Drill application of ammonium phosphate fertilizers with the seed of irrigated barley on calcareous soils

by J D Franklin

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science

Montana State University

Abstract:

Four field experiments in 1974 and seven in 1975 were conducted on calcareous soils to determine the effect of banding monoammonium phosphate (MAP, 11-55-0), diammonium phosphate (DAP, 18-46-0), and urea ammonium polyphosphate (UAPP, 28-28-0) with the seed of irrigated barley at N rates from 11 to 44 kg/ha. In 1975, a mixture of urea and DAP (U+DAP) in 1:1 ratio N:P2O5 was banded with seed at rates of 11 to 44 kg/ha of N and a mixture of ammonium nitrate and MAP (AN+MAP) in 1:1 ratio N:P2O5 was banded with seed at rates of 22 and 44 kg/ha of N.

The effects of volatilized NHo on barley germination, growth, and yield were not as pronounced in 1975 due to above-normal precipitation and delayed seeding dates caused by excessive rainfall during the April-May planting period.

In 1974, NH3 damage to irrigated barley seedlings was in the order UAPP >DAP %>MAP. In 1975, seedling injury was in the order UAPP >U+DAP = DAP >MAP. Differences between the fertilizer mixtures in 1:1 ratio N:P2O5 were not statistically different from either DAP or MAP alone.

In both years, N rates with the seed of greater than 22 kg/ha generally produced the greatest plant damage. In 1974, a significant interaction between fertilizer source and rate influenced results. Damaging effect on early season plant growth as N rates with the seed increased above 22 kg/ha was found to be in the order UAPP >DAP >MAP.

Of 16 different crop response variables measured, early season number of plants, number of stems, and plant top weight were found to be the most effective estimates of NH3 damage. Increases in number of spikes per plant, kernels per head, 1000-kernel weight, and kernel weight per spike as N rate with the seed increased revealed evidence of possible compensation by the barley plant to earlier damage.

Site variability associated with factors other than soil CaCO3 equivalent made estimates of the influence CaCO3 difficult. Using relative top weight values, negative slopes were attained with regression analysis with increasing CaCO3 levels. Further analysis of variance could not, however, refine the estimate of soil CaCO3 influence on damage caused by band-applied ammonium phosphate fertilizers.

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DRILL APPLICATION OF AMMONIUM PHOSPHATE FERTILIZERS WITH THE SEED OF IRRIGATED BARLEY ON CALCAREOUS SOILS

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ABSTRACT

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In both years, N rates with the seed of greater than 22 kg/ha generally produced the greatest plant damage. In 1974, a significant interaction between fertilizer source and rate influenced results. Damaging effect on early season plant growth as N rates with the seed increased above 22 kg/ha was found to be in the order UAPP $>$ DAP $>$ MAP.

Of 16 different crop response variables measured, early season number of plants, number of stems, and plant top weight were found to be the most effective estimates of NH_3 damage. Increases in number of spikes per plant, kernels per head, 1000-kernel weight, and kernel weight per spike as N rate with the seed increased revealed evidence of possible compensation by the barley plant to earlier damage.

Site variability associated with factors other than soil $CaCO_3$ equivalent made estimates of the influence $CaCO_3$ difficult. Using relative top weight values, negative slopes were attained with regression analysis with increasing $CaCO_3$ levels. Further analysis of variance could not, however, refine the estimate of soil $CaCO_3$ influence on damage caused by band-applied ammonium phosphate fertilizers.

INTRODUCTION

Fertilizer use by small grain farmers in Montana has increased rapidly in the past few years. Banding ammonium phosphate fertilizers with the seed has proven to be beneficial in increasing yields. Recently, grain growers in semi-arid regions have encountered damage to plants from gaseous ammonia volatilized from banded fertilizers on calcareous soils. Germination has been impaired; seedling growth has been slowed; and grain yields have been decreased. Extensive laboratory and greenhouse research has provided information on how the ammonia is released, how it produces toxic effects on small grain plants, and how environmental factors influence its activity.

In order to relate these laboratory findings to the problems of the small grain producer, the effects of banding ammonium phosphate fertilizer with barley seed in calcareous soils was studied under irrigated conditions in the field. These studies were conducted over a period of two years at 11 locations throughout south-western Montana. It is hoped that the results of these studies will prove to be of value to the small grain grower in avoiding crop injury from volatilized NH_3.

LITERATURE REVIEW

It has been well documented that fertilizers are a valuable tool which can be used to increase crop production. Recently, increased emphasis has been placed on problems resulting from improper fertilizer use. One of these is the problem of plant damage resulting from the release of free NH_3 when nitrogenous fertilizers, especially urea and ammonium phosphates, are applied to soils under certain conditions. This review brings together some of the more pertinent findings related to ammonia volatilization and toxicity. It will point out the questions that have been adequately answered and discuss those that remain to be answered.

A number of chemical equilibria are involved in the volatilization of NH_3 and most have been shown to be pH dependent. DuPlessis and Kroontje (1964) found that ammonia volatilization was directly related to the initial pH of the soil and increased with an increase in pH. They postulated that NH_3 may be volatilized, even from acid soils, due to the equilibrium:

$$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$$

Ernst and Massey (1960) found that increasing the soil pH by liming caused an increase in activity of both NH_4^+ and OH^- ions, thus driving the above equilibrium to the right and increasing the volatilization of ammonia.

When ammoniacal fertilizers were applied to calcareous soils, Larsen and Gunary (1962) found that NH_3 loss depended on the equilibrium:

$$P_{NH_3} = K \left[NH_4^+\right] / \left(\left[Ca^{2+}\right] P_{CO_2} \right)^{1/2}$$

where K is a constant equal to $K_{NH_4^+}/K_{CaCO_3}$ and P_{CO_2} is the partial pressure of CO_2. The terms $K_{NH_4^+}$ and K_{CaCO_3} are the dissociation constants of NH_4^+ and $CaCO_3$, respectively. As a result of the above equilibrium, NH_3 loss from a soil containing free $CaCO_3$ would be expected to be proportional to NH_4^+ concentration and inversely proportional to the square root of the Ca^{2+} concentration times the partial pressure of CO_2. The reaction of ammonium phosphate fertilizers in the soil to form relatively insoluble calcium phosphate compounds would be expected to enhance NH_3 volatilization because of a reduction in Ca^{2+} concentration.

