ABSTRACT

Corn and other grasses often become chlorotic during hydroponic production even when appropriate chelating agents are used and pH is maintained in appropriate ranges. When grown on soil, grasses use phytosiderophores (naturally-produced chelating agents) to obtain iron and are rarely chlorotic as a result. In hydroponics, corn seems to have more difficulty taking up iron apparently. This is likely because of a compromised or absent rhizosphere. Since ammonium nitrogen acidifies the rhizosphere, its presence in hydroponic solution may allow corn to take up iron better than a nitrate nitrogen only solution. Nitrate only and nitrate plus ammonium solutions were used to compare the pH changes of the nutrient solution as well as corn growth and chlorophyll content.

INTRODUCTION

The literature is full of information about the changes that occur within a plant as a result of taking up the two different forms of plant-available nitrogen, ammonium and nitrate (Wadleigh et al. 1937; Smiley and Cook 1973; Römheld and Marschner 1984; Mengel and Geurtzen 1988; Mengel et al. 1994; Mengel 1995). In the presence of ammonium nitrogen, the rhizosphere surrounding plant roots becomes more acidic as plants take up ammonium cations and exude hydrogen cations. Conversely, when nitrate nitrogen is present, plants exude
hydroxide anions as they take up nitrate anions and pH increases. Romheld and Marschner (1984) provided evidence that this is indeed the case with corn.

When growing in soil, grasses produce phytosiderophores which enable them to solubilize and take up iron. This iron uptake strategy is often referred to as strategy II and enables grasses to obtain sufficient iron to avoid chlorosis. Despite the fact that corn has this ability to take up iron when grown in soil, it is often chlorotic when grown hydroponically (Wadleigh et al. 1937). Even adding appropriate chelating agents does not always mitigate this problem. It seems that, with a compromised or non-existent rhizosphere, corn is unable to remove iron from the chelating agent.

Bernardo et al. (1984) found that nitrogen supplied as ammonium decreased the pH of the nutrient solution of hydroponic sorghum while nitrate nitrogen had the opposite effect. This indicates that grasses have the ability to reduce the pH of the nutrient solution. In soil, this pH reduction takes place near the surface of the root and creates a rhizosphere. This rhizosphere enables plants to take up nutrients that are insoluble at the pH of the bulk soil because they are solubilized in the rhizosphere. It also allows grasses to remove chelated iron from the chelating agent and take it up. Mengel and Geurtzen (1988) found that corn grown with nitrate only quickly became chlorotic, even in the presence of EDTA-chelated iron. This chlorosis was quickly reversed by transferring the plants to an ammonium sulfate nutrient solution. Presumably, this reversal is mediated by the change in nutrient solution pH induced by the ammonium nitrogen.

Because hydroponic solution is continually aerated, the resultant mixing of the solution may strip away the rhizosphere created by plant roots and make it difficult for them to take up
sufficient iron to avoid chlorosis—even when appropriate chelating agents are present.

Because of this it is difficult to demonstrate the potential existence of a rhizosphere in hydroponic systems. The agar gel method used by Romheld and Marschner (1984) in soil would be difficult to employ in hydroponics.

Though it is difficult to measure the pH of the rhizosphere in hydroponics, it is conceivable that a thin rhizosphere might exist in the narrow boundary layer that surrounds the roots. The objective for this experiment is to determine if corn can actually create a rhizosphere when grown hydroponically. In order to determine this, three questions must be answered. First, does the presence of ammonium in the nutrient solution result in a pH reduction? Second, does this reduction make it easier for the corn plant to take up iron and avoid chlorosis? And, finally, does any of this result in an increase in growth?

An affirmative answer to the first question merely means that corn plants are reducing the pH of the solution as they take up ammonium ions and exude hydrogen ions. But, if this pH reduction also helps the plants to avoid iron chlorosis, it provides evidence that a rhizosphere could, in fact, exist. Murphy and Lewis (1987) reported “increased productivity” of corn when supplied with a mixed nitrate and ammonium nitrogen source. This provides a basis for hypothesis that the ammonium-treated plants will grow better (larger). This difference in grown would be evidence that there is a sufficiently large rhizosphere to enable the corn to extract iron from the chelating agent and assimilate it (a rhizosphere effect).

