degree to which Cl suppressed the disease was dependent on other variables in the system. The greatest suppression of take-all was obtained with the following treatment combination: P + NH_4Cl + KCL. No mechanism of take-all inhibition was proposed.

Christensen et al. (1982) reported that NH_4Cl banded with the seed reduced the severity of take-all but did not significantly ($p = 0.10$) increase grain yield. However, spring top dressings of NH_4Cl (342 to 369 kg Cl/ha) increased grain yield of winter wheat, infected with take-all and *Septoria* spp., when compared to top dressings of $(NH_4)_2SO_4$ at an equivalent rate of N. It was also reported that the treatment $(NH_4)_2SO_4$ + KCl or $CaCl_2$ was as effective as NH_4Cl to increase grain yield, thus confirming the response to Cl; 92 kg Cl/ha was the rate (top dressing) at which near maximal yields were obtained. This rate is the rate of Cl recommended to wheat growers of western Oregon (Jackson et al., 1980).

Christensen et al. (1981) found that Cl uptake lowered the chemical potential of water in the plant and concluded that this lowering reduced the colonization of plant roots with G.g.t. They proposed this explanation to be the mechanism by which chloride affected take-all root rot and suggested that application of Cl could be used as a management tool to alter wheat plants' osmotic potential and consequently, to suppress or slow the rate of G.g.t root colonization.

Acid soils, lime, and take-all root rot

Although take-all of wheat has been reported to be usually associated with low fertility alkaline soils (Butler, 1961), severe infection can occur in acid soils where wheat monoculture is practiced (Nilsson, 1969).

Huber and Watson (1974) reported that the pathogen is capable of satisfactory growth over a wide pH range (3.2 to 9.6). In acid soils, they reported that the pH effect was to reduce or restrict the rate of nitrification allowing NH^+_4-N fertilizers to persist longer under this form and, consequently, would affect the take-all fungus.

The use of lime in acid soils has been reported to increase severity of take-all. Powelson and Jackson (1978) reported that raising the pH of a Willamette series soil from 5.7 to 6.0 and 6.2 aggravated the disease on 'Hyslop' soft white winter wheat.

Smiley and Cook (1973), emphasizing that the pH of the root rhizophere (pHr) has more influence on take-all severity than the soil bulk pH (pHb), reported that addition of lime to Puyallup series soil (pHb = 5.6) suppressed the ability of $NH^+{}_4$-N form to affect take-all. The pathogen growth was found to be nil in sterile and non-sterile soil at pHb less than 5.0.

Walker (1975) reported that liming lessened the antagonistic microflora, thus indirectly affecting the preconditions to take-all decline (TAD).

Date of planting and take-all root rot

Date of planting has not been widely reported as a means to reducing take-all, probably because it has not been considered a major control factor.

In western Oregon, it has been found that early planting (early October) favored disease severity (Powelson and Jackson, 1978). Delaying planting (late October) is recommended as part of the management strategy to counter the take-all problem because it avoids early infection and establishment of the fungus in wheat plant roots (Jackson, 1980).

Nitrogen fertilization and crop response

Nitrogen fertilizers are applied to small grain crops like wheat to increase grain yield and grain protein content. Recommendation of optimum levels of N fertilizers are conditioned by factors such as: N sources, N timing, method of N application, and their interaction with environmental and soil factors. Thus, N status of crops is influenced by the interaction of these factors.

Crop nitrogen recovery and fertilization efficiency

Under ideal conditions, high recoveries of N by crops can be expected. At Rothamstad, Gasser and Iordanou (1967) applied N at 56 and 112 Kg/ha to wheat, oats, and barley and found N recoveries (measured on entire plant material at harvest) averaged 74 and 72% in pot experiments and 68 and 59% in field experiments.

Nitrogen recovery by crops is greatly influenced by the fertilization practices followed. In earlier studies, Gasser (1961) reported low recoveries of N by the winter wheat variety 'Cappelle' when N was applied in the fall as $Ca(NO_3)_2$ or as $(NH_4)_2SO_4$ at a rate of 112 kg/ha. Limited fall applied N was taken up during the fall-winter period with heavy losses of N from the soil surface by March. Maximum N recovery from fall application was 27% with plant samples taken at ear emergence (in June). When N fertilizers were applied, half in the fall and half in the spring, the average N recovery was 42%.

In Indiana, Huber et al. (1980) found that fall applied NH_4-N fertilizer plus nitrapyrin (a nitrification inhibitor) produced grain yields comparable to a split application of N (25% fall-75%

spring) without nitrapyrin. Nitrogen losses, leaching, and denitrification from the upper soil profile were reduced by the nitrification inhibitor. It was also reported that protein content was increased and the severity of fungal root and crown rots of winter wheat was reduced. Stanford and Hunter (1973) reported that N recoveries by winter wheat cultivars were significantly greater with spring N applications than with fall N applications in Pennsylvania. The applied rates in both fall and spring were 34, 67, 101, 135, and 168 kg N/ha. The mean percent N recoveries were 56% and 48% for spring and fall N applications, respectively.

In western Oregon, Roberts et al. (1972) found that spring N applications gave greater grain yield increases than fall applications and no advantage was gained from a portion of N in the fall or making more than one spring application of N; these comparisons were made where wheat did not follow wheat in the crop schedule. Optimum grain yields were obtained with rates ranging from 84 to 164 kg N/ha and were closely related to cropping history and the N content of above plant parts at the jointing stage.

In northeastern Oregon, Rasmussen and Pumphrey (1975) showed that N recoveries by irrigated winter wheat were greater for spring applied N and increased with increasing rates of N. The fertilizer rates applied were 67, 134, and 202 kg N/ha. At site A, the resulting recoveries were 25, 60, and 49% for fall applied N and 68, 80, and 99% for spring applied N. At site B, the recoveries were 33, 75, and 57% and 52, 61, and 76% for fall and spring applications, respectively.

NH_4-N fertilizers are known to be a better source of N compared to NO_3-N fertilizers when take-all root rot is a problem and high risk of leaching losses exist. Taylor et al. (1983) showed that $(NH_4)_2SO_4$ and NH_4Cl were better sources of N than $Ca(NO_3)_2$ to increase grain yield of 'Yamhill' winter wheat infected with take-all root rot. Increased disease severity and leaching losses of N were the cause of the poor performance of $Ca(NO_3)_2$. Because of the inhibitory effect of chloride on take-all root rot, spring topdressing of NH_4Cl (at the same rate of nitrogen) has been reported to be superior to topdressings with $(NH_4)_2SO_4$ although $(NH_4)_2SO_4$ + Cl as KCl or $CaCl_2$ were as effective as NH_4Cl in reducing disease severity and increasing yields of winter wheat (Christensen et al., 1982; Taylor et al., 1983).

Nitrogen uptake and dry matter production

Dry matter production and N uptake of wheat usually reach maximum levels around the flowering stage (Boatwright and Haas, 1961; Gasser and Iordanou, 1967; Storrier, 1965). The maximum growth rate of wheat occurs during the period from late tillering to late milk stage and crop N (70-80%) is taken up at high rates (Doneen, 1934; Gasser, 1961; Olson and Kurtz, 1982; Stanford and Hunter, 1973). Rates of dry matter production and N uptake decrease sharply after the flowering stage (Boatwright and Haas, 1961; McNeal et al., 1966).

In North Dakota, Boatwright and Haas (1961) found that N uptake and dry matter production of spring wheat grown under dryland conditions reached a maximum at heading with adequate levels of N and P. When P was deficient, N uptake continued until the soft dough stage. Without N and P, nitrogen uptake continued until maturity. These findings showed that fertilized wheat attains maximum dry weight and N uptake at heading with the grain N content dependent upon transfer of N from plant parts rather than upon absorption from the soil during the grain formation period.

In Nebraska, Daigger et al. (1976), working with winter wheat, reported that maximum dry matter production and total N accumulation occurred during the soft dough stage. While dry matter was significantly different in different locations, N content was mostly influenced by the amount of applied N.

In Montana, McNeal et al. (1966) in a comparative dry matter study of five spring wheat varieties found that N uptake continued until harvest although the rate was much lower after flowering. Maximum leaf development was found to have occurred at flowering, and maximum stem development occurred at the filling stage. Dry matter production was found to be highly correlated with grain N uptake (r = 0.95). Thus, 90.2% of the variation in grain N was due to differences in plant dry weight.

Gasser and Iordanou (1967) noted that the dry matter production-N uptake relationship was not a relevant criterion of crop N status in early stages of growth because plants can accumulate N when other conditions can limit growth. In pot experiments, they found that at the flowering stage, on average of all three crops (wheat, barley, and oats), the amounts of dry matter produced were only 51 and 39% of the extra dry matter produced at harvest, although plants already contained 87 and 99% of the extra N taken up, at the low (56 Kg/ha) and high (112 Kg/ha) rates of N, respectively.

Rates of N greatly influence dry matter production and N uptake. Gasser and Iordanou (1967) found consistently higher N uptake and dry matter production levels by wheat, barley, and oats at the highest rate of N (112 kg N/ha) with both calcium nitrate and ammonium sulfate fertilizers. In Pennsylvania, Stanford and Hunter (1973) showed that nitrogen content of grain plus straw was associated with maximum attainable dry matter yield and was not significantly different among locations and varieties. The mean critical level for optimum dry matter was determined to be 1.38 ± 0.06% (standard deviation) N in grain plus straw material. The interaction of rates by timing of N on N uptake, dry matter production, and grain yield was not found to be significant in this study.

Nitrogen forms are known to influence plant growth and development, thus affecting dry matter production and N uptake in above ground parts. Spratt and Gasser (1970), in pot and field experiments, using spring wheat adequately supplied with water, produced more dry matter containing more N with calcium nitrate as compared to ammonium sulfate + nitrification inhibitor at 112 and 224 kg N/ha. When shortage of water limited growth, NH_4-N was as good as or better than NO_3-N to increase dry matter and N uptake. In Manitoba, Spratt (1974) found that application of N as NH_4-N (plus nitrification inhibitor) at sowing resulted in maximum leaf and stem growth and as NO_3-N at the boot stage led to higher N in the grain of 'Manitou' spring wheat. It was also found that application of NH_4-N only (with nitrification inhibitor) at both stages of growth increased P and Zn uptake while NO_3-N under the same conditions depressed P, Mn, and Zn uptake but enhanced Ca uptake measured at the dough stage. This is due to lowered pH of the root rhizosphere caused by uptake of NH_4-N (Smiley and Cook, 1973; Spratt, 1974).

In growth chamber studies, Leyshon et al. (1980) found that NO_3-N treated plants of 'Manitou' spring wheat were taller and had thicker stems and more spikelets/spike than NH_4-N treated plants. On the other hand, NH_4-N treated plants (NH_4-N +nitrification inhibitor) produced more spikes and matured faster. Grain yield levels were found higher for NH_4-N treated plants, especially at higher rates of N (N rates ranged from 23 to 360 kg N/ha); however, it was suspected that denitrification losses of N from NO_3-N treated soil contributed to the differential plant response to both N forms. Cox and Reisenauer (1973) showed that growth rate of wheat plants were maximum when a combination of NO_3-N and NH_4-N is present in the nutrient medium as compared to growth rates with NO_3-N or NH_4-N only.

Nitrogen in plant parts

Nitrogen content of above ground wheat plant parts has been widely used to understand the N-grain yield and grain protein relationship and the negative effect of excess N.

Average requirement levels of N for winter wheat at head emergence are: deficiency level, less than 1.25%; low levels, 1.25 to 1.75%; adequate levels, 1.75 to 3.0%; excessive levels, more than 3% (Olson and Kurtz, 1982).

In Arizona, Gardner and Jackson (1976) used NO_3-N concentration of the lower 5 to 8 cm of the stem as a basis for N recommendations for irrigated spring wheat and proposed the following critical levels: 3 to 4 leaf stage, 7,000 to 12,000 ppm; jointing stage, 5,000 to 10,000 ppm, and boot stage, 3,000 to 9,000 ppm. If NO_3-N levels were higher than these, they were found to decrease grain yield.

In western Oregon, Roberts et al. (1972) found total N content of winter wheat vegetation at tillering stage to be poorly correlated with grain yield. However, at jointing stage, grain yield was closely associated with N content of plant vegetation with a level of 2.6% required in plant vegetation for optimum grain yield, and with levels exceeding 3.5% N, there was a general trend toward depression in grain yield.

In Pennsylvania, Stanford and Hunter (1973), working with wheat, found that a level of 1.22 ± 0.66% (SD) N at maturity to be the critical N level for maximum grain yield.

As growth resumes, the N content of plant vegetative parts is greatly influenced by N fertilization. Hucklesby et al. (1971) increased grain yield, grain N content as well as grain protein with application of N (as KNO_3) on April 2 and 23 and May 9 at 56, 56, and 112 kg N/ha, respectively, to 'Arthur' and 'Blueboy' soft red winter wheats and to 'Parker' hard red winter wheat. A single application of N at 224 kg/ha on April 23 produced similar results.

Gasser and Iordanou (1967) showed that grain N content increased sharply during the grain filling period and that most of the N was derived from translocation of N from leaves and stem.

Singh et al. (1979) showed that increasing grain N content was dependent on availability of N as well as moisture during the period from flowering to maturity. Average grain percent N ranged from 3.8 to 4.4% when N rates ranged from 60 to 120 kg/ha and irrigation number ranged from 0 to 3. McNeal et al. (1968) found that %N in wheat grain was associated with top growth in both dryland and irrigated spring wheat. The correlation coefficients were 0.89 and 0.92, respectively. In an earlier study, it was reported that grain N content was closely associated with translocation of N from plant parts and that a translocation level of 70% or above was highly desirable (McNeal et al., 1966). In the 1968 study, the reported translocation percentages were 66.2% under irrigation and 74.8% under dryland condition suggesting that when excessive growth was stimulated, the percent N in the grain could be affected, and consequently, the grain protein content.

N losses from the plant

Losses of N from plants has been widely reported (Boatwright and Haas, 1961; Daigger et al.,1976; Doneen, 1934; Gasser, 1961; McNeal et al., 1968). Gasser (1961) reported a loss of 22 kg of N/ha by winter wheat between ear emergence and harvest. He suggested that wheat plants accumulated N they were not able to use and attributed the loss of N to leaf abscission and translocation of N back to the soil. Daigger et al. (1976) showed that N losses increased with increased rate of N. With rates of 0, 67, and 133 kg N/ha, N losses from anthesis to maturity were 26, 28, and 41% compared to the N content at anthesis. They explained these losses to be due to volatilization of NH_3 or N oxides from the plant following senescence. Hooker et al. (1980) showed that, in fact, these N losses were partially accounted for by volatilization of NH_3 from plant tissue. Boatwright and Haas (1961) showed that these N losses are low when N supply to the plant is low.