Terman and Hunt (1964) found that when diammonium phosphate is applied to limed acid or naturally calcareous soils the reaction is:

$$(NH_4)_2HPO_4 + CaCO_3 \xrightarrow{H_2O} CaHPO_4 \cdot 2H_2O + (NH_4)_2CO_3.$$

The $(NH_4)_2CO_3$ thus formed is unstable and decomposes easily according to the equilibrium:

$$(NH_4)_2CO_3 \rightleftharpoons 2NH_4^+ + HCO_3^- + OH^- \rightleftharpoons 2NH_3\uparrow + CO_2\uparrow + 2H_2O.$$

Ammonia volatilized from fertilizers can be toxic to plants and may reduce germination, seedling growth, and crop yields. Many of the mechanisms involved and their effects on plants have been explained by researchers but some specifics remain to be explained.

Several investigators (Khan and Mandal, 1968; Hunter and Rosenau, 1966) have theorized that the injurious effects of certain nitrogenous fertilizers on seed emergence is due to the contact of volatilized gaseous ammonia with the germinating seed. Hood and Ensminger (1964) found that when seeds were soaked in $MgSO_4$ or $MgCl_2$ after being soaked in $(NH_4)_2HPO_4$ germination was greater than when seeds had been soaked only in $(NH_4)_2HPO_4$. They concluded that detrimental effects of ammonium phosphates are not due to the ammonium or phosphate ions "per se." Ensminger, et al. (1965) reported that germination injury from $(NH_4)_2HPO_4$ appears to be largely due to inactivation of Mg in seeds. They found that harmful effects were largely alleviated by subsequent soaking of seeds in dilute solutions of $MgSO_4$.

Cell membranes were found by Warren (1962) to be impermeable to NH_4^+, whereas NH_3 passed tissue barriers with ease. Stuart and Haddock (1968) found that $(NH_4)_2SO_4$, $(NH_4)_2CO_3$, and gaseous NH_3 inhibit water uptake in sugarbeet roots when the pH is sufficiently high. In roots lacking an epidermis, NH_3 did not inhibit water uptake. This may indicate that the site of inhibition lies within the root epidermis.

While studying the effects of ammonia on plant metabolism, Vines and Wedding (1960) tried to locate one or more sites at which ammonia could be shown to have deleterious effects on normal metabolic processes of plants. Their findings indicate an inhibition of respiration. A possible site could be located in the electron-transport system, especially the DPNH→DPN reaction. Thus the transport of electrons from oxidized substrates to oxygen is blocked. Along these same lines Kramer (1955) reported an inhibition of oxidative formations.

Several researchers have reported effects on certain characteristics and yield components of crops by volatilized NH_3 (Cook et al., 1958; Lawton and David, 1960; Colliver and Welch, 1970) Results of unpublished research by Smith et al. (1968-1972) with non-irrigated winter wheat indicate that volatilized NH_3 may slow down or prevent germination, reduce stand, retard plant growth, and under certain circumstances reduce the number of heads per meter of row. Pairintra (1973) found that wheat seedlings subjected to toxic NH_3 levels had stunted coleoptiles and radicles with a brown color giving them a "burnt-off" appearance. He reported that ammonia content in soil samples from field experiments having fertilizer banded with wheat seed was directly related to dry weight of plants at the stem elongation stage of growth.

The ability of nitrogenous fertilizers to release NH_3 and the subsequent amount released are dependent on a number of factors. Factors identified by Pesek et al. (1971) include soil water content, temperature, surface roughness and residue, air movement, presence of carbonates, granular size of fertilizer, and time elapsed between fertilizer application and the next rainfall or irrigation. Mortland (1958) listed soil moisture, texture, pH, organic matter, placement, and soil tilth as factors affecting NH_3 loss in soils. The remainder of this review will be concerned with the role of soil texture, exchange capacity of the soil, soil pH, $CaCO_3$ content of the soil, soil temperature and moisture, fertilizer source, application method, and fertilizer rate on NH_3 volatilization.

Soil Texture

Jenny et al. (1945) reported that uptake of N in soil suspensions containing NH_3 and $(NH_4)_2SO_4$ is, broadly speaking, a function of soil texture. Wahhab et al. (1957) found twice as much NH_3 was volatilized from a sandy than from a sandy loam soil with applications of NH_4^+-N. When equal amounts of ammonia were applied to soils, Chao and Kroontje (1964) found that loss of NH_3 was in the order of: Norfolk fine sandy loam > Salinas clay > Yolo loam > Davidson clay. They stated that the larger NH_3 losses from coarse textured soil indicates that soil texture is a factor in NH_3 volatilization. Since surface layers of sandy soils dessicate sooner than those of heavy soils, van Shreven (1950) gave this as one of the reasons why loss of ammonia may be greater on sandy soils under field conditions. He further stated that the low adsorptive powers of sandy soils favors the loss of NH_3.

Conclusion: Coarse textured soils are more conducive to NH_3 volatilization than finer textured soils.

Exchange Capacity of Soil and Exchangeable Cations

Several investigators have shown that low cation exchange capacity (CEC) is more conducive to NH_3 loss (Martin and Chapman, 1951; Volk, 1959; Brown and Bartholomew, 1962; Liegel et al., 1976). Gasser (1964) stated that the property most likely to be related to the ability of the soil to retain NH_4^+-N and NH_3 is its base exchange capacity. His results suggest that, when 100 lb of N/acre is applied as urea to soils with base exchange capacities less than 10 meq/100g, more than 20% may be lost as ammonia; the maximum losses decrease to 10% at 20 meq/100g, with less than 10% lost from soils of greater CEC.