MATERIALS AND METHODS

Garst corn seeds were germinated in rag dolls at 26 °C day/24 °C night. After two weeks, seven corn plants were placed into each of two 50L hydroponic tubs containing 40 liters
of monocot nutrient solution. In the solution, the iron chelator HEDTA was replaced with EDDHA because the latter, though more expensive, is still effective at higher pH ranges (smart-fertilizer.com). Both tubs were placed in the greenhouse and grown at 26 °C day/20 °C night. Nutrient solution levels were monitored periodically and solution added to return the volume to 40 liters. The total volume of solution added to each tub was recorded as an indication of plant growth. Transpiration is often used as a method of measuring and comparing in-situ growth because there is a strong correlation between transpiration and biomass accumulation as described originally by Wilson and Jamieson (1985) and as shown below from Atwell et al. (1999) (Figure 1).

Figure 1. Transpiration rates are highly correlated with biomass accumulation.

Automated pH controllers (PHCN-201l, Omega Engineering, Inc., Stamford, Connecticut) and solenoids were used to dose 0.1 M nitric acid into the untreated control tub (Figure 2). The ammonium-treated tub was dosed with a 1:1 mixture of 0.5 M nitric acid and 0.1 M ammonium
nitrate solution. A datalogger recorded the pH reading of each automated pH controller continuously. The controllers were set to open the solenoid valves and dose the acid solution when the solution exceeded the desired level.

Figure 2. This Omega pH controller, solenoid valve and acid solution apparatus were used to prevent pH from rising above desired levels.

The nozzle from the acid container was pointed directly at the end of the pH probe to allow time for mixing before adding additional pulses of acid (Figure 3).
Figure 3. The acid output nozzle is pointed directly at the tip of the pH probe to allow time for mixing before adding additional acid solution.

The initial pH setting was 7.0. After 10 days, the pH setting was reduced to 6.3 for the remainder of the experiment. Eighteen days after planting, supplemental HID lighting was added (Figure 4).
Figure 4. Supplemental HID lighting was added at 18 DAP (11/24) to improve light levels.

Chlorophyll levels were calculated from hand-held chlorophyll measurements using the equation for maize: 

\[ \text{Chlorophyll content} \left[ \frac{\text{µmol}}{m^2} \right] = -121 + 129 \times CCI^{0.42} \]

as described by Parry et al. (2014) at 30 and 31 DAP. Sandoval-Villa et al. (1999) found that nitrate nitrogen in the solution resulted in higher leaf chlorophyll levels using a similar method. We hope to show a similar response in corn. Because all of the plants were so chlorotic, 0.56 g of iron(II) sulfate was added to both tubs on 29, 30 and 31 DAP to make bring the solution 50 µM iron(II) sulfate.

RESULTS

During the first ten days of growth, the treated corn was able to take up ammonium from the solution and acidify the pH sufficiently that the pH controller was never activated.
The corn grown with nitrate only required acid pH correction six times during the first ten days.

Figure 5. Plants grown with ammonium were similar in size and vigor to the nitrate-only plants, but pH control was not activated for the ammonium-treated plants. The pH controller dosed six times for the nitrate-only plants.

Differences in growth and color were not visibly detectable at this stage. Sixteen liters of nutrient solution were added to each tub, which further indicates that growth was similar for the treated and untreated plants (Figure 6). However, despite the fact that EDDHA was used as the chelating agent, all plants were very chlorotic at pH 7.0.
Figure 6. Similar water use rates indicate similar growth rates for treated and untreated corn plants through 10 DAP.