Chloride fertilization and crop response

Yield increases from the influence of chloride fertilization on wheat have been associated with reduction in wheat diseases. The effects of chloride in reducing some wheat diseases was discussed in an earlier section: refer to page 11. The reduction of take-all root rot with applications of chloride fertilizers has generated increases of grain yield (Christensen et al., 1982; Christensen et al., 1981; Powelson and Jackon, 1978; Taylor et al., 1983).

Christensen et al (1981) reported grain yield increases ranging from 770 to 2,150 kg/ha (11 to 40%) with NH_4Cl as compared to

$(NH_4)_2SO_4$ with rates of N at 135 to 145 kg/ha and rates of Cl at 342 to 355 kg/ha topdressed on March 10. The test weights were also found to be significantly increased with Cl application. The increase in grain yield was partially attributed to a mediated chloride reduction of root colonization by the pathogen (G.g.t.) through alteration of plant-water potentials. Measured osmotic potential reduction on leaves of the winter wheat varieties 'Yamhill' and 'Stephens' in May reached 4 and 2 bars, respectively, and persisted through June with Cl topdressing as noted earlier. Leaves of the variety 'Stephens' showed an erect growth habit in the period before the boot stage, being very pronounced at midday with NH_4Cl as compared to $(NH_4)_2SO_4$. This effect was attributed to increased cell turgor influenced by the Cl^- ion probably through osmoregulation.

Other significant effects of chloride fertilization on wheat response are related to the basic role of Cl^- ion in terms of plant nutrition. The Cl^- ion is antagonistic to the NO^-_3 ion, and high supply of Cl^- in a nutrient medium tend to lower the uptake of NO^-_3 and vice versa, thus affecting plant growth and development (Hiatt and Leggett, 1974; Mengel and Kirkby, 1979).

Hiatt and Leggett (1974) reported on this antagonistic effect in a solution culture study with barley. Plants absorbed decreasing amounts of Cl^- with increasing levels of NO^-_3 when the Cl^- concentration is constant.

Jackson et al. (1982), Murarka et al. (1973), and Saffigna and Keeney (1977) in field conditions, reported decreased NO_3-N as well as total N with increased Cl as KCl in petioles and tubers of potato plants.

This antagonistic effect of Cl^- and NO^-_3 could have important implications for wheat production in areas where take-all root rot is a problem because of the stimulatory effect of NO_3-N on G.g.t. (refer to section: Chloride fertilization and take-all root rot).

The function of chloride in wheat plants, as well as in plants in general, is still obscure. Bove et al. (1963) and Kelly and Izawa (1978) showed that Cl was required for photosynthetic O_2 evolution at photosystem II working with isolated chloroplasts. This function of Cl was questioned by Terry (1977).

Specific plant Cl content varies depending on the plant species, and ranges from 2 to 20 mg Cl/g (0.2 to 2%) of dry matter (Mengel and Kirkby, 1982). Cl concentrations measured on mature leaves of 'Stephens' winter wheat sampled on May 20 ranged from 0.16 to 1.04% (Christensen et al., 1981). Without Cl fertilization, leaf Cl content ranged from 0.15 to 0.20%; with 101 kg Cl/ha as KCl or NaCl, leaf Cl content ranged from 0.5 to 0.6%; with 355 kg Cl/ha resulting from application of NH_4Cl, leaf Cl content reached a level of 1.04%. In all cases, N was applied at 140 kg/ha.

Leaf Cl content is different for different wheat varieties. Typical leaf Cl content of the varieties 'Stephens' and 'Yamhill', when fertilized with at least 101 kg Cl/ha, ranged from 0.6 to 1.2% and 1 to 1.2%, respectively, while leaf Cl content of unfertilized wheat ranged from 0.10 to 0.15% and seemed to be constant (Christensen, 1983, personal communication).

Critical levels of Cl in wheat are not known. Deficiency symptoms of Cl in barley grown in solution culture were reported to be manifested as general chlorosis of newly emerging leaves, while older leaves remained wrapped in tubular form much longer than normal barley leaves and were slower growing, smaller, and more fragile (Johnson et al., 1957).

III. MATERIALS AND METHODS

Experimental sites

Seven experiments were conducted during the 1981-82 growing season on commercial wheat fields in western Oregon. The farm cooperators prepared the seedbeds using standard farming practices. The general characteristics of each experimental site are reported in Table 1. The experimental sites were selected to represent different expected infection of the take-all disease, thus reflecting the nature of the problem in the Willamette Valley. The objective was to evaluate the effects of nitrogen (N) and chloride (Cl) treatments on wheat yield and nitrogen uptake from different cropping sequences at these sites.

Field experiments

The randomized block design (RBD) with four replications was used in each of the seven locations with individual plot dimensions of 3.048 meters (10 feet) wide and 6.096 meters (20 feet) long. The treatments for each experiment are described in Table 2.

The fertilizer materials used were ammonium chloride (NH_4Cl: 26% N, 66% Cl), ammonium sulfate [$(NH_4)_2SO_4$: 21%N, 24%S], and urea [$CO(NH_2)_2$: 46% N]. A combination of at least two of these fertilizer materials was used for all treatments.

The determined fertilizer rates were handbroadcast on each experimental plot. A split spring application of fertilzier was applied in February and March on the Evers, Coon, Jones, and Keyt

Table 1. Location, legal description, soil classification, disease situation, and wheat cropping sequence of each experimental site.

Farm*	Closest Locality and County	Legal Description	Soil Classification, Series, Family, and Subgroup	Take-all root rot risk situation	Wheat crop status
Evers	Dayton YamhillCounty	NW 1/4 Section19 T.4S,R.3W	Amity Fine-silty,mixed,mesic ArgiaquicXeric Argiaboll	Established take-all decline	Longterm wheat (18th year)
Jones	Amity Yamhill County	SW 1/4 Section 23 T.5S, R.5W	Willamette Fine-silty loam, mixed mesic Aquultic Argixeroll	High risk of take-all	3rd year wheat
Keyt** I & II	Perrydale Polk County	NE 1/4 Section 23 T.6S, R.5W	Willamette Fine-silty, mixed, mesic Pachic Ultic Argixeroll	High risk of take-all Low risk of take-all	2nd year wheat 5th year wheat
Coon	Peoria Linn County	SE 1/4 Section 30 T.12S, R.4W	Woodburn Fine-silty, mixed, mesic Aquultic Argixeroll	Moderate risk of take-all	2nd year wheat
Nixon** I & II	Junction City Lane County	SW 1/4 Section 11 T.15S, R.5W	Malabon (experiment I) Silty clay-loam, mixed, mesic Pachic Ultic Argixeroll Salem (experiment II) Gravelly silt-loam, mixed, mesic Pachic Ultic Argixeroll	Low risk of take-all Moderate risk of take-all	1st year wheat 2nd year wheat

*Names of cooperating farmers

**Two experiments were conducted in each of these locations.

Table 2. Fertilizers used, rates and dates of application per experimental site. 1982.

		Rates of N and Fertilizer Materials Used						
N --Kg/ha--	Cl	Coon Farm	Evers Farm	Jones Farm	Keyt (I) Farm	Keyt (II) Farm	Nixon (I) Farm	Nixon (II) Farm
0	0	--	--	--	--	--	--	--
45	45	--	--	--	--	--	17 AC, 28 S	--
67	45	34 AC 33 S	--	--	--	--	--	17 AC, 50 S
67	90	--	34 AC 33 S	34 AC 33 Ur/S	34 AC 33 Ur/S	34 AC 33 Ur/S	--	--
90	45	--	--	--	--	--	17 AC, 28 S 45 Ur	--
134	0*	34 S 100 Ur	34 S 100 Ur	34 S 100 Ur	34 S 100 Ur	34 AC 100 Ur	45 S, 90 Ur	--
		--	--	134 Ur/S	--	--	--	--
134	45	--	--	--	--	34 AC 100 Ur	17 AC, 28 S 90 Ur	17 AC, 50 S 67 Ur
134	90	34 AC 100 Ur/S	34 AC 100 Ur/S	34 AC 100 Ur/S	34 AC 100 Ur/S	--	34 AC, 100 Ur	--
134	134	--	--	134 AC/S	--	--	--	--
202	0	--	--	--	--	--	--	67 S, 135 Ur
202	45	17 AC 17 S 168 Ur	--	--	--	17 AC, 17 S 17 S 168 Ur	--	17 AC, 50 S 135 Ur
202	90	--	34 AC 168 Ur/S	34 AC 168 Ur/S	34 AC 168 Ur/S	--	--	34 AC, 34 S 135 Ur
Fertilizer Application Dates		03/2 03/22	02/24 03/17	02/24 03/17	02/18 03/18	02/18 03/18	03/12	02/12

AC = Ammonium Chloride; S = Ammonium Sulfate; Ur = Urea

*Two different treatments (N = 134, Cl = 0) were studied at this location farm locations with a single application in March on the Nixon farm sites. On the locations with split applications, appropriate combinations of ammonium chloride plus ammonium sulfate were used depending on the rate of chloride and sulfur required for the individual treatments. The second and complementary application for each treatment consisted of either urea alone or a mixture of urea and ammonium sulfate to complete the projected N rate per treatment.

The wheat fields were planted by the cooperating farmers between October 15 and 31. The cultivar 'Stephens' was used in six of the seven locations with 'Yamhill' used on the Evers farm experiment. Both cultivars are soft white winter wheats developed through the Oregon State University cereal improvement program. The variety 'Yamhill' is more tolerant to lower pH levels and performs better in soils with limited drainage.

Potassium and phosphorus fertilizers were applied at planting time by the cooperating farmers with application based on the OSU soil tests. Plant analysis indicated all locations had adequate P levels; also, potassium deficiency symptoms were not evident. Herbicides were used to avoid any harmful competition from weeds. MCPA and dicamba were sprayed for the control of broadleaves and difenzoquat (Avenge) to control wild oats on the experiments at Evers, Jones, and both Keyt locations. At the Nixon farm, only MCPA and dicamba were used. These herbicides were applied in April at the recommended rates (MCPA: 0.75 Kg ai/ha; dicamba: 0.25 Kg ai/ha; difenzoquat 1 Kg ai/ha) for all the experiments. On the

Coon Farm, routine herbicide spray was performed against broadleaves by the farmer using conventional equipment. On the other experiments appropriate equipment for small plots was used. A spray application of Benlate (benomyl) at 1.1 Kg ai/ha was performed in mid-February on the experiments of the Evers, Jones, and Keyt locations and in mid-March on the experiments of the Coon and Nixon II locations to counter possible damage from *Pseudocercosporella trichoides* (eyespot). No Benlate was applied on the experiment of the Nixon I location.

Plant sampling and analysis

Plant percent nitrogen

Whole plant samples were harvested (0.837 m^2 or 1.0 yd ^{2}) in late June with hand sickles so that stems could be cut at the soil surface during the soft dough stage. Subsamples (400 to 600 grains) of plant material were oven dried at 60 C (140 F) for a period of more than 48 hours. The subsample oven dry weights were recorded and the quadrat dry matter yields computed. These dry whole plant samples were then ground using a Wiley Mill (20 mesh screen) and subsamples were taken to be analyzed for % N.

The % N determination was done using the standard micro-Kjeldahl procedure for total N of the OSU plant analysis laboratory.

Grain nitrogen and protein content

Just after harvest, 20 spikes were hand-picked at random from the area to be harvested for each plot, oven dried at 60 C for a period of 24 hours, and individually threshed with a single head thresher. The kernel weights for each 20 head samples were recorded using an electronic balance. Five hundred kernels from each sample were counted using an Old Mill electronic counter (broken kernels were discarded) and their weights recorded using the same electronic balance as above. These 500 kernels were finely ground with a 'Cyclone Sample Mill', and the subsequent flour samples were used to determine grain % protein and % nitrogen. The protein contents for all of the experiments were determined using a Technicon InfraAlyzer 400 calibrated with the micro-Kjeldahl procedure described by Nelson and Sommers (1973). The grain % nitrogen for the Evers and Keyt II experiments was determined using the OSU plant analysis micro-Kjeldahl procedure, and for the other experiments % N was determined using the relationship: Grain % N x 5.7 = Grain % protein cited by Martin et al. (1976). This was based on the fact that high correlation coefficients (0.90 and 0.80) for % N and % protein were observed between the results given by both procedures (Technicon and O.S.U. micro-Kjeldahl).

Determination of the grain yield and yield component levels

Plot grain yield

The experiments were harvested in July with a plot combine having a 1.47 meter wide header. The area harvested for each individual plot was 1.47 x 6.0 meters. Grain yields were recorded in the field using a Milk scale (precision of the scale was 5 grams). Subsamples from the grain harvested were taken for test weights determination which was performed using a conventional test weight unit.

Spikes/m^2:

This yield component was computed using the following formula:

$$\frac{\text{Grain Yield/m}^2 \times 20}{\text{Grain Yield of 20 Spikes}}$$

Grains/spike

500 grains were counted from the grain lots of the 20 spike samples and the number of the grain/spike was computed using the following relation:

$$\text{Grains/spike} = \frac{\text{Grain weight of 20 spikes} \times 500}{\text{Weight of 500 unbroken grains} \times 20}$$

1000 kernel weight

This was computed doubling the treatments 500 kernel weights.

Calculations

N uptake

a) by the plant

$$\frac{\text{Dry matter} \times \%\ \text{N in whole plant samples}}{100} = \text{Kg/ha}$$

b) by the grain

$$\frac{\text{Grain yield} \times \%\ \text{N in the grain}}{100} = \text{Kg/ha}$$

% N recovery

(Also referred to as N fertilizer efficiency)

a) by plants

$$= \frac{\text{Total (plant) N uptake - Check plot N uptake}}{\text{N applied to the plot (Kg/ha)}} \times 100$$

b) by the grain

$$= \frac{\text{Plot N uptake - Check plot N uptake}}{\text{N applied to the plot (Kg/ha)}} \times 100$$

Statistical analysis

The data were statistically analyzed using the Statistical Interactive Programming System (SIPS) of the Cyber 70/73 Computer System at Oregon State University. The appropriate analysis of variance (RBD - ANOVA) was performed and the F test was used to evaluate treatment effects. Significant differences between treatment means were determined using the appropriate LSD 5% level. The correlation coefficients to assess significant relationships among the factors studied were also determined. Regression analyses of the variables studied on N rates were performed and the subsequent R square of the relationships were computed. Graphs showing the relationship between the N rates and grain yields were obtained using the NOS Zeta Plot system.