Mortland (1958) reported the effect of exchangeable cations on NH_3 desorption was found to follow the order: $H^+ > Ca^{+2} > Na^+ > K^+$. He found that fixation of K^+ by bentonite particularly reduced the sorption of ammonia. Mortland further stated that it has been suggested that NH_3 is chemically sorbed in greatest quanities by clay minerals under acid conditions, i.e. when there is a supply of H^+ ions to react with the ammonia, while other work has shown that ammonia is chemically sorbed in greatest quantities by organic matter under alkaline conditions.

He stated that in all likelihood, the combination of these two soil constituents will provide for chemical sorption of NH_3 over a wide range in soil reaction.

Conclusions: Lower CEC's are more conducive to NH_3 loss. The effect of exchangeable cations on NH_3 desorption in bentonite clays follows the order of: $H^+ > Ca^{+2} > Na^+ > K^+$.

pH and $CaCO_3$ Content of Soil

A number of researchers have studied the effect of pH on the evolution of NH_3 from nitrogenous fertilizers. Most are in agreement that greater NH_3 loss can occur when soils have high pH's as compared to soils with lower ones (Mitsue, 1954; Wahhab et al., 1957; Volk, 1959; Ernst and Massey, 1960; Kresge and Satchell, 1960; Mills et al., 1971). Martin and Chapman (1951) report a 9% loss of NH_3 from NH_4OH on a soil with pH 4.5 and a 51% loss on a soil with pH 8.0. Steenbjerg (1947) found a 5% loss of NH_3 over a 4 week period on a soil with pH 6.0 and as much as a 60% loss on a soil with pH 8.0. He reports virtually no loss at pH less than 6.0. Feagley and Hossner (1975) state that substantial losses may occur from limed, acid soils.

Several researchers have shown that increasing $CaCO_3$ content in soils results in increased NH_3 volatilization from nitrogenous fertilizers which form insoluble reaction products such as calcium phosphate (van Schreven, 1950; Terman and Hunt, 1964). This occurs due to the equilibrium described by Larsen and Gunary (1962). Steenbjerg (1947) found a 25% loss of NH_3 from $(NH_4)_2SO_4$ on soils with 1-2% $CaCO_3$. On soils with 5-10% $CaCO_3$ a 50% loss occurred. On ten soils ranging in $CaCO_3$ content from 0% to 12.9% at constant moisture, Pairintra (1973) found NH_3 loss from four different fertilizers increased directly with %$CaCO_3$ in the soil. Ammonia production at most levels of $CaCO_3$ studied was less from ammonium polyphosphate than from monoammonium phosphate. Diammonium phosphate produced more NH_3 than monoammonium phosphate, and urea ammonium phosphate produced the most NH_3 at all $CaCO_3$ levels. Wahhab et al. (1957) state that the reason for the relationship between NH_3 production and $CaCO_3$ is the higher degree of calcium saturation of the soil exchange complex with an increasing amount of $CaCO_3$ and an associated increase in pH or OH^- activity in the soil solution which results in increased NH_3 production.

Conclusions: Greater ammonia loss can occur when soils have a high pH as compared to soils with a lower one. A direct relationship exists between ammonia loss from fertilizers which form insoluble reaction products in soil and increasing %$CaCO_3$ of the soil.

<u>Soil Temperature and Soil Moisture Content</u>

Volk (1959), Overrien and Moe (1967), and Watkins et al. (1972) reported that higher soil temperatures result in greater NH_3 loss from surface applications of urea. With applications of ammonium nitrate on a soil at 25% moisture capacity, Martin and Chapman (1951) found an 11% loss of added N when soil was at room temperature. When soil temperature was 100°F, a 21% loss occurred and a 32% loss occurred when soil temperature was 150°F. Ernst and Massey (1960) found that after 10 days, about 5% of the N applied as urea was lost when the soil temperature was 45°F. When the soil temperature was 60°F, about 10% was lost. At 75°F, approximately 15% was lost and about 23% was lost at 90°F. They stated that incomplete hydrolysis of the added urea could partially account for the decreased ammonia losses at the lower temperatures.

Soil moisture has been shown to play an important role in NH_3 volatilization. Decreases in the rate of NH_3 volatilization from anhydrous ammonia and ammonium sulfate occurring with increasing soil water content were reported by van Schreven (1950) and Parr and Papendick (1966). In early studies, Jones (1932) found that the rate of NH_3 accumulation from urea decreased with an increase in soil moisture in the early period of incubation. Jewitt (1942) reported that NH_3 loss from ammonium sulfate was influenced little by moisture content except when it approached air dry levels. Martin and Chapman (1951) also stated that moisture content has little effect except that evaporation of water was necessary for appreciable volatilization of ammonia from ammonium hydroxide. Wahhab et al. (1957) found negligible NH_3 losses from ammonium sulfate on air-dry soil. Maximum losses occurred at 0.25% moisture saturation and then decreased with increasing moisture.

Similarly, Volk (1959) found a significant rate of loss of NH_3 from urea with as little as 1% soil moisture on sandy soils while dry conditions retarded NH_3 loss.

Greater volatilization of NH_3 from urea was found to occur by Ernst and Massey (1960) when moisture was lost from the soil. Volatilization was found to be directly related to initial soil moisture content, presumably through the effect of this variable on the duration of the drying process. Kresge and Satchell (1960) reported more loss from urea on soils drying out from field capacity than from any other moisture content.