Since all plants were chlorotic at pH 7.0, pH was reduced at 10 DAP to 6.3. Both controllers dosed acid several times to reduce the pH to that level. Once pH stabilized at this level, the ammonium tub required pH correction only once over the remainder of the experiment (See Figures 7 and 9). The nitrate-only control tub required pH correction ~70 times over the next eight DAP (Figure 7).
A single pH correction was required for the ammonium-treated plants while ~70 corrections were required to maintain the pH at 6.3 for the nitrate controls.

Plants in both treatments still appeared similar in size, but the ammonium-treated plants were slightly greener. Water use from both tubs was 26 liters, indicating similar growth. (Figure 8). Ambient light levels were low, so supplemental HID lights were added at 18 DAP to help encourage greening and growth. In addition, to intensify the potential treatment effect, ammonium sulfate was added to the ammonium-acid correction solution to bring the ammonium levels to .3 M ammonium. Nitric acid concentration remained the same.
Figure 8. Water use from planting to 18 DAP was similar for treated and untreated plants which indicates that growth rates were similar.

The nitrate-only controls required ~175 pH corrections from 19 to 30 DAP, while the ammonium-treated plants required only a single correction. Corn plants in the ammonium treatment were able to reduce pH to ~5.6, but pH levels began to rise again. There was a steep rise in pH on 27 DAP and pH rose slowly after that. There was a sharp drop in pH on 29 DAP, similar to an acid dose, but that drop corresponds with the iron(II) sulfate treatment and appears on the nitrate-only graph as well (Figure 9).
Figure 9. Ammonium-treated plants required no pH correction and were able to acidify the solution and drop the pH to ~5.6. Nitrate-only plants required ~175 pH corrections.

Ammonium-treated plants were obviously greener than nitrate-only plants. Treated plants were also visibly much larger than the untreated controls (Figure 10).

Figure 10. Plants treated with ammonium (right) are larger than those grown with nitrate only (left).
In addition, total water use for the untreated plants at 30 DAP was 43.5 liters, while water use for the ammonium-treated plants was 57.5 liters (Figure 11).

Figure 11. From 21 to 30 DAP, ammonium-treated plants started to use more water than the nitrate-only plants indicating that they were growing faster.

Chlorophyll levels on both occasions were less for the untreated plants than for the treated. Treating with iron(II) sulfate increased the chlorophyll content within 24 hours of treatment. No significant difference in chlorophyll content occurred, but the difference on day 30 was nearly so (Figure 12).
Figure 12. Chlorophyll levels were higher for the ammonium-treated plants on both days. The iron(II) sulfate application increase the chlorophyll content for both groups.

DISCUSSION

Trends in growth indicate a linear response in the control while the ammonium-treated plants seem to be growing exponentially. At the risk of making too large of an extrapolation, it appears that ammonium-treated plants could be twice as big as the untreated plants by 60 DAP. Even if the more conservative linear projection holds, the treated plants would still be 1.3 times larger based on water use projections (Figure 13).
Figure 13. Water use data projection through 60 DAP indicate that treated plants could be 1.3 to 2 times bigger than untreated plants.

Both tubs of nutrient solution contained the same amount of nitrate and the same EDDHA chelating agent. In addition, the pH of both solutions was reduced as needed. The nutrient solution required very little pH correction when ammonium was present. In fact, pH correction only occurred once during the experiment. It is puzzling that the ammonium-treated tub required no acid pulses for pH correction in the first 10 DAP since the corn should not have been able to reduce the pH in the absence of ammonium uptake. The reason this was possible is because when setting up the acid-dosing system, the air needed to be bled from the tubing to prevent vacuum locking. This provided the initial quantities of ammonium required to start the process. Still, pH really began to drop in the treated tub when the concentration of ammonium was tripled. The pH controller did not dose during this period, but, once again, the purging of the tubing provided initial dosing of this more concentrated ammonium.
With the exception of correction needed to reduce the pH from 7.0 to 6.3 on day 10 and those doses given when bleeding the system, acid correction was only required once for the ammonium-treated plants. These exceptions also apply to the nitrate only control solution, but pH correction there was required frequently. This provides evidence that ammonium is being taken up and hydrogen ions exuded. The fact that pH in the ammonium-treated solution begins to rise again at 27 DAP indicates that the available ammonium had been consumed and hydrogen ions were no longer being exuded. All of this provides evidence that the corn is indeed reducing the pH and that, if a sufficient boundary layer exists, a rhizosphere is being created.