The following variables were analyzed in each experiment: Grain yield, spikes/m ^{2}, 1000 kernal weight, percent protein, percent N in the grain, dry matter production and percent N in the plant at the dough stage, plant N uptake, and grain N uptake. The complete data for all variables for all experiments are included in Appendices 2 through 8.

IV. RESULTS AND DISCUSSION

The 1981-82 wheat growing season in western Oregon was characterized by unusually low rainfall from April 20th to June 20th with minimum rainfall during this period. The rainfall in May was a record low in the areas where the experiments were conducted. The rainfall at Hyslop Farm (taken as a reference location in this study) as compared to the expected rainfall in a normal year in the Willamette Valley is shown in Appendix Table 1.

The 'dry period' made moisture stress a source of yield decrease where take-all root rot reduced the efficiency of the root system to take up soil moisture (Jones, Keyt I and Keyt II locations) and restricted yield at the Nixon II location where the soil was gravelly and shallow. On the other hand, this dry period limited the manifestation of severe leaf diseases such as *Septoria spp.* and stripe rust (*Puccinia striiformis*).

Take-all root rot was not manifested during this crop season, as described in Table 1. The experimental data of the different variables studied at each location which is reported in Appendix Tables 2 through 8 suggested two main situations: take-all root rot was a factor at Jones, Keyt I, and Keyt II and was not a factor at Coon, Nixon I, and Nixon II; Evers location was a take-all decline situation.

The variables studied were primarily affected by nitrogen fertilization with chloride fertilization affecting yield where take-all root rot was a factor. The response relationship of the variables studied as affected by nitrogen fertilization measured in terms of their regression are reported in Table 3. The yield levels of the different variables were mostly linearly associated with N rates. The exception was the variable grain yield in which a curvilinear relationship best described the influence of nitrogen fertilization and this was the case at all locations.

Dry matter production

Dry matter yields per treatment and per experimental site are summarized in Table 4 (complete data per experimental site are reported in Appendix Tables 2 through 8).

Nitrogen fertilization produced marked dry matter increases at all locations. Yields increased with increasing N rates and reached a plateau between 134 and 202 Kg N/ha; no significant ($p = 0.05$) differences were observed among the levels of dry matter obtained at these N rates (this observation does not apply for Nixon I where the 202 Kg N/ha rate was not used). On the other hand, the only significant contribution from Cl to increase dry matter production was at at the Jones location. Significantly higher yields of dry matter were obtained with application of 134 Kg of N and 90 Kg of Cl than other treatments that received 134 Kg of N with or without Cl.

The lack of response from the highest rates of N (202 Kg) at all locations, especially where take-all was not a factor, indicates that these rates were probably either excessive or their effect on crop growth was offset by the unusually 'dry' month of May.

Table 3. Relationship between the variables studied and the rates of nitrogen per experimental site and per take-all root rot risk situation as measured by the R^2 values of regression analyses.

Variables Studied	Experimental Sites and Take-all Root Rot Situations						Take-all Decline
	High risk of take-all		Moderate risk of take-all		Low risk of take-all		
	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
Grain yield	0.83[1]	0.60	0.93	0.74	0.81	0.53	0.85
Spikes/m^2	0.43	0.40	0.66	0.67	0.38	0.22	0.68
Kernels/spike	NC[2]	NC	0.71	0.62	0.59	NC	NS
1000 kernel weight	NS[3]	NS	0.27	0.61	NS	NS	NS
Protein content	0.46	0.35	0.65	0.66	0.40	0.57	0.56
Plant N content	0.66	0.49	0.78	0.71	0.57	0.66	0.78
Grain N content	0.46	0.33	0.65	0.66	0.39	0.66	0.80
Dry matter	0.86	0.70	0.76	0.70	0.67	0.66	0.56
Plant N uptake	0.92	0.70	0.89	0.87	0.59	0.84	0.78
Grain N uptake	0.83	0.57	0.90	0.79	0.76	0.60	0.91

[1] R^2 values for grain yield are from quadratic regression analysis, while for the other variables, the R^2 values are from linear regression analyses.

[2] NC : no regression analysis was performed.

[3] NS : regression analysis was not significant ($p=0.05$)

Table 4. Dry matter yield as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		metric tons/ha						
0	0	5.183 c	3.902 d	7.012 c	6.889 c	11.326 c	6.835 c	9.900 c
45	45	-	-	-	-	13.078 bc	-	-
67	45	-	-	10.383 b	13.255 b	-	-	-
67	90	9.561 b	7.015 c	-	-	-	10.764 b	13.508 b
90	45	-	-	-	-	13.969 b	-	-
134	0	12.989 a	8.309 b	14.881 a	-	18.574 a	14.665 a	13.864 ab
		-	9.917 b	-	-	-	-	-
134	45	-	-	-	15.643 ab	18.335 a	14.296 a	-
134	90	13.380 a	12.187 a	16.890 a	-	17.411 a	-	15.219 ab
134	134	-	9.520 b	-	-	-	-	-
202	0	-	-	-	17.159 a	-	-	-
202	45	-	-	15.739 a	16.938 a	-	15.291 a	-
202	90	15.142 a	12.656 a	-	16.833 a	-	-	16.914 a
LSD.05		2.227	2.172	2.297	3.457	2.429	2.590	3.365

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

Optimum dry matter yields at the best rates of N (134 to 202 Kg/ha) are reported in Table 5. It is clearly shown that where take-all root rot was a factor - Jones (3rd year wheat), Keyt I (2nd year wheat), Keyt II (5th year wheat) - dry matter yields were lower than those obtained at the other locations. It appears that crop dry matter production (measured at the dough stage) was most limited at Jones, followed by Keyt I and Keyt II, indicating that the disease was most severe at Jones. This is consistent with the findings of Slope and Cox (1964) who showed the evolution of take-all root rot severity in successive wheat crops to be highest in 3rd and 4th years. This has been observed to also be the case in the Willamette Valley (Christensen et al., 1982). The fact that dry matter production was higher at Keyt II as compared to the Jones and Keyt I locations (Table 5) seems to suggest that take-all root rot has probably entered the decline phase. Take-all root rot severity seems to be best expressed by the levels of dry matter yields of the check plots at the former three locations. The lower dry matter yields at Jones, Keyt I and Keyt II as compared to the other locations were in fact due to a combined effect of take-all root rot and moisture stress.

The highest dry matter yield, 18.107 ± 0.806 metric tons/ha (Table 5) was obtained at the Nixon I location (1st year wheat after clover) with 134 Kg of applied N with or without applied chloride. The contribution of residual N, as also indicated by the dry matter yield of the check treatment, is certain, indicating that the high level of dry matter production resulted from a

Table 5. Dry matter yield increases from optimum N rate(s) and associated rate(s) of Cl per experimental location.

Location	Check Plot Yield	Optimum Yield	Yield Increase	N Rate(s)	Cl Rate(s)
	------- metric tons/ha ------			----- Kg/ha -----	
Jones	3.902	12.422	8.520	134-202	90
Keyt I	5.183	13.837	8.654	134-202	0-90
Keyt II	6.835	14.751	7.916	134-202	0-45
Evers	9.900	15.332	5.432	134-202	0-90
Nixon I	11.326	18.107	6.781	134	0-45-90
Nixon II	6.889	16.643	9.754	134-202	0-45-90
Coon	7.012	15.837	8.825	134-202	0-45-90

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[1] Mean dry matter yields from all treatments that received optimum rates(s) of N.

nitrogen contribution from the soil. Optimum dry matter yields at Keyt II (5th year wheat), Coon, and Nixon II (2nd year wheat) locations were not very much different (Table 5). This is especially true at Nixon II and Coon (where take-all root rot was not a factor), thus confirming that crop growth at Keyt II was slightly restricted by take-all root rot. Dry matter yield at Keyt II was about 1.0 metric ton lower than at Coon and about 2.0 metric tons lower than at Nixon II locations. The fact that crop growth at Nixon II was less than at the other locations was probably a result of reduced moisture storage by the gravelly silt loam shallow soil (Table 2). The optimum dry matter yield at Evers (18th year wheat) was in the range of the yield levels obtained at Nixon II and Coon (Table 5). This was not the case for check plots where dry matter yield at Evers was higher than at the other locations. This suggests a contribution to increased dry matter from soil organic matter N, possibly derived from the regular use of turkey manure as a fertilization practice at this location.

Dry matter yields were highly associated with applied N at most locations as indicated by the R^2 values (Table 3) of the regression analyses. At Nixon I ($R^2 = 0.67$) and Evers ($R^2 = 0.56$), dry matter yields, as expected, showed less association with applied N, confirming the contribution of soil N.

Plant nitrogen content

Mean N contents of whole plants sampled at the dough stage per treatment and per experiment are summarized in Table 6. (complete

Table 6. Plant nitrogen content (measured at the dough stage) as affected by nitrogen chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--					%			
0	0	0.56 d	0.46 c	0.54 c	0.60 cd	0.57 c	0.51 c	0.45 c
45	45	-	-	-	-	0.57 c	-	-
67	45	-	-	0.52 c	0.55 d	-	-	-
67	90	0.61 cd	0.50 c	-	-	-	0.61 bc	0.50 c
90	45	-	-	-	-	0.64 bc	-	-
134	0	0.69 bc	0.51 c	0.74 b	-	1.09 a	0.77 ab	0.64 b
		-	0.77 a	-	-	-	-	-
134	45	-	-	-	0.72 c	1.16 a	0.84 a	-
134	90	0.81 b	0.64 b	0.75 b	-	0.78 b	-	0.71 b
134	134	-	0.75 ab	-	-	-	-	-
202	0	-	-	-	1.20 a	-	-	-
202	45	-	-	1.08 a	1.03 b	-	0.92 a	-
202	90	1.00 a	0.79 a	-	1.07 ab	-	-	0.92 a
LSD.05		0.12	0.12	0.08	0.15	0.16	0.16	0.12

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

data for individual plots and experimental sites are reported in Appendix Tables 2 through 8).

Nitrogen fertilization greatly influenced plant N content at all sites. Mean maximum levels of N in the plant were obtained at the highest rates of N at all sites except at Jones and Keyt II. At these two locations, the levels of N obtained with 202 Kg N/ha were not significantly (p = 0.05) different from those obtained with 134 Kg N/ha. Take-all root rot was a factor at both of these locations. The best plant N contents (Table 7) at these two locations averaged 0.77 and 0.84, respectively, and were lower than N levels at the other locations. At the Keyt I location where take-all root rot was also a factor, plant N content was higher than at Jones and Keyt II at 201 Kg N/ha, but was not higher at 134 Kg N/ha. Take-all root rot probably reduced the ability of roots to absorb N.

At Nixon I, Nixon II and Coon (where take-all root rot was not a factor), the best plant N contents were consistently higher than 1.00, averaging 1.12, 1.14, and 1.08%, respectively (Table 7). These values show that plant N content at Nixon I (where the highest N rate used was 134 Kg/ha) is almost the same as at Nixon II and Coon where N rates were 202 Kg/ha. The availability of high amounts of residual N at Nixon I probably originated from the previous clover crop.

Plant N content was highly associated with applied N fertilizer, and this relationship was stronger where take-all root rot was not a factor (Nixon II, Coon, and Evers). This is supported by

Table 7. Plant N content increases from optimum N rates(s) and associated rate(s) of Cl per experimental location.

Location	Check Plot Plant % N	Optimum Plant % N	Plant % N Increase	N Rate(s)	Cl Rate(s)
	-------------	%	------------	------ Kg/ha	------
Jones	0.46	0.77*	0.31	134-202	0-90-134
Keyt I	0.56	1.00	0.44	202	90
Keyt II	0.51	0.84*	0.33	134-202	0-45
Evers	0.45	0.92	0.47	202	90
Nixon I	0.57	1.12*	0.55	134	0-45
Nixon II	0.60	1.14*	0.54	202	0-90
Coon	0.54	1.08	0.54	202	45

* Mean plant N contents from all treatments that received optimum rate(s) of N.

the R^2 values of the linear regression of plant N content on N rates shown in Table 3. At Evers, Coon, and Nixon II, more than 70% of the variation in plant N content was associated with variation in N rates applied. The influence of residual N at Nixon I reduced this R^2 to 0.57. The relationship was poorest at Jones (R^2 = 0.49) indicating the interference of take-all root rot (most severe at this location). The linear regression was somewhat intermediate at Keyt I and II (R^2 = 0.66 at both sites), which probably indicates that take-all root rot interference was not as severe at these locations as compared to Jones.

Another way of evaluating N fertilization efficiency in relation to take-all root rot is to consider the increases of plant N content over the check plot levels shown in Table 7. Nitrogen fertilization was more efficient in increasing plant N contents where take-all root rot was not a factor, as shown by the identical values of plant % N increase, at Nixon I, II, and Coon locations (increases in plant N content were 0.55, 0.54, 0.54%, respectively). The increase in plant N content was lowest at Jones and Keyt II (0.31 and 0.33%, respectively) where the level of take-all root rot infection was greater.

On the other hand, plant N contents were not associated with chloride fertilization. From Table 6 it can be noted that no significant increases or decreases in plant N content levels were found due to chloride. At Nixon I, the level of plant N content obtained with 134 Kg of N and 90 Kg of Cl gives the illusion of a negative chloride effect. This level of plant N content was significantly lower than the other two levels obtained with the same rate of N without chloride and with a lower rate (45 Kg/ha) of Cl. This probably was a situation of sulfur deficiency since N was applied as urea and NH_4Cl and not as $(NH_4)_2SO_4$ (see Table 2) which usually provides enough sulfur to the crop; chloride could have accentuated sulfur deficiency through ion competition.

Plant nitrogen uptake and % recovery

The computed mean values of plant N uptake (dry matter x plant N content) per treatment and per experiment are shown in Table 8 (complete data are reported in Appendix Tables 2 through 8).

Nitrogen uptake levels were strongly influenced by the fluctuation in dry matter yields and plant N content. Because the highest dry matter yields and plant N contents were generally associated with the highest N rates at each location, plant N uptake levels followed the same trend. The exception was at the Keyt II location where significant differences between levels of plant N uptake obtained with 134 or 202 Kg N (Table 8) were not observed.