Rolston et al. (1972) stated that moist soil has a greater capacity for ammonia sorption than a dry one. Pairintra (1973) found that total 6-day NH_3 production in the soil decreased as soil moisture increased from 10 to 20%. However, he observed that the amount of NH_3 produced in the first day of the experiment was in the order of magnitude: 20% $>$ 15% $>$ 10% soil water. He speculated that this first-day effect is the direct result of more rapid hydrolysis of the fertilizer with greater moisture. Ammonia volatilization from $(NH_4)_2SO_4$ was found by Fenn and Escarzaga (1976) to be greatly reduced on soils with 55% water as compared to soils with 30% water. Losses were highest when soils contained 13-30% soil water. Dry NH_4^+ chemicals did not dissolve in soils with 1% and 8% soil water; therefore, little NH_3 was lost.

Conclusion: A direct relationship exists between increasing soil temperatures and NH_3 production. The relationship between NH_3 volatilization and soil moisture content is more complex. Early research led to only inconsistent results. The work of Fenn and Escarzaga (1976) helps to explain some of these inconsistencies. Dry ammonium-chemicals do not dissolve at low soil water contents, thus explaining small losses in dry soils. Greatest losses occur when soils contain 13-30% water and decrease with further increases in soil water content.

Method of Fertilizer Application

Severe stand reductions and yield losses as a result of banding nitrogenous fertilizers with the seed have been noted by several researchers (Olson and Dreier, 1956; Cook et al., 1958; Brage et al., 1960; Molberg, 1961). Under greenhouse conditions, Lawton and Davis (1960) found that contact placement of wheat seed with 5-20-20 fertilizer at a 500 lb/A rate seriously delayed and reduced emergence of seedlings and subsequent growth. They observed that applying mixed fertilizer in a band below or 1 1/2 inches to the side and 1 1/2 inches below the seed was the most desirable method of placement from the standpoint of emergence and growth.

Colliver and Welch (1970) reported that toxic effects of anhydrous NH_3 on germination and early growth of corn were severe when the NH_3 was applied 10 cm deep immediately before planting at a 5 cm depth. Injury was largely prevented when application depth was 25 cm for all times and rates of application. Three methods of placement of ammonium phosphate fertilizers in relation to seed placement were studied by Smith et al. (1970). The first method was direct application of fertilizer with seed in a 3.2 cm band. This was compared with applications of fertilizer and seed in wider (6.4 cm) bands and with fertilizer placed 3.8 cm below the seed. With monoammonium phosphate (11-48-0), damage was virtually eliminated by placement below seed. Damage to wheat plants was less when the band was spread (6.4 cm) as compared to the narrow band (3.2 cm).

Conclusions: Contact placement of certain nitrogenous fertilizers with crop seed can result in stand reduction and yield loss. Spreading the band or placing fertilizer below seed may reduce damage.

Fertilizer Rates

Loss of gaseous ammonia from ammonium sulfate was observed by Jewitt (1942) to be greatly influenced by the rate of application of the fertilizer. Overrein and Moe (1967) found that rates of NH_3 volatilization increased at an exponential rate as rates of urea application increased. Recent work by Hauck (1976) may help to explain this exponential increase. He stated that increasing the rate of application and/or banding urea brings fertilizer granules closer together, thereby permitting the chemistry of the fertilizer to override the chemistry of the soil. Overlapping of these "microsite" reactions of the granules could explain exponential increases in NH_3 volatilization.

Guttay (1957) reports that complete fertilizers used at rates which placed 100 lb/acre or more of nutrients in contact with wheat seed seriously delayed and curtailed germination and emergence. Olson and Dreier (1956) found damage to germination under critical soil moisture to be apparent at 10 lb N/acre, increasing to the point of stand elimination with 160 lb N/acre. Mills et al. (1971) observed ammonia volatilization increases with increases in the rate of N application from 112 to 1344 kg N/ha as ammonium chloride. In field tests, Molberg (1961) found that 20 lb N/acre applied with flax seed significantly reduced emergence. When reagent grade urea was placed with the seed of corn and barley by Brage et al. (1960), they found stand depressions of 25% and 60% when 40 and 80 lb N/acre, respectively, were applied. Pairintra (1973) measured greater amounts of NH_3 from ammonium phosphates as rate of N application increased. In field studies with urea ammonium phosphate, number of stems was found to increase with application of 11 kg N/ha but then decrease with subsequent applications of 22, 33, and 44 kg N/ha with wheat seed. When urea ammonium phosphate (24-42-0) was banded with wheat seed, Smith et al. (1970) found reductions in number of wheat crowns with increasing N rates. With 5 lb N/acre approximately 45 crowns/100 cm of row were measured. Number of crowns dropped to approximately 35/100 cm of row with 20 lb N/acre and less than 25 crowns/100 cm of row with 30 lb N/acre.

Conclusions: Increasing the rate of application of certain fertilizers can result in increased ammonia volatilization. Formation of "microsites" around fertilizer granules and their subsequent overlapping by increasing the rate of application may result in exponential rates of increase in ammonia release.

Fertilizer Source

Terman and Hunt (1964) stated that differences between N fertilizers can be explained largely in terms of urea hydrolysis or the reaction of certain acid radicals of ammonium salts with calcium compounds in soil. These differences in losses of nitrogen as NH_3 from various N fertilizers have been studied by several researchers. When comparing ammonium hydroxide to ammonium sulfate, Martin and Chapman (1951) observed that 9-51% of the added N as NH_4OH was lost on soils ranging in pH from 4.5 to 8.0, while 1-27% of added N as $(NH_4)_2SO_4$ was lost on the same soils. Olson and Dreier (1956) found the order of magnitude of NH_3 loss from three N sources to be: $NH_4OH > (NH_4)_2SO_4 > NH_4NO_3$. Detrimental effects of various fertilizers on the germination of wheat were found by Cummins and Parks (1961) to decrease in the order: anhydrous ammonia $>$ urea $> NH_4NO_3 > (NH_4)_2SO_4$. Hargrove et al. (1976) found estimates of NH_3 volatilized from NH_4NO_3 in field studies ranged from 3-10% of applied N while losses from pelleted and liquid $(NH_4)_2SO_4$ ranged from 25 to 55% of the applied N at rates of 140 and 280 kg N/ha. Matocha (1976) reported that surface applied $(NH_2)_2CO$ and $(NH_4)_2SO_4$ lost significant amounts of NH_3-N, while losses from sulfur-coated urea and NH_4NO_3 were negligible. Fenn and Kissel (1976) found that ammonium sulfate produced higher soil pH values and NH_3 losses than did NH_4NO_3. The pH of the soil decreased with increasing NH_4NO_3 application rates. These findings may aid in explaining earlier inconsistencies existing in the research done with these two fertilizers.