A reduction in solution pH alone was not sufficient to avoid chlorosis entirely—even with the EDDHA chelating agent. Treated plants were slightly greener and had higher chlorophyll content, but were still very sickly. We can conclude that there is a rhizosphere effect even in hydroponic systems, but this effect does not seem to be strong enough for the corn plants to obtain sufficient iron. Chlorosis is still severe. Perhaps starting the experiment with a lower pH may have prevented the extreme chlorosis experienced in the first 10 DAP. The fact that the treated plants greened some after the reduction in pH indicates that this could be the case. Additionally, a 0.3 M ammonium solution seems to create a more dramatic reduction in pH without reducing pH to problematic levels. In the future, this would probably be a good starting concentration.

The difference in growth between the two groups intensified when the higher concentration of ammonium was used. It is likely that small differences in growth occurred from the beginning because the uptake of ammonium was making pH control unnecessary.
However, since water use is our only non-destructive measure of growth, that conclusion cannot be made for certain. We can safely conclude, however, that adding ammonium to the nutrient solution of hydroponic corn results in decreasing solution pH, greater chlorophyll content and better growth. All of this is evidence that some type of rhizosphere exists even in aerated hydroponic systems.

Water use efficiency is defined here as yield of plant product (tonnes of wheat grain, Y) per unit of crop water use (megalitres of water lost by evapotranspiration, ET), and is important in all areas of plant production. Water use efficiency (Y/ET) is the outcome of an entire suite of plant and environmental processes operating over the life of a crop to determine both Y and ET. Consequently, biomass production per unit ET, has been used extensively as an interim measure of water use efficiency.


Abstract Sorghum [Sorghum bicolor (L.) Moench] seedlings were grown in nutrient solutions in a growth chamber to investigate the effects of different ratios of NO3⁻ and NH4⁺ on nutrient solution pH, dry matter yield, and N uptake. Nutrient solutions and plant tissues were assayed throughout the time plants grew in the nutrient solutions. Nutrient solution pH depended on source of N. The pH rose to near 8 with NO3⁻ as the sole source of N and decreased to near or below 4 with NH4⁺ added to the solutions. Upon depletion of NH4⁺ from solution, pH values rose abruptly to near 8 and remained near this value throughout the duration of the experiments. Dry matter yield was generally higher for plants grown with some NH4⁺ compared to plants grown with NO3⁻ alone. Nitrogen uptake was generally higher in plants grown with the higher proportions of NH4⁺. Nitrogen concentrations remained unchanged with plant age as NO3⁻/NH4⁺ ratio varied. For solutions low in NH4⁺, N concentrations in roots increased with plant age. Severe Fe deficiency appeared in plants when solution pH reached and remained above 7.


The article describes factors and processes which lead to Fe chlorosis (lime chlorosis) in plants grown on calcareous soils. Such soils may contain high HCO₃⁻ concentrations in their soil solution, they are characterized by a high pH, and they rather tend to accumulate nitrate than ammonium because due to the high pH level ammonium nitrogen is rapidly nitrified and/or even may escape in form of volatile NH3. Hence in these soils plant roots may be exposed to high nitrate and high bicarbonate concentrations. Both anion species are involved in the induction of Fe chlorosis. Physiological processes involved in Fe chlorosis occur in the roots and in the leaves. Even on calcareous soils and even in plants with chlorosis the Fe concentration in the roots is several times higher than
the Fe concentration in the leaves. This shows that the Fe availability in the soil is not the critical process leading to chlorosis but rather the Fe uptake from the root apoplast into the cytosol of root cells. This situation applies to dicots as well as to monocots. Iron transport across the plasmamembrane is initiated by FeIII reduction brought about by a plasmalemma located FeIII reductase. Its activity is pH dependent and at alkaline pH supposed to be much depressed. Bicarbonate present in the root apoplast will neutralize the protons pumped out of the cytosol and together with nitrate which is taken up by a H+/nitrate cotransport high pH levels are provided which hamper or even block the FeIII reduction. Frequently chlorotic leaves have higher Fe concentrations than green ones which phenomenon shows that chlorosis on calcareous soils is not only related to Fe uptake by roots and Fe translocation from the roots to the upper plant parts but also dependent on the efficiency of Fe in the leaves. It is hypothesized that also in the leaves FeIII reduction and Fe uptake from the apoplast into the cytosol is affected by nitrate and bicarbonate in an analogous way as this is the case in the roots. This assumption was confirmed by the highly significant negative correlation between the leaf apoplast pH and the degree of iron chlorosis measured as leaf chlorophyll concentration. Depressing leaf apoplast pH by simply spraying chlorotic leaves with an acid led to a regreening of the leaves.