At the optimum rates of N (Table 9), the levels of plant N uptake were lower where take-all root rot was a factor (Jones, Keyt I, and Keyt II) as compared to where it was not a factor (Nixon I, Nixon II, and Coon). Plant N uptake at Jones was lowest reaching a level of 100 ± 6.4 Kg/ha, corresponding to a nitrogen recovery of 40.7% (Appendix Table 9). This is a clear indication that take-all reduced the efficiency of the root system to absorb N. At the Keyt I and Keyt II locations where take-all root rot was not as severe

Table 8. Plant nitrogen uptake (measured at the dough stage) as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		kg / ha						
0	0	30.1 e	17.8 d	37.8 c	40.7 c	64.4 c	33.7 d	44.4 d
45	45	-	-	-	-	73.7 c	-	-
67	45	-	-	52.4 c	72.9 c	-	-	-
67	90	58.2 d	35.2 cd	-	-	-	63.6 c	68.4 cd
90	45	-	-	-	-	87.5 c	-	-
134	0	89.4 c	42.5 c	110.2 b	-	205.6 a	112.9 b	88.9 bc
		-	75.8 b	-	-	-	-	-
134	45	-	-	-	112.5 b	214.1 a	119.2 ab	-
134	90	108.2 b	78.6 b	127.4 b	-	136.7 b	-	102.2 b
134	134	-	71.1 b	-	-	-	-	-
202	0	-	-	-	203.5 a	-	-	-
202	45	-	-	169.1 a	172.5 a	-	140.9 a	-
202	90	150.0 a	100.0 a	-	179.7 a	-	-	156.6 a
LSD.05		16.3	19.1	22.6	33.0	42.5	28.4	30.5

[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

Table 9. Plant N uptake increases from optimum N rate(s) and associated rate(s) of Cl per experimental location.

Location	Check Plot N Uptake	Optimum N Uptake	N Uptake Increase	N Rate(s)	Cl Rate(s)	N Recovery
	Kg/ha					%
Jones	17.8	100.0	82.2	202	90	40.7
Keyt I	30.1	150.0	119.9	202	90	59.3
Keyt II	33.7	130.0*	96.3	134-202	45	61.5
Evers	44.4	156.6	112.2	202	90	55.5
Nixon I	64.4	209.8*	145.4	134	0-45	108.5
Nixon II	40.7	185.2*	144.5	201	0-45-90	71.5
Coon	37.8	169.1	131.3	201	45	65.0

* Mean plant N uptake levels from all treatments that received optimum rate(s) of N.

** % N Recovery = N uptake increase/mean optimum N rate x 100 as at Jones, the levels of plant N uptake reached 150 ± 5.3 and 130.0 ± 9.2 Kg/ha with N recoveries of 59.3 and 61.5%, respectively (practically the same recovery of applied N). The small difference in N uptake levels might be explained by the higher rate of chloride used at Keyt I as shown in Table 9. At the Nixon I, Nixon II, and Coon locations, plant N uptake levels were much higher than at the other locations reaching 209.8 ± 14.1, 185.2 ± 10.9, and 169.1 ± 7.3 kg/ha corresponding to N recoveries of 108.5, 71.5, and 65.0%, respectively. Although different from one location to another, the levels of plant N uptake produced almost the same increase levels as indicated in Table 9, especially at Nixon I and Nixon II. At Nixon I, the level of plant N uptake was higher than the amount of applied N by about 67 Kg/ha, confirming the availability of high levels of N arising from the preceeding clover crop. At the Evers location, plant N uptake reached a level of 156.6 ± 9.89, corresponding to a N recovery of 55.5%. The relatively low N recovery at this location might be related to the use of a different wheat variety, 'Yamhill'.

Plant N uptake levels were highly linearly associated with N rates as indicated by the R^2 values of the linear regression reported in Table 3. As expected, the relationship was not highly linear ($R^2 = 0.59$) at Nixon I because of the influence of residual N: and, because of more take-all root rot interference, this relationship was not as good at the Jones location ($R^2 = 0.70$) as compared, for instance, to the Keyt I and II locations.

Grain yield

Average grain yields per treatment at each experiment are summarized in Table 10 (complete data per experiment are reported in Appendix Tables 2 through 8).

Grain yields were primarily influenced by nitrogen fertilization as application of chloride was not significant (p = 0.05) for yield. This was expected as grain yield increases due to spring topdressings of chloride were reported only with high rates, above 300 Kg/ha, (Christensen et al., 1981). The purpose of the chloride rates used in this study was to limit take-all root rot severity.

Where take-all root rot was not a factor (Nixon I, Nixon II, Coon, and Evers experiments), grain yields increased with increasing N rates, reaching a plateau between 134 and 202 Kg N/ha (differences were not significant). Grain yields at these locations had a highly significant curvilinear relationship with N rates, as indicated by R^2 in the range of 0.81 to 0.93 (Table 3). The fitted curves for individual experiments are shown in Figures 1 and 2.

Where take-all root rot was a factor (Jones, Keyt I, and Keyt II experiments), two distinct yield response situations were observed. At Jones and Keyt II, grain yields were poorly associated with nitrogen rates (R^2 were 0.60 and 0.53, respectively), indicating that a large part of the variation was due to a combined negative effect from take-all root rot and moisture stress. On the other hand, grain yields were highly associated (R^2 = 0.83) with N rates at Keyt I. However, yields were lower,

Table 10. Grain yield as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		---metric tons/ha---						
0	0	2.375 c	1.674 c	3.055 c	3.055 c	4.767 d	3.456 b	3.992 c
45	45	-	-	-	-	6.226 c	-	-
67	45	-	-	5.647 b	5.323 b	-	-	-
67	90	4.667 b	3.371 b	-	-	-	5.932 a	5.783 b
90	45	-	-	-	-	7.861 b	-	-
134	0	5.508 ab	2.839 b	8.370 a	-	8.478 ab	5.801 a	6.963 a
		-	3.526 b	-	-	-	-	-
134	45	-	-	-	6.919 a	8.972 a	6.503 a	-
134	90	5.539 ab	3.701 b	8.594 a	-	7.992 ab	-	6.758 a
134	134	-	3.826 b	-	-	-	-	-
202	0	-	-	-	7.132 a	-	-	-
202	45	-	-	8.277 a	7.428 a	-	6.688 a	-
202	90	5.639 a	6.464 a	-	8.015 a	-	-	7.326 a
LSD.05		0.881	1.155	0.859	1.525	0.999	1.883	0.918
CV (%)		12.04	20.38	8.21	16.06	8.98	21.52	5.76

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

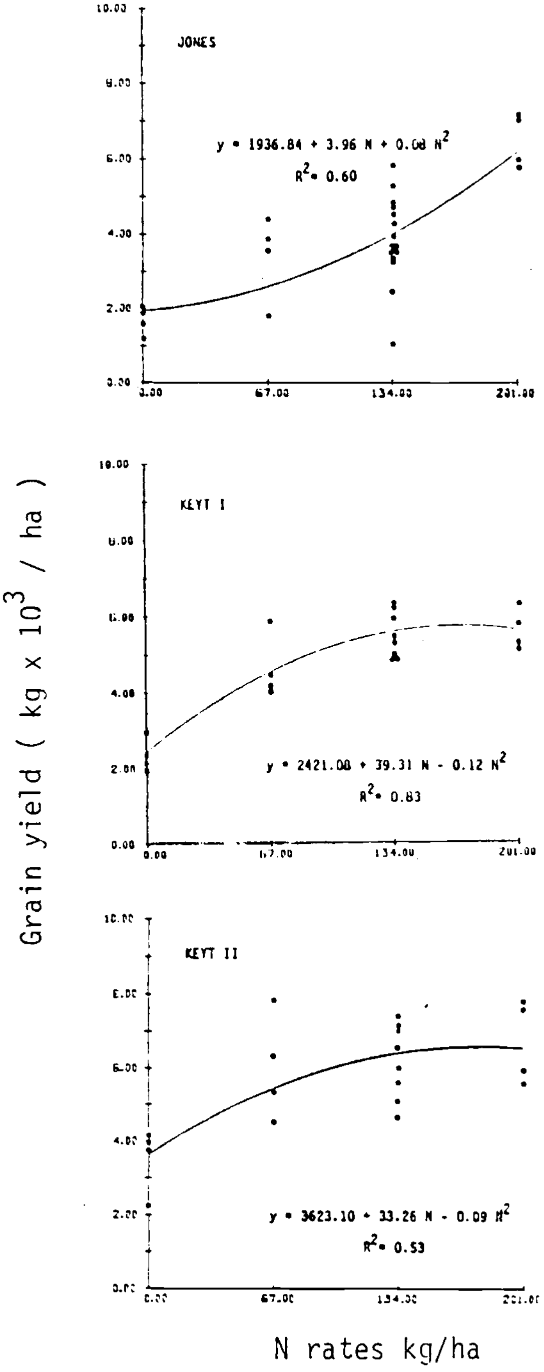

Figure 1. The relationship between grain yield and nitrogen fertilization where take-all root rot was a problem: Jones, Keyt I, and Keyt II experiments. 1982.

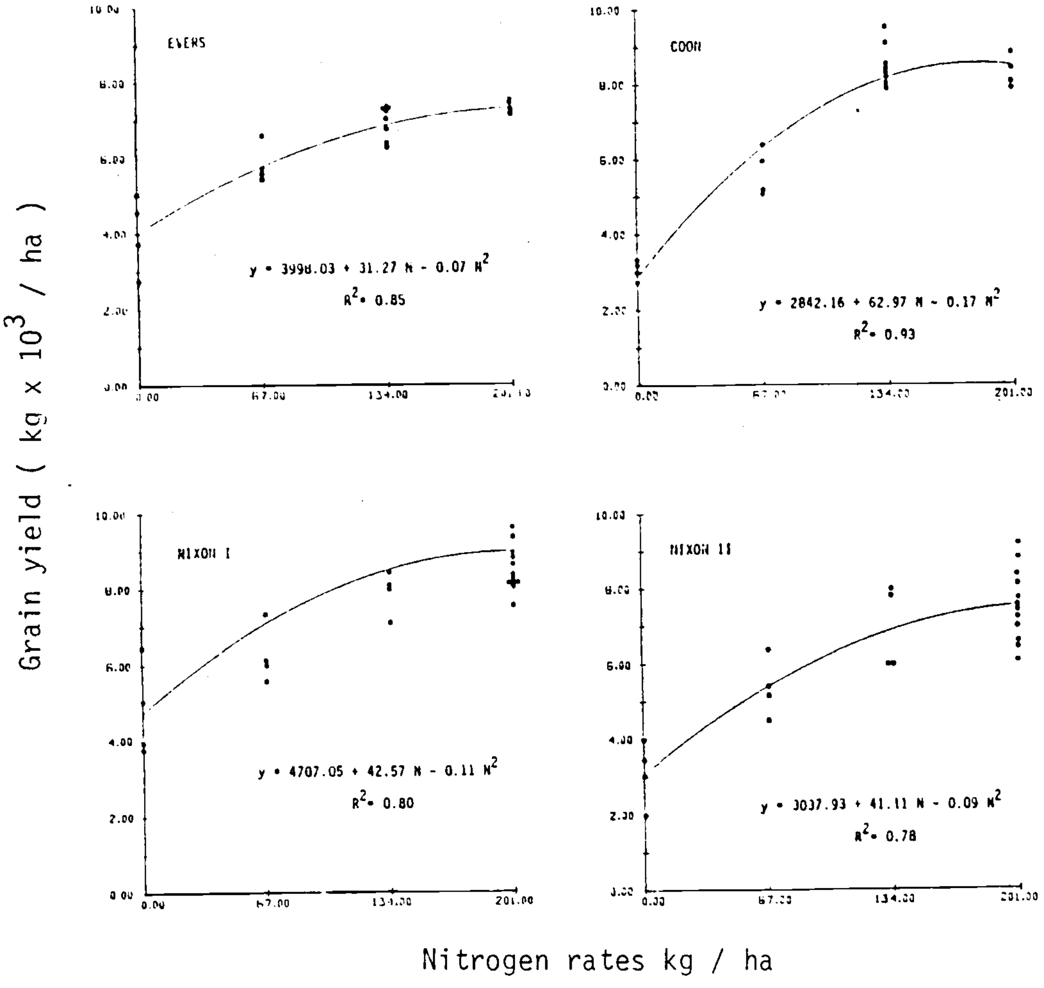

Figure 2. The relationship between grain yield and nitrogen fertilization where take-all root rot was not a problem: Evers Nixon I, Nixon II, and Coon experiments. 1982.

suggesting that moisture stress was probably responsible for lower grain yields rather than the influence of take-all root rot.

The highest grain yields for all locations except Keyt II were associated with the highest rates of N (134 and 202 Kg/ha), whether chloride was applied or not (Table 10); the 67 Kg N/ha rate produced optimum yield at Keyt II. The lack of significant ($p = 0.05$) difference in grain yield and dry matter production from these rates of N suggests that rates of 202 Kg N/ha were excessive in relation to the prevailing climatic conditions of the region. The lack of fertilizer response might have been accentuated by the effect of 'drought' in May and by other factors such as NH_4^+N fixation (as fertilizers are applied only in this N-form), leaching, and denitrification. The fact that rates of 202 Kg N/ha are not recommended in commercial wheat production (Jackson et al., 1980) is also an indication of lack of fertilizer response at these rates in the Willamette Valley.

The optimum rates of N (Table 11) were consistently 134 and 202 Kg/ha at the locations where take-all root rot was not a factor (Nixon I, Nixon II, Coon, and Evers). At Nixon I (1st year wheat after clover) the optimum rates were, in fact, 134 Kg N/ha as no higher rates were used. On the other hand, optimum N rates were distinct for each location where take-all root rot was a factor. Jones was the only location where a highly significant ($p = 0.01$) response to a rate of 202 Kg N/ha was observed (Table 10). At Keyt I, optimum rates of N were 134 and 202 Kg/ha, as for the location where the disease was not a factor; however, in this case, yields

Table 11. Grain yield increases from optimum N rate(s) and associated rate(s) of Cl per experimental location.

Location	Check Plot Yield	Optimum Yield	Yield Increase	N Rate(s)	Cl Rate(s)
			Kg/ha		
Jones	1674	6464	4790	202	90
Keyt I	2375	5562	3187	134-202	0-90
Keyt II	3456	6231	2775	67-202	0-45-90
Evers	3992	7016	3024	134-202	0-90
Nixon I	4767	8481	3714	134	0-45-90
Nixon II	3055	7374	4319	134-202	0-45-90
Coon	3055	8414	5359	134-202	0-45-90

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[1] Mean grain yields from all treatments that received optimum rate(s) of N.

of treatments that received 134 Kg N/ha were not significantly ($p = 0.05$) different from those that received 67 Kg N/ha (Table 10). At the Keyt II location, N response was limited to the rate of added N 67 Kg N/ha. Furthermore, yield differences between 67 and 134 Kg N/ha were not significantly ($p = 0.05$) different at the Jones, Keyt I, and Keyt II locations. The distinct yield response situations (as indicated by the data of Table 10) indicate that take-all root rot was most severe at Jones (3rd year wheat), moderately severe at Keyt I (2nd year wheat), and slightly severe at Keyt II (5th year wheat).