While studying ammonium phosphates of a 1:1:0 ratio, Olson and Dreier (1956) concluded that they are harmful when placed with the seed under conditions of limited moisture. Allred and Ohlrogge (1964) found that free NH_3 associated with diammonium phosphate fertilizer was toxic to germinating corn. They stated that the effects of diammonium phosphates were more pronounced than the effects of equal amounts of monoammonium phosphates. Along this same line, Hood and Ensminger (1964) observed that urea ammonium polyphosphate treatments banded with corn seed resulted in less than 25% germination, compared to 60-90% for NH_4NO_3 plus concentrated superphosphate treatments.

Smith et al. (1969) studied the effect of various rates of different fertilizer materials on the number of winter wheat plants per foot of row. At all rates above 5 lb N/acre, diammonium phosphate (18-46-0) produced more damage than monoammonium phosphate (11-48-0). Both of these fertilizers resulted in fewer plants than did ammonium polyphosphate (15-60-0) at 20 and 30 lb N/acre rates. Greatest damage at all rates was caused by urea ammonium phosphate (24-42-0). The total amount of NH_3 measured over a six day period by a "diffusion can" technique developed by Pairintra (1973) was in the ratio of 18:4.5:1.5:1 for urea ammonium phosphate, diammonium phosphate, monoammonium phosphate and ammonium polyphosphate, respectively.

The effect of $CaCO_3$ on NH_3 production has already been discussed, but its interaction with fertilizer source is also important. Matocha (1976) found that topdressing lime with N caused more NH_3 loss from $(NH_4)_2SO_4$ than from $(NH_2)_2CO$ during the initial 48 hours following application. Pairintra (1973) concluded from his studies that fertilizers and allowable soil $CaCO_3$ percentage before serious seedling damage occurs are as follows: ammonium polyphsphate, 12.5% $CaCO_3$; monoammonium phosphate, 10.5%; diammonium phosphate, 3.5%; and urea ammonium phosphate exceeds the limit at 0% $CaCO_3$.

Effects of mixing low and high loss ammonium compounds have been studied by several researchers. Volk (1959) found that the average volatile losses of nitrogen as ammonia were 20.6% and 29.3% for pelleted and crystallized urea, respectively, during seven days following application of 100 pounds of urea-nitrogen to various grasses in field tests. The average loss following an equivalent application of NH_4NO_3 was 0.3%, and that following application of a solution containing 16.5% urea-nitrogen and 15.5% NH_4NO_3-N was 11.5%. Kresge and Satchell

(1960) observed that NH_4NO_3 mixed with urea in concentrated solutions reduced ammonia volatilization as compared to urea alone in solution. Fenn (1975) stated that losses of NH_3-N from surface applications of NH_4F and $(NH_4)_2SO_4$ to a calcareous soil were reduced by mixing either $NH_4H_2PO_4$ or NH_4NO_3 with these two compounds.

Conclusions: Ammonia is volatilized more readily from some nitrogenous fertilizers than others. Studies have shown the following order of loss: anhydrous ammonia $>$ urea $>$ NH_4OH $>$ $(NH_4)_2SO_4$ $>$ NH_4NO_3. Recent studies have shown an order of NH_3 loss as: urea ammonium phosphate $>$ diammonium phosphate $>$ mono-ammonium phosphate $>$ ammonium polyphosphate. High $CaCO_3$ percentage of the soil may accentuate these differences. Mixing low loss ammonium compounds with high loss ammonium compounds may result in less NH_3 volatilized than from high loss compounds alone.

OBJECTIVES

As has been pointed out in the literature review, ammonia volatilization and toxicity depend upon the chemical composition of fertilizers and the chemical and physical properties of soils. Most studies reported have examined only one or two variables with respect to their effect on ammonia volatilization. As a result of interactions between variables or failure to consider all variables, results have sometimes been inconsistent. Bennet and Adams (1970) stated that failure to consider adequately all equilibria has prevented many investigators from establishing generally applicable parameters for ammonia loss or toxicity. The study reported herein is an attempt to quantify the effects of fertilizer source, rate, soil $CaCO_3$ content, and soil moisture level as they relate to growth and development of irrigated barley grown in Montana.

Specific objectives of this study are to:

1. Determine the rate at which several ammonium phosphate fertilizers can be safely applied with barley seed under irrigated conditions.
2. Determine the magnitude of damage by several ammonium phosphate fertilizers including 1:1 ratio $N:P_2O_5$ mixtures of fertilizers with low and with high volatilization potentials.
3. Determine the effect of soil $CaCO_3$ content on damage caused by fertilizers banded with seed.
4. Determine the effect of soil moisture content at seed level on damage from banding fertilizers with seed.

5. Evaluate interactions between the aforementioned factors and assess their effect on NH_3 damage and overall crop performance.

6. Determine which measures of plant growth and development are the best indicators of ammonia damage.

This research is among the first on the effects of volatilized NH_3 on irrigated barley. It also includes one of the first major field tests of the volatilization potential of the experimental fertilizer urea ammonium polyphosphate (28-28-0).