Maize (Zea mays L. cv. Anjou 21) grown in nutrient solution with Fe-EDTA and with nitrate as the sole nitrogen source showed typical Fe-chlorosis symptoms after a growth period of 14–21 days. Alkalinity in roots, stems and leaves of the chlorotic plants was high. Transferring the chlorotic plants from the nitrate-containing nutrient solution to a solution of (NH4)2SO4 resulted in a regreening of leaves within 2–3 days which was associated with a decrease in solution pH, a decrease in alkalinity of plant parts, a translocation of Fe from roots to tops and a release of Fe into the outer solution. Similar effects were obtained when Fe chlorotic plants were transferred to a dilute HO solution with pH 3.5. Spraying chlorotic leaves with indoleacetic acid or with fusicoccin led also to a regreening of leaves without having a major effect on leaf alkalinity. Interpretation of the experimental results is based on the assumption that nitrate as sole N source leads to a high pH level in the apoplast resulting in the precipitation of Fe compounds, probably Fe oxide hydrate. Ammonium nutrition has the reverse effect since it lowers the apoplast pH and this can result in the dissolution of Fe compounds. Application of indoleacetic acid as well as fusicoccin supposedly stimulates the proton pumps in the plasmalemma of the leaf tissue. The resulting decrease in apoplast leaf pH in the microenvironment also leads to a dissolution of Fe compounds in the apoplast and thus promotes the uptake of Fe by the symplasm.


Abstract A hypothesis has been presented and tested that bicarbonate (HCO3) and nitrate (NO3) are the most important anions inducing iron (Fe) chlorosis because these anions
increase the pH of leaf apoplast which in turn depresses ferric iron [Fe(III)] reduction, and hence, the uptake of Fe into the symplasm. Experiments with young sunflower (Helianthus annuus) plants showed that nutrition with NO3 as the sole nitrogen (N) source induced chlorosis whereas ammonium nitrate (NH4NO3) did not. Monohydrogen carbonate (bicarbonate) also favoured the development of chlorosis. The degree of chlorosis was not related to the Fe concentration in the leaves. Both anion species, NO3 and HCO3, increased the pH of the leaf apoplast which was measured by means of the fluorescence dye 5’carboxyfluorescein. A highly significant negative correlation between leaf apoplast pH and chlorophyll concentration in the leaves (r = -0.97) was found. Ferric Fe reduction in the apoplast measured by means of ferrocene provided evidence that a low leaf apoplast pH, obtained with ammonium (NH4) supply, favoured the reduction of Fe(III) as compared with a higher leaf apoplast pH obtained with NO3 supply. These results support the hypothesis tested.