Grain yields at the optimum rates of N are reported in Table 11. Where take-all root rot was not a factor, yield levels ranged from 7 to 8.5 metric tons/ha and were highest at Nixon I (8481 ± 331 Kg/ha) and Coon (8414 ± 279 Kg/ha), following one and two years of wheat, respectively. Grain yields at Nixon II and Evers were slightly lower (7374 ± 507 and 7016 ± 298 Kg/ha, respectively). The yield difference of the variety 'Stephens' between Nixon I and Coon as compared to Nixon II is due to the fact that the crop was affected by moisture stress at Nixon II where the soil type is a shallow gravelly silt loam (Table 1). On the other hand, the yield difference between the Nixon I and Coon locations and the Evers location was probably due to the higher yield potential of 'Stephens'over the variety 'Yamhill' in these environments.

Where take-all root rot was a problem, grain yields at the optimum rates of N were much lower than at the previous locations (especially at Jones) and ranged from 3 to 6.5 metric tons/ha (Table 11).

The highest optimum yield (6464 ± 389 Kg/ha) was observed at Jones (3rd year wheat) and was due to a strong yield response to N. Grain yield at this location was almost doubled with N applied at 202 Kg/ha as compared to treatments that received 67 or 134 Kg N/ha and was about 4 times the grain yield of the check plot (Table 10). These results suggest that in a third year of continuous wheat (with severe take-all root rot expected) using high rates of N (202 Kg/ha), applied in the NH_4^+N form, may be another cultural practice to consider in countering take-all root rot and insuring higher grain yields.

However, it is important to emphasize that on the overall take-all root rot was most severe at Jones, as indicated by the low levels of grain yields shown in Table 10, despite the fact the best grain yield at optimum rates of N was recorded at this same location.

Grain yields at Keyt I (2nd year wheat) were consistently lower than those recorded at Keyt II (5th year wheat), as indicated by the data of Table 10. Dry matter yields also were consistently higher at Keyt II; both situations suggest that take-all root rot was more severe at Keyt I than at Keyt II (as expected) and entered the decline phase at Keyt II. This is supported by the fact that the optimum yield at Keyt II (6331 ± 611 Kg/ha) was higher than at Keyt I (5562 + 286 Kg/ha) and was obtained over a wider range of N rates (67, 134, 202 Kg/ha) and also supported by the fact that test weights at Keyt II were consistently higher than at Keyt I (see Appendix Table 10).

At all three locations (Jones, Keyt I, and Keyt II) moisture stress induced or combined with take-all root rot influence were tha main factors that limited grain yields. The negative influence of both factors can be better pictured through the grain yields of the check treatments (Table 11), although it should be taken into consideration that other factors such as N deficiency, for instance, also influence these yield levels.

Grain nitrogen content

Mean grain N content per treatment and per experimental site are summarized in Table 12 (complete data per plot and per location are reported in Appendix Tables 2 through 8).

Levels of grain N content increased with increasing amounts of N and reached a maximum at the highest rates at all locations except at Keyt I and Keyt II where no significant ($p = 0.05$) treatment differences were observed between rates of 134 and 202 Kg N/ha (Table 12). Take-all root rot and moisture stress most probably were the main cause for the lack of response from the highest rate of N (202 Kg/ha). So far, this effect was consistently observed at the Keyt II location for all the variables considered earlier.

Grain N contents were better linearly associated with N rates at Coon, Nixon II, Evers (where take-all was not a factor), and at Keyt II (where take-all entered the decline phase) than at Nixon I (because of the influence of residual N) and at Jones and Keyt I

Table 12. Grain nitrogen content as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		----------------------------------			%	----------------------------------		
0	0	1.45 c	1.38 c	1.32 c	1.38 d	1.41 bc	1.27 c	1.27 d
45	45	-	-	-	-	1.31 c	-	-
67	45	-	-	1.29 c	1.47 cd	-	-	-
67	90	1.55 bc	1.37 cd	-	-	-	1.37 b	1.32 d
90	45	-	-	-	-	1.43 bc	-	-
134	0	1.62 ab	1.31 d	1.46 b	-	1.69 a	1.59 a	1.51 c
		-	1.44 b	-	-	-	-	-
134	45	-	-	-	1.58 bc	1.64 ab	1.61 a	-
134	90	1.71 a	1.41 bc	1.44 b	-	1.57 ab	-	1.64 b
134	134	-	1.46 b	-	-	-	-	-
202	0	-	-	-	1.76 a	-	-	-
202	45	-	-	1.64 a	1.74 ab	-	1.66 a	-
202	90	1.76 a	1.59 a	-	1.79 a	-	-	1.81 a
LSD.05		0.15	0.06	0.11	0.17	0.21	0.18	0.12 .

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

(because of more disease severity than at Keyt II). This is supported by the R^2 of the linear relationship at each location shown in Table 3. The best relationship was observed at Evers (R^2 = 0.80); this is probably due to a better N translocation potential of the variety 'Yamhill' (used at this location) as compared to the variety 'Stephens' (used at all the other locations (especially where take-all was not a problem: Coon and Nixon II).

Grain N contents at the optimum rates of nitrogen and associated rate or rates of chloride are shown in Table 13. Where take-all root rot was a factor (Jones, Keyt I, and Keyt II locations), grain N contents were not consistently lower than at the other locations where the take-all disease was not a factor as it was consistently observed for the variables discussed before (Tables 5,7,9,11). However, in both disease situations it was consistently observed that where grain yield was relatively lower, grain N content was higher and vice versa (Tables 11 and 13), probably indicating that plants which produced a higher number of grains accumulated less N per grain.

Where take-all root rot was a factor, the highest grain nitrogen content was recorded at Keyt I reaching 1.70% (Table 13); grain yield was lowest at this location compared to Jones and Keyt II (Table 11). Where take-all root rot was not a factor, the highest grain N contents were recorded at Evers (where the variety 'Yamhill' was used) and Nixon II reaching 1.81 and 1.76%, respectively (Table 13); grain yields at these locations were lower than those obtained at the Nixon I and Coon locations (Table 11).

Table 13. Grain N content increases from optimum N rates and associated rate(s) of Cl per experimental location.

Location	Check Plot Yield	Optimum Grain % N	Grain % N Increase	N Rate(s)	Cl Rate(s)
	------------	%	------------	----- Kg/ha	-------
Jones	1.38	1.59	0.21	202	90
Keyt I	1.45	1.70*	0.25	134-202	0-90
Keyt II	1.27	1.62*	0.35	134-202	0-45-45
Evers	1.27	1.81	0.54	202	90
Nixon I	1.41	1.63*	0.22	134	0-45-90
Nixon II	1.38	1.76*	0.38	202	0-45-90
Coon	1.32	1.64	0.32	202	45

* Mean grain N contents from all treatments that received optimum rates(s) of N.

The relative nitrogen fertilization efficiency, measured in terms of increase in grain N content over the check treatment at each location (Table 13), was best at Keyt II compared to Jones and Keyt I where take-all root rot was a factor. On the other hand, where take-all root rot was not a factor, N fertilization efficiency was highest at Evers, confirming the better N translocation as compared to the variety 'Stephens± used at the Nixon I, Nixon II, and Coon locations. N fertilization efficiency at Nixon I was lowest because of the influence of residual N on the grain N content at the check plot.

Grain N contents were not significantly (p = 0.05) influenced by chloride fertilization at most locations. Where take-all root rot was a problem, a non-conclusive response to Cl was observed at Keyt I between treatments that received 134 Kg N/ha without or with 90 Kg Cl/ha (Table 12). However, where take-all root rot was not a problem, a significant (p = 0.05) response to Cl was observed at Evers where the 134 Kg N treatment that received 90 Kg Cl/ha had a greater grain N content than the one that did not receive a Cl application. On the other hand, at Nixon I the application of 45 and 90 Kg Cl/ha to the treatment that received a rate of N of 134 Kg/ha appeared to have depressed grain N content.

Protein content

Mean grain protein contents per treatment and per experimental site are summarized in Table 14 (complete data per plot and location are reported in Appendix Tables 2 through 8).

Table 14. Grain protein content as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		----------	----------	----------	%	----------	----------	----------
0	0	8.28 c	7.85 c	7.55 c	7.87 d	8.04 bc	8.08 c	7.49 c
45	45	-	-	-	-	7.45 c	-	-
67	45	-	-	7.37 c	8.49 d	-	-	-
67	90	8.82 bc	7.83 c	-	-	-	8.25 bc	7.50 c
90	45	-	-	-	-	8.16 bc	-	-
134	0	9.25 ab	7.46 d	8.34 b	-	9.66 a	9.14 a	8.74 b
		-	8.22 b	-	-	-	-	-
134	45	-	-	-	9.01 bc	9.37 a	8.90 ab	-
134	90	9.76 a	8.06 bc	8.23 b	-	8.95 ab	-	9.44 ab
134	134	-	8.33 b	-	-	-	-	-
202	0	-	-	-	10.02 a	-	-	-
202	45	-	-	9.34 a	9.93 ab	-	9.48 a	-
202	90	10.01 a	9.07 a	-	10.20 a	-	-	10.27 a
LSD.05		0.83	0.31	0.60	0.95	1.17	0.78	1.04 .

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

Grain protein contents are included in the discussion as another way to evaluate grain N content because, as described earlier (Materials and Methods section, page 32), grain N content was derived from the relationship: grain % N x 5.7 = grain % protein. Thus, the conclusions derived from the discussion of the variable 'grain N content' also apply to the variable 'grain protein content'. The most relevant conclusions are emphasized in this section.

The best levels of grain protein content for each location were obtained at the highest N rates (Tables 14 and 15). At the Keyt I and Keyt II locations (where take-all root rot was a problem), and at the Evers location (where the wheat variety 'Yamhill" was used instead of 'Stephens'), no significant ($p = 0.05$) differences in grain protein content were observed among treatments that received 134 or 202 Kg N/ha.

Grain protein contents at the optimum rates of nitrogen were in the range of 9 to 10% for all experiments (Table 15).

In either disease situation (locations where take-all root rot was or was not a factor) grain protein contents were higher (Table 15) at the locations where grain yields were relatively lower (Table 11), indicating that there was less N accumulation per individual grain when a high number of grains were produced.

Chloride fertilization did not significantly ($p = 0.05$) influence grain protein contents at all locations.

Table 15. Grain protein content increases from optimum N rate(s) and associated rates of Cl per experimental location.

Location	Check Plot Yield	Optimum Yield	Yield Increase	N Rate(s)	Cl Rate(s)
	%				
Jones	7.85	9.07	1.22	202	90
Keyt I	8.28	10.01	1.73	134-202	0-90
Keyt II	8.08	9.17	1.09	134-202	0-45
Evers	7.49	9.85	2.36	134-202	90-90
Nixon I	8.04	9.32	1.28	134	0-45-90
Nixon II	7.87	10.05	2.18	202	0-45-90
Coon	7.55	9.34	1.79	202	45

[1] Mean grain protein contents from all treatments that received optimum N rate(s), except at Jones.

Grain nitrogen uptake and % recovery

Computed mean levels of grain N uptake (grain yield x grain N content) per treatment and per experiment are shown in Table 16 (complete data are reported in Appendix Tables 2 through 8).

Grain N uptake levels generally increased with increasing rates of nitrogen at most locations and the highest levels were associated with rates of N equal or greater than 134 Kg/ha, except at the Keyt II location, where no significant ($p = 0.05$) differences in grain N uptake were observed among all treatments that received a fertilizer application (Table 16). On the other hand, at the Nixon II location, and especially at the Coon and Keyt I locations, no significant ($p = 0.05$) differences in grain N uptake were observed whether the nitrogen rate was 134 or 202 Kg/ha. Chloride fertilization did not significantly ($p = 0.05$) influence the levels of grain N uptake at all locations.

Where take-all root rot was not a problem (Evers, Nixon I, Coon, and Nixon II experiments), grain N uptake levels exhibited better linear responses with applied nitrogen than where take-all root rot was a problem (particularly in the Jones and Keyt II experiments), as indicated by the R^2 values of the linear regression of grain N uptake on rates of N, shown in Table 3. At the Keyt I location, although a good linear relationship was observed ($R^2 = 0.83$), the levels of grain N uptake for each treatment were lower than those of the locations where a good relationship was also observed. The relatively low R^2 values obtained at the Nixon I and Nixon II locations (0.76 and 0.79,

Table 16. Grain nitrogen uptake as affected by nitrogen and chloride treatments in different take-all root rot situations.

		Take-All Root Rot (TA) Situations and Experimental Sites						
Treatments		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--		kg/ha						
0	0	34.4 c	23.1 d	40.3 c	42.2 d	69.6 c	44.1 b	50.7 d
45	45	-	-	-	-	81.4 c	-	-
67	45	-	-	72.8 b	78.2 c	-	-	-
67	90	72.3 b	46.2 bc	-	-	-	82.3 a	76.3 c
90	45	-	-	-	-	112.2 b	-	-
134	0	89.2 a	37.2 cd	122.2 a	-	143.3 a	92.3 a	105.1 b
		-	50.8 bc	-	-	-	-	-
134	45	-	-	-	109.3 b	147.0 a	104.9 a	-
134	90	94.7 a	70.7 b	123.7 a	-	125.3 ab	-	110.8 b
134	134	-	55.9 b	-	-	-	-	-
202	0	-	-	-	125.7 ab	-	-	-
202	45	-	-	135.7 a	129.8 ab	-	110.3 a	-
202	90	99.2 a	102.8 a	-	142.7 a	-	-	132.6 a
LSD.05		11.4	17.4	15.0	31.0	23.4	31.9	16.7

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

respectively) were due to the influence of residual N from the preceding clover crop at the first location and probably due to the influence of moisture stress at the second location (Nixon II) where the soil is a shallow gravelly silt loam with restricted moisture storage capacity.