MATERIALS AND METHODS

Field experiments designed to measure the effects of banding different ammonium phosphate fertilizers with irrigated barley seed were conducted at eleven locations in south-western Montana. Four experiments were initiated in the spring of 1974 by Dr. Charles M. Smith, former Professor and Extension Soil Scientist at Montana State University.[1/] In the spring of 1975 seven additional experimental sites were selected.

Site Selection

A number of factors were taken into consideration when choosing sites for the experiments. Uniformity of the experimental area was one of these factors. In particular, estimated variations in soil color, depth, texture, and slope within the proposed site were considered. Another factor was the willingness of the farmer to cooperate by allowing us to conduct our studies on the proposed site within his irrigated barley field. It was imperative that the cooperator be growing barley in the same field as the site because irrigation of the experiment was to done by the farmer.

One of the objectives of this study was to determine the effects of $CaCO_3$ content of the soil on NH_3 volatilization. In accordance with this, a wide range in $CaCO_3$% between the different locations was sought.

[1/] Dr. Smith is currently Chairman of the Soils Department at North Dakota State University, Fargo, N.D.

In order to get an approximation of the $CaCO_3$ equivalent of a location, a field volume calcimeter as described by Black[2/] was used. A description of the basic procedure follows. A sample is weighed into the barrel of a 50 ml syringe and the plunger inserted. Approximately 4N HCl is inserted into this syringe from a 5 ml syringe attached to its tip by a 1/2 inch length of 1/8 inch I.D. tubing. CO_2 evolves from the sample and forces back the plunger. The volume of gas evolved is read from the syringe markings. Corrections for temperature and elevation are made by adjusting the sample weight. The adjusted volume of CO_2 evolved is equivalent to the $CaCO_3$ content of the sample in percent.

As a matter of simplification, individual locations will be designated by a two digit number. Those ending in 4 (14, 24, 34,44) were studies conducted in 1974. Those ending in 5 (15, 25, 35, 45, 55, 65, 75) were studies conducted in 1975. Certain location specifics are listed in Table. I.

Table 1. Location specifics for 1974 and 1975

Number	Cooperator	Address	Barley Variety	Date Seeded	Type of Irrigation
14	L. Flikkema	Belgrade	Compana	5-6-74	Hand-line sprinkler
24	B. Booher	Townsend	Firlbecks	5-1-74	Flood
34	C. Diehl	Townsend	Moravian	4-26-74	Side-Wheel roll sprinkler

[2/] Methods of Soil Analysis, C.A. Black, Ed. ASA Monograph 9. 1965.

Table 1. (continued)

Number	Cooperator	Address	Barley Variety	Date Seeded	Type of Irrigation
44	R. Lee	Fairfield	Shabet	5-2-74	Hand-line sprinkler
15	D. Boylan	Bozeman	Moravian	5-30-75	Side-wheel roll sprinkler
25	A. Kimm	Churchill	Moravian	5-28-75	Hand-line sprinkler
35	T. Visser	Amsterdam	Piroline	5-27-75	Hand-line sprinkler
45	D. Quinn	Dillon	Ingrid	5-29-75	Hand-line sprinkler
55	B. Booher	Townsend	Unitan	5-26-75	Flood
65	S. Marks	Townsend	Moravian	6-3-75	Side-wheel roll sprinkler
75	D. Burnham	Helena	Klages	6-2-75	Side-wheel roll sprinkler

Soil Sampling and Test Results

Before the results of a field experiment can be fully understood, a number of factors other than the effects under study must be considered. For this reason numerous tests were conducted on soil samples taken from each location. Samples were taken within each replication of each experiment before any fertilizer applications were made. Samples for NO_3^--N analysis were taken with a 4-foot Veimeyer king tube at 30.5 cm depth intervals. Samples were placed on dry ice until placed in the oven for drying. Other samples were taken with an Oakfield Sampler to a depth of 15 cm. The Oakfield Sampler was also used to take samples in the fertilizer-seed band to determine moisture content of the soil at seed level. The seed-level moisture samples were also placed on dry ice until weighed and placed in the drying oven.

All samples were analyzed by the Montana State University Soil Testing Laboratory. Nitrate-Nitrogen was analyzed by the Phenoldisulfonic Acid method. Phosphorus was determined by the 1:50 ratio Bray #1 method. Potassium, calcium, magnesium, and sodium were extracted with 1N Ammonium Acetate and determined by atomic absorption spectrometry. Soil texture was estimated by the hand feel method. Organic matter content was analyzed by the Walkley-Black method. For outlines of these procedures see Black.[3/] Soil pH and salt content were analyzed according to the 2:1 saturation method as described in Handbook 60.[4/] Method 23b of Handbook 60 was used to determine $CaCO_3$ equivalent in the laboratory. Results of these analyses are listed in Tables 2 and 3. At location 75, only the top 30.5 cm of soil was analyzed for NO_3^--N content. Soil texture at location 75 and seed-level soil moisture at locations 24, 34, 44, and 55 were not determined.

[3/] Methods of Soil Analysis. C. A. Black, ed. ASA Monograph 9, 1965.

[4/] Diagnosis and Improvement of Saline and Alkaline Soils. Agr. Handbook 60. U.S.D.A., 1969.

Table 2. Soil test results

Location Number	Total NO_3^--N to 4'	P	K	pH	Salt	O.M.	Ca	Mg	Na	Soil Texture
	kg/ha	ppm	ppm		mmhos	%	----meq/100g---			
14	46	26	612	8.1	0.8	3.03	46.7	5.9	0.4	Clay loam
24	50	55	1134	7.9	2.7	3.41	39.4	5.2	1.2	Clay loam
34	29	23	451	8.2	0.8	1.82	40.3	6.5	0.6	Loam
44	9	38	696	7.8	0.8	2.06	19.2	7.9	0.5	Clay loam
15	11	19	340	7.7	0.7	2.63	17.4	5.0	0.2	Silty clay loam
25	161	34	528	7.9	0.8	3.83	26.1	4.2	0.1	Clay loam
35	66	16	355	8.2	0.6	2.60	38.1	3.7	0.1	Loam
45	76	24	216	8.3	0.8	2.00	34.8	4.5	0.3	Silty clay loam
55	26	49	675	8.1	0.9	2.84	65.7	6.9	0.3	Clay loam
65	34	31	594	8.3	0.9	2.19	38.6	5.5	0.2	Silty clay loam
75	20	34	448	7.5	0.5	1.52	13.2	7.2	0.5	----------

Table 3. Soil $CaCO_3$ equivalent and seed-level soil moisture at planting.