Maize plants (Zea mays L. cv. R201) were grown to 21 d in pH-controlled gravel culture with 2 mM inorganic N supplied as nitrate alone, ammonium alone or 1:1 nitrate + ammonium. At 21 d, the 14N feeding solutions were replaced with 15N solutions, and xylem sap collections were made 4 and 8 h after the commencement of feeding. Leaf and root material was harvested also for in vitro nitrate reductase and glutamine synthetase activity assays. Xylem sap analyses showed that in nitrate-only fed plants the major supply of nitrogen from root to shoot was in the nitrate form (60%) with 35% carried as amino compounds. However, 93% of 15N was transported to the shoot as nitrate and only 6% in amino compounds, indicating the more direct routing of newly absorbed nitrogen to the shoot via the former. Leaf NRA was seven-fold greater than that of the root, confirming the shoot as the major site of nitrogen assimilation in plants fed only nitrate. In ammonium-only fed plants, 84% of xylem N was found in organic form (66%16N), the remainder translocating as ammonium, identifying the root as the major site of ammonium N assimilation. In ammonium + nitrate fed plants, 64% of xylem N was present as organic N (55%16N), 34% as nitrate (43%16N), indicating shared N assimilation between shoot and root, with root assimilation predominating. In plants receiving nitrate, glutamine was the major N compound translocated, in plants receiving only ammonium, asparagine predominated. GS activity was approximately the same in root and shoot and showed no response to N source. The significance of these results is discussed with respect to the reported increased productivity of maize fed a mixed nitrate-ammonium N source.


In situ optical meters are widely used to estimate leaf chlorophyll concentration, but non-uniform chlorophyll distribution causes optical measurements to vary widely among
species for the same chlorophyll concentration. Over 30 studies have sought to quantify the in situ/in vitro (optical/absolute) relationship, but neither chlorophyll extraction nor measurement techniques for in vitro analysis have been consistent among studies. Here we: (1) review standard procedures for measurement of chlorophyll; (2) estimate the error associated with non-standard procedures; and (3) implement the most accurate methods to provide equations for conversion of optical to absolute chlorophyll for 22 species grown in multiple environments. Tests of five Minolta (model SPAD-502) and 25 Opti-Sciences (model CCM-200) meters, manufactured from 1992 to 2013, indicate that differences among replicate models are less than 5%. We thus developed equations for converting between units from these meter types. There was no significant effect of environment on the optical/absolute chlorophyll relationship. We derive the theoretical relationship between optical transmission ratios and absolute chlorophyll concentration and show how non-uniform distribution among species causes a variable, non-linear response. These results link in situ optical measurements with in vitro chlorophyll concentration and provide insight to strategies for radiation capture among diverse species.


In intact root systems of soybean and corn cultivars differing in Fe efficiency the pH gradients at the soil:root interface (rhizosphere) have been studied. For this purpose a combination of an agar technique (fluid agar + pH indicator) and a soil culture (sandy soil, pH 6.0) were used. In addition the rhizosphere pH was measured with antimony microelectrodes. With this method, striking differences in rhizosphere pH could be observed both between the cultivars and within a cultivar along the root system. In general, the rhizosphere pH was higher in ?Fe?inefficient?; cultivars compared to ?Fe?efficient?; cultivars. Compared to the bulk soil (pH 6.0) the rhizosphere pH in the basal root zones of Fe?inefficient cultivars (PI?54169; ys1/ ys1) increased up to pH 7.5 and pH 6.8, respectively; the corresponding pH values for the Fe?efficient cultivars (Hawkeye; WF9) were pH 6.8 and pH 5.6, respectively. Within the root system of the same plant the rhizosphere pH of apical zones was always more than one pH unit lower than in the basal root zones. The method presented in this paper for measuring pH changes in the rhizosphere offers a simple and rapid way for detailed studies of root?induced changes in the rhizosphere in general.