Grain N uptake levels at the optimum nitrogen rates (Table 17) were lower where take-all root rot was a problem and reached 102.8 ± 5.9, 94.4 ± 3.7, and 97.5 ± 10.3 Kg N/ha at the Jones, Keyt I, and Keyt II locations, respectively. The corresponding N recoveries were 39.2, 38.3, and 39.8%. Where take-all root rot was not a factor, grain N uptake levels accounted for by the best N rates were, on the average, more than 30 Kg N/ha higher than each of the levels obtained where the disease was a factor (Table 17), suggesting that this amount of N could represent the amount accounted for by the negative effect of take-all root rot on grain N uptake.

The optimum levels of grain N uptake obtained where the disease was not a factor ranged from 127 to 138 Kg N/ha (Table 17). These levels of grain N uptake were observed at the Coon and Nixon I locations, respectively, while at the Evers and Nixon II locations, practically the same grain N uptake levels were obtained (132.6 ± 5.4 and 132.7 ± 10.3 Kg N/ha, respectively). N recoveries were more variable than where the disease was a problem, ranging from 40.5 to 55.5% (Table 17), with the highest recovery observed at the Coon location and the lowest recovery observed at the Evers location. At the Nixon I and Nixon II locations, N recoveries were

Table 17. Grain N uptake increases from optimum N rate(s) and associated rate(s) of Cl per experimental location.

Location	Check Plot Yield	Optimum N Uptake	N Uptake Increase	N Rate(s)	Cl Rate(s)	N Recovery
	----------------------	Kg/ha	--------------------			-- % --
Jones	23.1	102.8	79.2	202	90	39.2
Keyt I	34.4	94.4	60.0*	134-202	0-90	38.3
Keyt II	44.1	97.5	53.4*	67-202	0-45-90	39.8
Evers	50.7	132.6	81.9	202	90	40.5
Nixon I	69.6	138.3	68.7*	134	0-45-90	51.3
Nixon II	42.2	132.7	90.5*	202	0-45-90	44.8
Coon	40.3	127.2	86.9*	134-202	0-45-90	55.5

* Mean grain N uptake levels from all treatments that received optimum rate(s) of N.

** % N Recovery = N uptake increase/mean optimum N rate x 100.

51.3 and 44.8%, respectively. The low N recoveries observed at the Evers and Nixon II locations were due to the fact that the optimum N rates at these locations were higher (202 Kg N/ha, Table 17). It was found that N recoveries consistently decreased with rates of N higher than 134 Kg/ha. This relationship is clearly shown for each location in Appendix Table 11, where the N recoveries per treatment are reported.

The efficiency of applied nitrogen to increase grain N uptake measured by the increases in grain N uptake (accounted for by the optimum rates of N) over the check treatments (no applied N) was as expected, better where the take-all disease was not a factor. Where take-all root rot was a problem, the application of high rate of N (202 Kg/ha) was very beneficial at the Jones location (where the disease was most severe). This is supported by the fact that at this location, grain N uptake accounted for by a nitrogen rate of 202 Kg/ha was almost twice the amount of grain N uptake accounted for by rates of N of 134 Kg/ha (Table 16).

Where take-all root rot was not a factor, the relative efficiency was almost identical at the Evers, Nixon II, and Coon locations as indicated by the levels of grain N uptake increases (Table 17). On the other hand, at the Nixon I location, the level of grain N uptake increase was lowest (68.7 Kg/ha), indicating a lower N fertilization efficiency because of the contribution from residual N as indicated by the level of grain N uptake of the check treatment (Table 17).

Yield components

Spikes/m^2

Mean computed numbers of spikes/m^2 per treatment and per experiment are reported in Table 18 (complete data per plot and per location are reported in Appendix Tables 2 through 8).

The data in Table 18, as expected, indicates that the increase in number of spikes/m^2 was mainly associated with the increase in N rates at all locations, as no significant effect from chloride fertilization was observed. The highest numbers of spikes/m^2 were associated with rates of N equal or higher than 134 Kg/ha at most locations but Keyt I and Nixon I. At the Keyt II location, no significant ($p = 0.05$) differences were observed among all treatments (whether N was applied or not), most probably due to higher variability caused by a sampling error. The data figures for the number of spikes/m^2 were, in fact, obtained from a formula involving plot grain yields/m^2 and grain yield from 20 spike samples taken from each plot (refer to Materials and Methods section, page 32-33). The sampling error seems to have affected all locations, as indicated by the poor association of the number of spikes/m^2 and the applied rates of nitrogen (Table 3). The R^2 values of the linear regression of number of spikes/m^2 on N rates were, in fact, especially low at the locations where take-all root rot was a problem (Jones, Keyt I, and Keyt II). Where take-all root rot was not a factor, more than 65% of the variation in the number of spikes/m^2 was accounted for by nitrogen treatments at the Coon, Nixon II, and Evers locations. On the other hand, at the

Table 18. Number of spikes per square meter as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--								
0	0	141.9 b	98.7 c	141.3 c	149.5 a	235.2 b	166.6	191.4 c
45	45	-	-	-	-	279.7 ab	-	-
67	45	-	-	228.9 b	235.2 b	-	-	-
67	90	242.3 a	166.8 b	-	-	-	275.9	254.3 b
90	45	-	-	-	-	329.3 a	-	-
134	0	255.8 a	140.3 bc	319.5 a	-	338.7 a	253.5	318.6 a
		-	158.8 b	-	-	-	-	-
134	45	-	-	-	301.1 a	327.9 a	277.8	-
134	90	261.9 a	188.5 ab	303.7 a	-	313.2 ab	-	282.4 ab
134	134	-	158.8 b	-	-	-	-	-
202	0	-	-	-	316.1 a	-	-	-
202	45	-	-	286.0 a	299.4 a	-	272.2	-
202	90	256.8 a	232.5 a	-	309.9 a	-	-	313.0 a
LSD.05		54.7	52.0	35.6	55.6	84.2	NS	46.4

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

Nixon I location, a lower R^2 value was observed, most probably because of the influence of residual N from the preceding clover crop.

Mean numbers of spikes/m^2 at the optimum rates of nitrogen (Table 19) were as expected, lower at the location where take-all root rot was a problem. The number of spikes/m^2 at the Jones and Keyt I locations reached 210.5 ± 17.7 and 254.2 ± 17.5, respectively, confirming that take-all root rot had a more restrictive effect on number of spikes/surface area at Jones. This effect is also clearly illustrated by the number of spikes/m^2 at the check treatments of both locations, which received 98.7 ± 17.7 at Jones and 141.9 ± 17.5 at Keyt I.

The mean number of spikes/m^2 accounted for by the optimum N rates at the other locations (where the disease was not a problem) were very close in the range of 300 to 320 (Table 19). Although the number of spikes/m^2 was practically the same at all four locations (Evers, Nixon I, Nixon II, and Coon), the efficiency of the optimum rates of N to increase the spike number/m^2 over the check was best at the Nixon II and Coon locations. At these locations, the increase in spikes/m^2 accounted for by the optimum rates of N were 157.1 and 161.8, respectively, while at the Nixon I and Evers locations, the respective increases were only 64.5 and 113.3 spikes/m^2. The lower increases at these locations are due to the contribution from available soil nitrogen, as indicated by the high numbers of spikes/m^2 at the check treatment of the Evers and Nixon I locations (Table 19).

Table 19. Increases in number of spikes/m^2 from optimum N rate(s) and associated rate(s) of Cl per experimental location.

	--------Spike Number------------			N	Cl
Location	Check Plot	Optimum	Increase	Rate(s)	Rate(s)
Jones	98.7	210.5[1]	111.8	134-202	90
Keyt I	141.9	254.2	112.3	67-202	0-45-90
Keyt II[2]	166.6	-	-	-	-
Evers	191.4	304.7	113.3	134-202	0-90
Nixon I	235.2	317.7	64.5	45-202	0-45-90
Nixon II	149.5	306.6	157.1	134-202	0-45-90
Coon	141.3	303.1	161.8	134-202	0-45-90

[1] Mean number of spikes/m^2 from all treatments that received optimum rates of N.

[2] No significant (p=0.05) difference was observed between the check and the treatments that received a fertilization application.

Kernels/spike and 1000 kernel weights

Mean number of kernels/spike and mean 1000 kernel weight per treatment and per experiment are reported in Appendix Tables 12 and 13, respectively (complete data per plot and per location for each yield component are shown in Appendix Tables 2 through 8).

The data of both yield components were downgraded to nonrelevant information after they were submitted to appropriate statistical analyses, which revealed that the procedure by which the data was gathered (refer to Materials and Methods section, page 32-33) involved bias. This bias made the data of the variable 1000 kernel weight for the Jones, Keyt I, and Keyt II locations void of significant treatment effects as shown in Appendix Table 13. On the other hand, the data for the same variable was not found statistically (regression analysis) associated with the treatments (N rates) at all locations except the Nixon II location, as shown in Table 3. Because kernel weights were used in the computation of kernels/spike (refer to Materials and Methods section, page 32-33), the data for both yield components were considered non-reliable at all locations and therefore were not considered part of the results gathered in this study.

Because of the difficulty in relating the different agronomic variables discussed in this section, a summary table (Table 20) comprising the optimum response levels of each variable at all locations, is presented.

Table 20. Response of the variables studied as affected by optimum rates of nitrogen[1] and take-all root rot.

	Variables studied[2]										Take-all
Locations	D M	NPLT	PNUP	PNRC	GYLD	NGR	GNUP	GNRC	PROT	SPK	Root Rot
Jones	12.422	0.77	100.0	40.7	6464	1.59	102.8	39.2	9.07	210.5	Yes
Keyt I	13.837	1.00	150.0	59.3	5562	1.70	94.4	38.3	10.01	254.5	Yes
Keyt II	14.751	0.84	130.0	61.5	6231	1.62	97.5	39.8	9.17	-	Yes
x̄	13.670	0.87	126.7	53.8	6086	1.64	98.2	39.1	9.42	232.4	
Evers	15.332	0.92	156.6	55.5	7016	1.81	132.6	40.5	9.85	304.7	TAD[3]
Nixon I	18.107	1.12	209.8	108.5	8481	1.63	138.3	51.3	9.32	317.7	No
Nixon II	16.643	1.14	185.2	71.5	7374	1.76	132.7	44.8	10.05	306.6	No
Coon	15.837	1.08	169.1	65.0	8414	1.64	127.2	55.5	9.34	303.1	No
x̄	16.480	1.06	180.2	75.2	7821	1.71	132.7	48.0	9.64	308.0	

[1] The optimum rates of N associated with the levels of each variables at each location are shown in Tables 5, 7, 9, 11, 13, 15, 17, and 19.

[2] DM = dry matter in metric tons/ha, NPLT = plant N content in %, PNUP = plant N uptake in kg/ha, PNRC = plant N recovery in %, GYLD = grain yield in kg/ha, NGR = grain N content in %, GNUP = grain N uptake in kg/ha, GNRC = grain N recovery in %, PROT = grain protein content in %, SPK = number of spikes/square meter.

[3] TAD = take-all decline.

V. SUMMARY AND CONCLUSION

Response from nitrogen and chloride fertilization was measured in a series of field experiments where winter wheat was grown in an environment with a range of take-all root rot situations through the study of several agronomic variables.

Low rainfall during a relatively long period (April 20th to June 20th) restricted crop response particularly at the locations where the disease was a problem or where the soil was light textured and shallow.

The data presented in this study strongly indicate that take-all root rot (TARR) was a problem only at the Jones (third year wheat), Keyt I (second year wheat), and Keyt II (fifth year wheat) locations where it greatly restricted crop response, confirms the state of take-all decline (TAD) at the Evers location (long term wheat), and Coon (second year wheat) locations. For the sake of simplicity, the Evers location is also considered a situation where TARR was not a problem.

Nitrogen fertilization was the main factor that greatly influenced the response of the variables studied while chloride fertilization did not have significant ($p = 0.05$) effects on these variables, but definitely influenced their response particularly at the locations where TARR was a problem.

Responses of the variables studied accounted for by the optimum rates of nitrogen (summarized earlier in Table 20) were as follows:

1. Dry matter yields (measured at the dough stage) ranged

from 12.422 ± 0.731 to 14.751 ± 0.841 metric tons/ha and averaged 13.670 metric tons/ha for the locations where TARR was a problem; on the other hand, they ranged from 15.332 ± 1.092 to 18.107 ± 0.806 metric tons/ha and averaged 16.480 metric tons/ha for the locations where TARR was not a problem. Dry matter yields were associated with N rates of 134 kg/ha as rates of 202 kg/ha consistently failed to significantly ($p = 0.05$) increase levels of dry matter yield.

2. Levels of plant N content (measured at the dough stage) ranged from 0.77 to 1.00% (the respective standard deviations were too small to be included) and averaged 0.87% for the locations where TARR was a problem; on the other hand, they ranged from 0.92 to 1.14% and averaged 1.06% for the locations where TARR was not a problem. The highest rates of N (202 Kg/ha) were associated with plant N content at all locations except at the Jones and Keyt II locations where rates of 134 kg N/ha accounted for the optimum levels of plant N content.

3. Levels of plant nitrogen uptake (measured at the dough stage) ranged from 100.0 ± 6.4 to 150.0 ± 5.3 Kg/ha and averaged 126.7 kg/ha for the locations where TARR was a problem; on the other hand, they ranged from 156.6 ± 9.9 to 209.8 ± 14.1 kg/ha and averaged 180.2 kg/ha for the locations where TARR was not a problem. The levels of plant nitrogen uptake were associated with the highest rates of nitrogen (202 kg/ha) at all locations except the Keyt II location where the optimum rate of nitrogen was 134 kg/ha.

4. Plant nitrogen recoveries (measured at the dough stage) ranged from 40.7 to 61.5% and averaged 53.8% for the locations where TARR was a problem; on the other hand, they ranged from 55.5 to 108.5% and averaged 75.1% for the locations where TARR was not a problem.

5. Grain yields ranged from 5563 ± 286 to 6464 ± 389 kg/ha and averaged 6086 kg/ha for the locations where TARR was a problem; on the other hand, they ranged from 7016 ± 298 to 8481 ± 331 kg/ha and averaged 7821 kg/ha for the locations where TARR was not a problem. Grain yields were associated with rates of 134 kg N/ha at five out of seven locations. Rates of 202 kg/ha significantly increased grain yield where TARR was most severe (Jones location) and failed to increase yield levels at the other locations. At one location (Keyt II) grain yields obtained from plots receiving N applications of 67, 134, or 202 kg/ha where not significantly ($p = 0.05$) different.