Location Number	--------$CaCO_3$ Equivalent-------				Seed-Level Soil Moisture
	-------Replication-----				
	I	II	III	$\overline{X}$	
	%	%	%	%	%
14	8.4	6.6	8.3	7.8	18.8
24	4.7	4.4	7.0	5.4	----
34	4.1	5.1	4.6	4.6	----
44	1.1	0.8	0.5	0.8	----
15	1.2	2.3	5.5	3.0	22.3
25	16.6	9.0	12.3	12.6	17.9
35	11.6	12.6	8.9	11.1	18.4
45	17.1	11.0	17.1	15.1	19.3
55	16.3	8.1	5.9	10.1	----
65	13.9	12.1	9.4	11.8	22.1
75	0.6	0.2	0.3	0.4	14.1

The soils at the experimental sites were medium to medium-fine textured. All locations except number 25 had NO_3^--N levels low enough to expect a yield response to nitrogen fertilizer. Most locations were low to very low in available phosphorus and medium to high in extractable potassium. Soil pH ranged from 7.5 to 8.3 (slightly to moderately alkaline). Salt contents were low for all locations except 24 which was slightly salty. Because barley is relatively tolerant to saline conditions, no adverse effects of salinity would be expected at location 24. Soil organic matter (O.M.) ranged from 1.52 to 3.83% and should be considered low. Soil $CaCO_3$ equivalent ranged from 0.8 to 7.8% in 1974 and from 0.4 to 15.1% in 1975. Variation in $CaCO_3$% between replications within 1975 locations was substantial as can be seen in Table 3.

Experimental Design

Tables 4 and 5 list fertilizer treatments used in 1974 and 1975, respectively. In 1974 (Table 4), comparison of treatments 3, 16, 4, 20, and 21 show increasing rates of N at constant rates of P and K and were used to evaluate nitrogen response. Phosphorus response was evaluated at constant N and K rates by comparison of treatments 13, 14, 15, 2 and 4. Potassium response was evaluated at constant N and P rates by comparing treatment 19 with 15, 2 and 4. In 1975 (Table 5), N response was determined by comparison of treatments 2, 3,

Table 4. List of treatments for 1974

Treatment Number	Fertilizer Treatments[1/] N (kg/ha) Bdc	Drill	Sum	P (kg/ha) Bdc	Drill	Sum	K (kg/ha) Bdc	Kind of Fertilizer[2/]
1	--	--	--	--	--	--	--	Check
2	78	11	89	34	--	34	45	1-2-3
3	--	11	11	34	25	59	45	2-3-6
4	78	11	89	34	25	59	45	1-2-3-6
5	78	11	89	34	13	47	45	1-2-3-7
6	78	11	89	34	5	39	45	1-2-3-8
7	67	22	89	34	49	83	45	1-2-3-6
8	67	22	89	34	25	59	45	1-2-3-7
9	67	22	89	34	10	44	45	1-2-3-8
10	56	33	89	34	74	108	45	1-2-3-6
11	56	33	89	34	38	72	45	1-2-3-7
12	56	33	89	34	15	49	45	1-2-3-8
13	78	11	89	--	--	--	45	1-3
14	78	11	89	--	13	13	45	1-2-3
15	78	11	89	--	25	25	45	1-3-6
16	33	11	44	34	25	59	45	1-2-3-6
17	33	11	44	34	25	59	45	2-3-4-6
18	33	11	44	34	25	59	45	2-3-4-6
19	78	11	89	34	25	59	--	1-2-6
20	123	11	134	34	25	59	45	1-2-3-6
21	168	11	179	34	25	59	45	1-2-3-6
22	33	11	44	34	25	59	45	2-3-5-6

[1/]Treatments 2, 18, and 22 have broadcast N topdressed after seeding. Treatment 20 has 45 kg N/ha topdressed after seeding and treatment 21 has 90 kg N/ha topdressed.
Treatment 22 has 3 kg S/ha.

[2/]
1. 34-0-0 ammonium nitrate
2. 0-45-0 treble superphosphate
3. 0-0-60 muriate of potash
4. 45-0-0 urea
5. 40-0-0-4(S) urea ammonium sulfate (UAS)
6. 11-55-0 monoammonium phosphate (MAP)
7. 18-46-0 diammonium phosphate (DAP)
8. 28-28-0 urea ammonium polyphosphate (UAPP)

11, 9, and 10. Treatments 5, 6, 7, 8, and 11 were used to evaluate P response. Response to K was determined by comparing treatment 4 to treatment 11. Several rates of nitrogen and phosphorus were used to determine the optimum rate of application for the cooperator in his particular field and for response data for this study. All treatments received 45 kg/ha of K broadcast and incorporated before seeding since irrigated barley often responds to K fertilizer at soil test levels greater than 250 ppm K. Treatments 17, 18 and 22 in Table 4 were for use in other studies being conducted by the Montana Cooperative Extension Service and have no bearing on this study. They are included here only as a source of reference for future use.