Abstract Combinations of NH4?N:NO3?N usually result in higher tomato (Lycopersicon esculentum Mill.) yields than when either form of nitrogen (N) was used alone. Leaf chlorophyll content is closely related to leaf N content, but the effect of the NH4?N:NO3?N ratio on leaf greenness was not clear. The objective of this study was to determine the influence of NH4?N:NO3?N ratios on chlorophyll meter (SPAD) readings,
and evaluate the meter as a N status estimator and tomato yield predictor in greenhouse production systems. Fruit yield and SPAD readings increased as the amount of NH4\(^+\)N in solution increased up to 25%, while higher ratios of NH4\(^+\)N resulted in a decline in both. The N concentration in tomato leaves increased as concentration of NH4\(^+\)N in solution increased. Fruit yield increased as chlorophyll readings increased. SPAD readings, total N in leaves, fresh weight of shoots, and fruit yield all showed a quadratic response to NH4\(^+\)N, reaching a peak at 25 or 50% of N as NH4\(^+\)N. SPAD readings taken at the vegetative and flowering stages of growth had the highest correlation (r\(^2\)=0.54) with N concentration in leaves, but this could not be used as a reliable estimate of N status and fruit yield. Lack of correspondence between high N concentration values and fruit yield indicated a detrimental effect of NH4\(^+\)N on chlorophyll molecules or chloroplast structure. The SPAD readings, however, may be used to determine the optimum NH4\(^+\)N concentration in solution to maximize fruit yield.


Take-all of wheat caused by Ophiobolus graminis was reduced by ammonium-nitrogen (NH4-N) supplemented with 2-chloro-6-(trichloromethyl) pyridine (N-Serve 24) to slow nitrification, but was severe with no added N, or with Ca(NO3)\(_2\) at N rates equivalent to that supplied by NH4-N. The addition of lime (CaO) negated control with NH4-N. The correlation between disease severity and bulk soil pH (pHb) was relatively poor. A higher correlation existed between disease severity and rhizosphere pH (pHr). The pHr dropped with uptake of NH4-N by roots, increased with uptake of NO3-N, and remained generally unchanged with no added N. Disease severity in nonsterile soil was progressively less as the pHr decreased below 7.0 and was greatly reduced at pHr values below 6.6. In comparable soil treated with methyl bromide, disease was controlled only when pHr dropped below 5.0. Pathogen growth was nil in sterile and nonsterile soil at pH less than 5.0. Reduced disease apparently resulted from direct inhibition of the pathogen at pHr less than 5.0 and indirect inhibition (possibly a biological control) above 5.0. Best control in field plots occurred when (NH4)2SO4 was mixed into the tilled layer rather than broadcast.


It has been commonly observed that corn plants grown in complete nutrient media often develop chlorosis. This type of chlorotic condition in the leaves is intervenal in nature and is not associated with the total absence of any essential mineral in the nutrient medium. That is, this type is distinguishable from those types which occur under conditions of magnesium or manganese deficiency such as have been amply described by Pettinger et al. (21). Plate 1 illustrates the type of chlorosis observed in the experiments reported herein. This chlorosis has been observed under, and ascribed to, a wide range of nutritional conditions. It has been attributed to maladjustment of the pH of the substrate, to an excessively high nitrate nitrogen content of the growing medium, to sodium toxicity, and to excess phosphate in the nutrient supply, in addition to being "lime induced."
Inasmuch as the nature of the symptoms in the plants observed under these varied conditions are very similar, it is reasonable to assume that the same mechanisms within the plant are disturbed in all these various conditions which induce the same type of chlorotic symptoms.


Most agronomic research on wheat in New Zealand has consisted of empirical field trials, with conventional statistical analyses producing information specific to the time and location of the trial or series of trials. We have attempted to overcome this limitation by using simple models to analyse the growth and water use of wheat crops so that responses to agronomic treatments can be explained, and separated from site and seasonal variability. In this paper we briefly describe the models, present the results of the analyses, and consider their practical implications and limitations. The models were used to analyse results from eleven crops grown in three experiments at Lincoln (latitude 43, 38'S, altitude 11 m) in the 1980, 1982 and 1983 seasons. Two New Zealand cultivars, Rongotea and Oroua, were sown on two or three dates in each experiment. All the experiments were conducted on a soil consisting of 0.3 m of silt loam overlying a sandy loam subsoil to a depth exceeding 1.5 m, the maximum rooting depth of the crops. The soil profiles retained 18% by volume of plant-available water at saturation.