6. Levels of grain nitrogen content ranged from 1.59 to 1.70% and averaged 1.64% for the locations where TARR was a problem; on the other hand, they ranged from 1.63 to 1.81% and averaged 1.71% for the location where TARR was not a problem. The highest rate of N (202 kg/ha) was associated with the optimum levels of grain N content at all locations except two (Keyt I and Keyt II) where the best rate was 134 kg/ha.

7. Grain protein contents ranged from 9.07% ± 0.10 to 10.01 ± 0.27% and averaged 9.42% for the locations where TARR was a problem; on the other hand, they ranged from 9.32 ± 0.39 to 10.05 ±

0.27% and averaged 9.64% for the locations where TARR was not a problem.

8. Levels of grain nitrogen uptake ranged from 94.4% ± 3.7 to 102.8 ± 5.9 kg/ha and averaged 98.2 kg/ha for the locations where TARR was a problem; on the other hand, they ranged from 127.2 ± 4.8 to 138.3 ± 7.8 kg/ha and averaged 132.7 kg/ha for the locations where TARR was not a problem. The rates of nitrogen associated with the optimum levels of grain nitrogen uptake were variable. At one location (Keyt II) rates of 67 and 202 kg/ha did not produce significant ($p = 0.05$) grain nitrogen uptake differences. At the other locations, the optimum rates of nitrogen were equally 134 and 202 kg/ha.

9. Grain nitrogen recoveries ranged from 38.3 to 39.8% and averaged 39.1% for the locations where TARR was a problem; however, they ranged from 40.5 to 55.5% and averaged 48.0% for the locations where TARR was not a problem.

10. Numbers of spikes/m^2 ranged from 210.5 ± 17.5 to 254.2 ± 17.7 and averaged 232.2 (average of two locations only) for the locations where TARR was a problem; on the other hand, they ranged from 303,1 ± 11.5 to 317.7 ± 22.2 and averaged 308.0 for the locations where TARR was not a problem. The rates of nitrogen associated with the optimum numbers of spikes/m^2 were 134 kg/ha at four locations; on the other hand, at the other two locations rates of 45 and 67 kg N/ha (at Nixon I and Keyt I, respectively) produced significantly ($p = 0.05$) similar responses as rates of 202 kg N/ha.

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APPENDICES

Appendix Table 1. Rainfall distribution during the growing season at Hyslop farm, Benton Co. 1981-1982.

	October	November	December	January	February	March	April	May	June
Year 1981-1982	140.2**	170.9	355.1	183.1	180.8	89.9	62.5	12.4	38.3
Normal year *	86.1	156.7	197.4	191.8	123.4	117.6	116.5	48.8	30.5

Source: Oregon State University, Atmospheric research center.

* The monthly rainfall for a normal year is the average of the rainfall recorded over a 30 year period.

** Numbers are in millimiters (mm)

CAPTION MEANINGS FOR APPENDIX TABLES 2 THROUGH 8

GYLD : grain yield (kg/ha)

SPK : number of spikes/m^2

KRN : number of kernels/spike

KRWT : 1000 kernel weight (grams)

PROT : grain protein content (%)

NGR : grain nitrogen content (%)

DM : above ground dry matter measured at the dough stage (grams/m^2)

NPLT : plant nitrogen content (%)

PNUP : plant nitrogen uptake (kg/ha)

GNUP : grain nitrogen uptake (kg/ha)

N : rate of applied nitrogen (kg/ha)

Cl : rate of applied chloride (kg/ha)

Appendix Table 2. Effects of N and Cl fertilization on the response of third year wheat infected with take-all root rot. Jones farm, Yamhill Co. 1982.

GYLD	SPK	KRN	KRWT	PROT	NGR	DM	NPLT	PNUP	GNUP	N	CL
1944.	129.2	28.20	53.42	7.850	1.380	438.9	.4600	20.20	26.83	0.	0.
2036.	106.5	34.70	55.04	7.690	1.350	343.2	.4900	16.80	27.49	0.	0.
1172.	69.50	32.50	51.80	7.650	1.340	362.4	.4600	16.70	15.70	0.	0.
1543.	89.70	33.80	50.82	8.200	1.440	416.2	.4700	17.50	22.22	0.	0.
3826.	193.7	38.10	51.30	7.790	1.370	796.5	.4900	39.00	52.42	67.00	90.00
4382.	179.7	46.20	52.80	7.790	1.370	778.6	.4900	38.10	60.03	67.00	90.00
3518.	182.6	35.70	53.88	7.840	1.380	681.7	.4900	33.40	48.55	67.00	90.00
1759.	111.2	31.60	50.12	7.500	1.320	549.0	.5500	30.20	23.22	67.00	90.00
3579.	186.0	36.70	52.42	7.300	1.280	891.0	.4400	39.20	45.81	134.0	0.
3209.	170.0	36.40	51.86	7.360	1.290	710.4	.4400	31.20	41.40	134.0	0.
3549.	140.1	49.00	51.70	7.790	1.370	995.1	.6000	59.70	48.62	134.0	0.
1018.	65.20	30.00	51.99	7.410	1.300	727.2	.5500	40.00	13.23	134.0	0.
4227.	173.3	47.50	51.32	7.970	1.400	1322.	.6000	79.30	59.18	134.0	90.00
5801.	200.7	53.70	53.86	7.880	1.380	1259.	.6600	83.10	80.05	134.0	90.00
4721.	198.7	45.30	52.42	8.000	1.400	1064.	.5500	58.50	66.09	134.0	90.00
5276.	181.3	53.50	54.38	8.400	1.470	1230.	.7600	93.40	77.56	134.0	90.00
7035.	256.4	51.80	53.00	8.970	1.570	1335.	.9200	122.8	110.5	202.0	90.00
5955.	196.1	55.50	54.70	9.140	1.600	1331.	.7100	94.50	95.28	202.0	90.00
5739.	197.6	53.80	53.98	8.910	1.560	1130.	.8200	92.70	89.53	202.0	90.00
7128.	279.9	48.50	53.94	9.280	1.630	1267.	.7100	89.90	116.2	202.0	90.00
4752.	230.6	38.90	52.92	8.120	1.420	1362.	.7100	96.70	67.48	134.0	0.
3456.	130.1	50.70	52.36	8.320	1.460	760.6	.8200	62.40	50.46	134.0	0.
3487.	141.5	44.80	55.00	8.470	1.490	908.9	.6900	62.70	51.96	134.0	0.
2407.	133.2	38.30	47.16	7.990	1.400	935.3	.8700	81.40	33.70	134.0	0.
3541.	146.8	46.00	53.92	8.100	1.420	867.1	.7600	65.90	51.70	134.0	134.0
4474.	176.1	47.30	53.68	8.170	1.430	1255.	.7100	89.10	63.98	134.0	134.0
3919.	187.2	40.60	51.54	8.540	1.500	870.7	.8700	75.70	58.79	134.0	134.0
3271.	125.3	46.90	55.60	8.500	1.490	815.7	.6600	53.80	48.74	134.0	134.0

Appendix Table 3. Effects of N and Cl fertilization on the response of second year wheat infected with take-all root rot. Keyt farm (experiment 1), Polk Co. 1982.

GYLD	SPK	KRN	KRWT	PROT	NGR	DM	NPLT	PNUP	GNUP	N	CL
2993.	171.6	34.40	50.71	8.280	1.450	471.2	.5600	26.40	43.40	0.	0.
2374.	138.5	34.90	49.02	8.570	1.500	469.6	.5300	24.90	35.61	0.	0.
2191.	128.9	34.00	50.04	8.190	1.440	578.9	.5600	32.40	31.55	0.	0.
1944.	128.7	29.00	51.40	8.390	1.470	553.7	.5900	36.60	28.58	0.	0.
4042.	208.1	37.60	51.66	8.620	1.510	1008.	.5900	59.50	61.03	67.00	90.00
4505.	236.9	36.70	51.80	8.590	1.510	1027.	.6600	67.80	68.03	67.00	90.00
5894.	328.4	35.40	50.64	8.740	1.530	964.0	.5900	56.90	90.18	67.00	90.00
4227.	195.8	40.80	52.88	8.540	1.500	825.2	.5900	48.70	63.41	67.00	90.00
4906.	270.1	34.40	52.74	10.78	1.890	1219.	.9700	118.8	92.72	134.0	90.00
5030.	207.8	45.40	53.26	10.07	1.770	1328.	.9100	120.8	89.03	134.0	90.00
6264.	291.4	41.90	51.28	9.490	1.660	1436.	.6600	94.80	104.0	134.0	90.00
5955.	278.5	38.70	54.20	8.720	1.530	1369.	.7200	98.60	91.11	134.0	90.00
5338.	279.4	36.20	52.78	9.370	1.640	1204.	.7800	93.90	87.54	134.0	0.
4875.	206.1	48.60	48.62	10.31	1.810	1432.	.6600	94.50	88.24	134.0	0.
5492.	254.0	39.80	54.62	8.940	1.570	1166.	.5900	68.80	86.22	134.0	0.
6326.	283.8	41.10	54.22	8.390	1.470	1393.	.7200	100.3	92.99	134.0	0.
5122.	264.6	39.00	49.56	10.95	1.920	1489.	1.040	154.8	98.34	202.0	90.00
5276.	214.7	47.60	51.64	10.83	1.900	1292.	1.160	149.8	100.2	202.0	90.00
6326.	311.9	38.30	52.96	9.410	1.650	1861.	.8500	158.2	104.4	202.0	90.00
5832.	236.0	47.10	52.48	8.850	1.550	1415.	.9700	137.2	90.40	202.0	90.00

Appendix Table 4. Effects of N and Cl fertilization on the response of fifth year wheat infected with take-all root rot. Keyt farm (experiment 2), Polk Co. 1982.

GYLD	SPK	KRN	KRWT	PROT	NGR	DM	NPLT	PNUP	GNUP	N	CL
3857.	160.4	43.50	55.26	8.480	1.440	764.2	.5100	39.00	55.54	0.	0.
3734.	168.8	36.80	60.08	7.880	1.240	1050.	.4400	46.20	46.30	0.	0.
4042.	228.6	31.60	55.98	7.680	1.170	429.4	.5400	23.20	47.29	0.	0.
2191.	108.8	37.10	54.32	8.280	1.240	490.4	.5400	26.50	27.17	0.	0.
5276.	227.3	39.80	58.26	8.240	1.240	1163.	.5400	62.80	65.42	67.00	90.00
6233.	253.8	42.10	58.28	8.240	1.370	1285.	.4700	60.40	85.39	67.00	90.00
4443.	204.3	36.70	59.28	8.060	1.370	900.6	.6700	60.30	60.87	67.00	90.00
7776.	418.4	36.00	51.60	8.460	1.510	958.0	.7400	70.90	117.4	67.00	90.00
7097.	298.1	41.80	56.94	8.970	1.570	1479.	.8800	130.2	111.4	134.0	0.
4598.	200.3	42.10	54.48	8.790	1.510	1720.	.6700	115.2	69.43	134.0	0.
5554.	252.3	40.60	54.26	10.05	1.770	1251.	.7400	92.60	98.31	134.0	0.
5955.	263.4	39.60	57.12	8.730	1.510	1416.	.8100	114.7	89.92	134.0	0.
5060.	195.3	46.20	56.12	9.150	1.570	1441.	.8100	116.7	79.44	134.0	45.00
6511.	282.8	41.00	56.16	8.510	1.510	1464.	.8100	118.6	98.32	134.0	45.00
7066.	317.4	40.60	54.86	8.380	1.640	1746.	.8100	141.4	115.9	134.0	45.00
7375.	315.6	43.50	53.74	9.540	1.710	1067.	.9400	100.3	126.1	134.0	45.00
7745.	298.4	46.20	56.16	8.740	1.510	1623.	.8100	131.5	117.0	202.0	45.00
7560.	319.3	45.60	51.90	9.760	1.710	1739.	.9400	163.4	129.3	202.0	45.00
5863.	253.3	43.30	53.50	9.320	1.640	1368.	.7400	101.2	96.15	202.0	45.00
5585.	217.0	46.80	55.02	10.10	1.770	1386.	1.210	167.7	98.85	202.0	45.00

Appendix Table 5. Effects of N and Cl fertilization on the response of long term wheat grown on a soil where take-all decline has been established. Evers farm, Yamhill Co. 1982

CYLD	SPK	KRN	KRWT	PROT	NGR	DM	NPLT	PNUP	GNUP	N	CL
4989.	211.7	51.80	45.50	7.620	1.270	1326.	.4000	53.10	63.36	0.	0.
2722.	160.4	37.90	44.74	7.640	1.270	629.1	.4000	25.20	34.57	0.	0.
3719.	166.7	49.80	44.84	7.310	1.270	715.2	.5400	38.60	47.23	0.	0.
4536.	226.8	45.80	43.70	7.380	1.270	1289.	.4700	60.60	57.61	0.	0.
5352.	242.6	47.50	46.46	7.390	1.140	1302.	.4000	52.10	61.01	67.00	90.00
5534.	267.7	44.70	46.06	7.790	1.340	1325.	.4700	62.30	74.16	67.00	90.00
6577.	255.9	56.00	45.92	7.480	1.340	1447.	.5400	78.10	88.13	67.00	90.00
5670.	250.8	49.10	46.08	7.650	1.480	1329.	.6100	81.00	83.92	67.00	90.00
6350.	259.5	52.20	46.88	9.370	1.610	1601.	.6100	97.70	102.2	134.0	90.00
7257.	323.7	49.00	45.80	8.700	1.680	1599.	.7400	118.3	121.9	134.0	90.00
6713.	247.1	60.60	44.80	10.30	1.680	1658.	.8100	134.3	112.8	134.0	90.00
6713.	299.4	49.90	44.90	9.380	1.610	1230.	.6700	82.40	108.1	134.0	90.00
7212.	328.2	50.40	43.58	6.250	1.480	1446.	.6700	96.90	106.7	134.0	0.
6305.	283.1	48.30	46.08	8.410	1.480	1423.	.6700	95.40	93.31	134.0	0.
7303.	350.5	47.70	43.70	8.590	1.480	1484.	.6100	90.50	108.1	134.0	0.
7031.	312.4	51.70	43.74	8.700	1.610	1192.	.6100	72.70	113.2	134.0	0.
7484.	289.9	54.40	47.46	10.17	1.740	1873	1.010	189.2	130.2	202.0	90.00
7394.	341.8	48.20	44.86	9.190	1.940	1734.	.9400	163.0	143.4	202.0	90.00
7167.	321.0	48.60	45.90	10.94	1.810	1751.	.8100	141.8	129.7	202.0	90.00
7257.	299.3	52.10	46.54	10.76	1.740	1408.	.9400	132.3	126.3	202.0	90.00

Appendix Table 6. Effects of N and Cl fertilization on the response of first year wheat (after clover) in the absence of take-all root rot. Nixon farm (expt. 1), Lane Co. 1982.

CYLD	SPK	KRN	KRWT	PROT	NCR	DM	NPLT	PNUP	GNUP	N	CL
6449.	313.7	33.40	61.50	10.27	1.800	1197.	.6000	79.00	116.1	0.	0.
3734.	185.3	34.80	57.90	6.950	1.220	967.6	.5000	48.40	45.55	0.	0.
3888.	195.2	34.90	57.12	7.190	1.260	1314.	.5500	72.30	48.99	0.	0.
4999.	246.6	34.40	59.00	7.750	1.360	1051.	.5500	57.80	67.98	0.	0.
8609.	375.2	42.50	54.00	9.850	1.730	1944.	1.210	235.2	148.9	134.0	0.
8825.	392.5	43.20	52.08	10.36	1.820	1945.	1.160	225.6	160.6	134.0	0.
8331.	301.0	50.70	54.54	9.150	1.610	2051.	1.160	237.9	134.1	134.0	0.
8146.	286.1	53.20	53.56	9.270	1.630	1490.	.8300	123.7	132.8	134.0	0.
6017.	275.4	37.60	58.16	7.560	1.330	1446.	.5500	79.50	80.02	45.00	45.00
6048.	266.8	38.80	58.48	7.420	1.300	1355.	.5600	75.90	78.62	45.00	45.00
7344.	359.4	36.50	55.94	7.410	1.300	1197.	.5600	67.00	95.47	45.00	45.00
5492.	217.3	45.60	55.36	7.400	1.300	1233.	.5900	72.50	71.40	45.00	45.00
8393.	371.6	38.90	58.00	7.780	1.360	1456.	.7200	104.8	114.1	90.00	445.0
8023.	308.7	44.70	58.20	8.460	1.480	1649.	.5500	90.70	118.7	90.00	45.00
7961.	315.0	42.80	59.08	7.800	1.370	1432.	.5500	78.70	109.1	90.00	45.00
7066.	321.8	38.50	57.06	8.580	1.510	1051.	.7200	75.70	106.7	90.00	45.00
9596.	327.0	52.30	56.12	9.530	1.670	1961.	1.210	237.3	160.3	134.0	45.00
8856.	317.5	48.70	57.24	9.540	1.670	2038.	1.320	269.0	147.9	134.0	45.00
9319.	347.6	46.00	58.30	8.780	1.540	1585.	1.050	166.4	143.5	134.0	45.00
8115.	319.3	47.70	53.28	9.570	1.680	1750.	1.050	183.7	136.3	134.0	45.00
8177.	358.8	38.40	58.54	8.420	1.480	1839.	.7200	132.4	121.0	134.0	90.00
7529.	256.7	49.50	59.28	9.570	1.680	1939.	.8800	170.6	126.5	134.0	90.00
8177.	291.6	48.00	58.40	9.580	1.680	1572.	.7700	121.0	137.4	134.0	90.00
8084.	345.5	39.40	59.36	8.510	1.440	1615.	.7600	122.7	116.4	134.0	90.00

Appendix Table 7. Effects of N and Cl fertilization on the response of second year wheat in the absence of take-all root rot infection. Nixon farm (expt. 2), Lane Co. 1982.

GYLD	SPK	KRN	KRWT	PROT	NGR	DM	NPLT	PNUP	GNUP	N	CL
3950.	188.3	36.40	57.60	7.900	1.390	975.9	.5500	53.70	54.90	0.	0.
3394.	170.4	35.20	56.64	8.300	1.460	557.3	.7100	39.60	49.55	0.	0.
1913.	109.3	30.20	58.00	7.310	1.280	430.6	.6000	25.80	24.48	0.	0.
2962.	130.0	37.90	60.12	7.960	1.400	791.7	.5500	43.50	41.47	0.	0.
6511.	291.8	45.10	49.44	9.310	1.630	1798.	1.100	197.7	106.1	202.0	0.
8115.	367.3	45.00	49.08	10.47	1.840	1796.	1.140	204.7	149.3	202.0	0.
6418.	280.3	46.70	49.04	10.22	1.790	1436.	1.410	202.5	114.9	202.0	0.
7486.	325.3	43.60	52.46	10.08	1.770	1833.	1.140	209.0	132.5	202.0	0.
4443.	222.5	34.40	58.08	7.860	1.380	1306.	.5500	71.80	61.31	67.00	45.00
5400.	275.7	35.50	55.12	7.550	1.320	1131.	.5500	62.20	71.28	67.00	45.00
6326.	236.7	49.50	53.96	9.860	1.730	1521.	.5500	83.70	109.4	67.00	45.00
5122.	205.9	43.10	57.72	8.330	1.460	1343.	.5500	73.90	74.78	67.00	45.00
7807.	349.1	40.10	55.80	8.940	1.570	1418.	.6000	85.10	122.6	134.0	45.00
5986.	276.6	41.70	51.92	9.200	1.610	1519.	.8700	132.1	96.37	134.0	45.00
5986.	258.6	45.20	51.20	9.910	1.740	1525.	.8200	125.0	111.4	134.0	45.00
7899.	320.1	43.10	57.30	8.010	1.410	1795.	.6000	107.7	104.2	134.0	45.00
9195.	351.4	48.60	53.80	9.870	1.730	2079.	1.030	214.1	159.1	202.0	45.00
7436.	344.0	42.70	50.62	10.53	1.850	1805.	.9200	166.0	137.6	202.0	45.00
7035.	286.9	46.80	52.38	10.11	1.770	1714.	1.140	188.6	124.5	202.0	45.00
6048.	215.4	51.10	54.96	9.220	1.620	1178.	1.030	121.3	97.98	202.0	45.00
7190.	290.7	47.40	52.20	9.040	1.590	1703.	.9200	156.7	114.3	202.0	90.00
7683.	317.2	47.30	51.24	10.59	1.860	1629.	1.140	185.7	142.9	202.0	90.00
8393.	299.2	52.60	53.34	10.51	1.840	1762.	1.030	181.4	154.4	202.0	90.00
8794.	332.4	48.80	54.16	10.30	1.810	1640.	1.190	195.1	159.2	202.0	90.00

Appendix Table 8. Effects of N and Cl fertilization on the response of second year wheat in the absence of take-all root rot infection. Coon farm, Linn Co. 1982.

CYLD	SPK	KRN	KRWT	PROT	DM	NPLT	NGR	GNUP	PNUP	N	CL
3333.	167.4	33.10	60.16	7.860	578.9	.5400	1.380	31.30	46.00	0.	0.
3178.	143.2	37.30	60.08	7.020	785.8	.5400	1.230	42.40	39.09	0.	0.
2715.	130.1	34.10	55.98	7.840	687.7	.5400	1.380	37.10	37.47	0.	0.
2993.	124.4	40.70	54.32	7.490	752.3	.5400	1.310	40.60	39.21	0.	0.
5091.	246.0	36.80	56.24	6.900	1064.	.4700	1.210	50.00	61.60	67.00	45.00
5986.	234.2	44.00	58.06	7.560	1016.	.5400	1.330	54.90	79.61	67.00	45.00
5091.	206.2	41.70	59.34	7.520	977.1	.5400	1.310	52.80	66.69	67.00	45.00
6418.	229.2	47.20	59.34	7.520	1096.	.5400	1.320	52.20	84.72	67.00	45.00
9072.	333.0	53.00	51.36	7.990	1550.	.6100	1.400	94.60	127.0	134.0	0.
8300.	309.8	46.40	57.74	8.210	1508.	.7400	1.440	111.6	119.5	134.0	0.
8239.	341.1	43.70	55.24	8.450	1666.	.8100	1.480	134.9	121.9	134.0	0.
7868.	294.1	48.20	55.50	8.720	1228.	.8100	1.530	99.50	120.4	134.0	0.
8486.	284.7	52.50	56.68	8.610	1641.	.7400	1.510	121.4	128.1	134.0	90.00
9535.	362.8	46.50	56.52	8.010	1752.	.7800	1.410	136.6	134.4	134.0	90.00
7961.	280.1	49.90	56.98	8.300	1476.	.6700	1.460	98.90	116.2	134.0	90.00
8393.	287.3	51.80	56.44	7.990	1887.	.8100	1.400	152.9	117.5	134.0	90.00
8023.	307.0	48.00	54.44	8.500	1767.	1.010	1.490	178.4	119.5	202.0	45.00
7868.	304.5	49.90	51.80	9.380	1511.	1.140	1.650	172.2	129.8	202.0	45.00
8794.	251.4	62.00	56.40	9.580	1476.	1.080	1.680	159.4	147.7	202.0	45.00
8424.	281.1	54.10	55.40	9.890	1543.	1.080	1.740	166.6	146.6	202.0	45.00

Appendix Table 9. Plant nitrogen recovery measured at the dough stage as affected N and Cl treatments in different take-all root rot situations.

		Take-all root rot (TA) Situations and Experimental Sites						
Treatments		High risk of TA		Moderate risk of TA		Low risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
---kg/ha---					%			
0	0	-	-	-	-	-	-	-
45	45	-	-	-	-	20.7	-	-
67	45	-	-	21.8	48.1	-	-	-
67	90	41.9	26.0	-	-	-	44.6	35.8
90	45	-	-	-	-	25.7	-	-
134	0	45.6	18.4	54.0	-	105.4	59.3	33.2
		-	43.3	-	-	-	-	-
134	45	-	-	-	53.6	111.7	63.8	-
134	90	58.3	45.4	66.8	-	53.9	-	47.6
134	134	-	39.8	-	-	-	-	-
202	0	-	-	-	80.6	-	-	-
202	45	-	-	65.0	65.2	-	53.1	-
202	90	59.3	40.7	-	68.8	-	-	55.5

Appendix Table 10. Test weights as affected by nitrogen and chloride treatments in different take-all root rot situations.

		Take-all root rot (TA) Situations and Experimental Sites						
Treatments		High risk of TA		Moderate risk of TA		Low risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
---kg/ha---		kg/hl						
0	0	76.4	74.8	74.6	74.2	74.4	76.1	71.4
45	45	-	-	-	-	74.9	-	-
67	45	-	-	75.2	74.2	-	-	-
67	90	76.2	75.0	-	-	-	77.5	71.5
90	45	-	-	-	-	75.7	-	-
134	0	76.4	76.3	77.2	-	76.2	77.1	73.2
		-	75.3	-	-	-	-	-
134	45	-	-	-	75.2	76.6	77.5	-
134	90	76.8	76.1	77.3	-	76.8	-	73.5
134	134	-	75.9	-	-	-	-	-
202	0	-	-	-	73.7	-	-	-
202	45	-	-	77.7	74.9	-	77.3	-
202	90	76.3	76.9	-	75.0	-	-	73.4

Appendix Table 11. Grain nitrogen recovery as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-all root rot (TA) Situations and Experimental Sites						
		High risk of TA		Moderate risk of TA		Low risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
---kg/ha---		-------------------------------			%	--------------------------------		
0	0	-	-	-	-	-	-	-
45	45	-	-	-	-	26.2	-	-
67	45	-	-	47.8	53.7	-	-	-
67	90	56.6	34.5	-	-	-	57.0	38.2
90	45	-	-	-	-	47.3	-	-
134	0	40.9	10.5	61.1	-	55.0	36.0	44.8
		-	20.7	-	-	-	-	-
134	45	-	-	-	49.8	57.7	45.4	-
134	90	45.0	35.7	62.2	-	41.6	-	40.6
134	134	-	24.5	-	-	-	-	-
202	0	-	-	-	41.1	-	-	-
202	45	-	-	47.2	43.2	-	30.8	-
202	90	32.1	39.4	-	49.5	-	-	40.5

APPENDIX TABLE 12. Number of kernels per spike as affected by nitrogen and chloride treatments in different take-all root rot situations.

Treatments		Take-All Root Rot (TA) Situations and Experimental Sites						
		High Risk of TA		Moderate Risk of TA		Low Risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
--kg/ha--								
0	0	33.1	32.3	36.3 c	34.9 d	34.4 d	37.2	43.6
45	45	-	-	-	-	36.6 cd	-	-
67	45	-	-	42.4 bc	40.6 c	-	-	-
67	90	37.6	37.9	-	-	-	38.7	49.3
90	45	-	-	-	-	41.2 bc	-	-
134	0	41.4	38.0	47.8 ab	-	47.4 ab	41.0	52.9
		-	43.2	-	-	-	-	-
134	45	-	-	-	42.5 bc	48.7 a	-	-
134	90	40.1	50.0	50.2 a	-	43.8 ab	40.1	49.5
134	134	-	45.2	-	-	-	-	-
202	0	-	-	-	45.1 abc	-	-	-
202	45	-	-	53.5 a	47.3 ab	-	-	-
202	90	43.0	52.4	-	49.0 a	-	43.0	50.8
LSD.05		NS	NS	6.8	5.4	6.2	NS	NS

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[1] Numbers followed by the same letter are not significantly different.

[2] Crop status at each location : first year wheat after clover at Nixon I; second year wheat at Coon, Nixon II, and Keyt I; third year wheat at Jones; fifth year wheat at Keyt II; eighteenth year wheat at Evers.

Appendix Table 13. 1000 kernel weights as affected by nitrogen and chloride treatments in different take-all root rot situations.

		Take-all root rot (TA) Situations and Experimental Sites						
Treatments		High risk of TA		Moderate risk of TA		Low risk of TA		TA Decline
N	Cl	Keyt I	Jones	Coon	Nixon II	Nixon I	Keyt II	Evers
---kg/ha---		------------------------------				------------------------------		
0	0	51.79	52.77	57.64	58.09	58.88	56.41	44.70
45	45	-	-	-	-	56.99	-	-
67	45	-	-	58.20	56.22	-	-	-
67	90	51.74	52.02	-	-	-	56.86	46.13
90	45	-	-	-	-	58.07	-	-
134	0	52.52	51.99	47.80	-	53.54	55.70	44.28
		-	51.86	-	-	-	-	-
134	45	-	-	-	54.05	56.24	55.22	-
134	90	53.12	53.00	50.20	-	58.90	-	45.60
134	134	-	53.71	-	-	-	-	-
202	0	-	-	-	50.00	-	-	-
202	45	-	-	53.5	52.94	-	54.15	46.19
202	90	51.66	53.91	-	52.73	-	-	
LSD	.05	NS	NS	6.80	1.70	2.19	NS	1.36