The ammonium phosphate fertilizers included in 1974 were monoammonium phosphate (11-55-0), diammonium phosphate (18-46-0), and urea ammonium polyphosphate. These fertilizers were drill applied in a band with barley seed at rates of 11, 22, and 33 kg/ha of N. This is shown in treatments 4 through 12 in Table 4. In 1975 these same fertilizers were banded with the seed at rates of 11, 22, 33, and 44 kg/ha of N. A mixture of urea + diammonium phosphate was also applied at these same rates and a mixture of ammonium nitrate and monoammonium phosphate was drill applied in a band with barley seed at rates of 22 and 44 kh/ha of N. The 1975 ammonium phosphate treatments are numbers 11 through 28 in Table 5. In both 1974 and 1975, the total N rate on treatments used to compare ammonium phosphate fertilizers was

Table 5. List of treatments for 1975

Treatment Number	Fertilizer Treatments[1/] N (kg/ha) Bdc	Drill	Sum	P (kb/ha) Bdc	Drill	Sum	K (kg/ha) Bdc	Fertilizer[2/]
1	--	--	--	--	--	--	--	Check
2	--	11	11	39	25	64	45	2-3-4
3	33	11	44	39	25	64	45	1-2-3-4
4	78	11	89	39	25	64	--	1-2-4
5	78	11	89	--	--	--	45	1-3
6	78	11	89	--	13	13	45	1-3-4
7	78	11	89	--	25	25	45	1-3-4
8	78	11	89	39	--	39	45	1-2-3
9	123	11	134	39	25	64	45	1-2-3-4
10	168	11	179	39	25	64	45	1-2-3-4
11	78	11	89	39	25	64	45	1-2-3-4
12	78	11	89	39	13	52	45	1-2-3-5
13	78	11	89	39	5	44	45	1-2-3-6
14	78	11	89	39	5	44	45	1-2-3-7
15	67	22	89	39	49	88	45	1-2-3-4
16	67	22	89	39	25	64	45	1-2-3-5
17	67	22	89	39	10	49	45	1-2-3-6
18	67	22	89	39	10	49	45	1-2-3-7
19	56	33	89	39	74	113	45	1-2-3-4
20	56	33	89	39	38	77	45	1-2-3-5
21	56	33	89	39	15	54	45	1-2-3-6
22	56	33	89	39	15	54	45	1-2-3-7
23	45	44	89	39	99	138	45	1-2-3-4
24	45	44	89	39	50	89	45	1-2-3-5
25	45	44	89	39	20	59	45	1-2-3-6
26	45	44	89	39	20	59	45	1-2-3-7
27	67	22	89	39	10	49	45	1-2-3-8
28	45	44	89	39	20	59	45	1-2-3-8

[1/]Treatments 18, 26, 27, and 28 were omitted for locations 65 and 75. Locations 45 and 65 had 78 kg P/ha broadcast before seeding.

89 kg/ha. As N rates drill applied in a band with the barley seed increased, broadcast rates were reduced an equivalent amount. Broadcast N was applied as ammonium nitrate (34-0-0) and incorporated into the soil before seeding. To overcome the effects of variable rates of band-applied P established when ammonium phosphates were banded at equivalent N rates, treble superphosphate (0-45-0) was broadcast and incorporated before seeding at rates thought to be sufficient to meet the P requirement of the crop.

Treatments were arranged in a randomized complete block design with three replications. Plots were 2.1 meters wide (7 rows) by 9 meters long. At locations where side-wheel roll sprinkler irrigation systems were used, 2.1 meter wide seeded alleys were left where needed for the wheels to move through without disturbing the plots. In 1975, treatments 13 and 25 were placed adjacent to each other in one replication at each location. It was hoped that if differences existed in the growth of the barley plants on these plots, they could be shown to local farmers on tours conducted by the Montana Cooperative Extension Service.

2/1. 34-0-0 ammonium nitrate
2. 0-45-0 treble superphosphate
3. 0-0-60 muriate of potash
4. 11-55-0 monoammonium phosphate (MAP)
5. 18-46-0 diammonium phosphate (DAP)
6. 28-28-0 urea ammonium polyphsophate (UAPP)
7. urea + DAP (1:1 ratio $N:P_2O_5$)
8. ammonium nitrate + MAP (1:1 ratio $N:P_2O_5$)

Seeding and Management of Experiments

Prior to seeding, Fargo (Triallate) E.C. herbicide was applied as a pre-emergent spray at a rate of 1.4 kh/ha active ingredient for wild oat control. The spray equipment was inoperative when location 65 was seeded. At this location, Avenge (difenzoquate) herbicide was applied as a post-emergent spray when wild oats plants (Avena fatua L.) were in the 4-leaf stage of growth, but control was ineffective at this location. Nitrogen, phosphorus, and potassium fertilizer treatments in excess of the ammonium phosphates to be banded with the seed were broadcast and incorporated into the soil with duckfoot shovels and a springtooth harrow prior to seeding. Seeding and simultaneous drill fertilizer application were done with a modified Minneapolis Moline deep furrow press drill with 30 cm row spacings. Spreaders attached to the bottoms of the seed spouts produced a fertilizer-seed pattern approximately 6.5 cm wide within the row. Seeding dates and barley varieties used are shown in Table 1. Barley varieties were those being grown by the farmer and were seeded at a rate of approximately 100 kg/ha. Irrigation at all locations was conducted by the farmer during the course of his regular irrigations.

Measurement of Crop Response to Treatments

In order to determine the occurrence and extent of ammonia damage to irrigated barley plants, a number of crop response variables were measured at different stages of plant growth. Smith et al. (1968-1972) and Pairintra (1973) showed that ammonia damage occurred within the first few days after seeding in field studies with wheat. In order to measure this initial damage, selected response variables were measured at tillering stage (Feekes stage 2)[1/] in 1974 and at boot stage (Feekes stage 10) in 1975. Besides final harvest measurements of grain yield, several other crop response variables were measured at harvest. These measurements were designed to show if ammonia damage could still be determined at plant maturity and to determine whether plants compensated for the initial damage during their development. Table 6 presents the crop response variables measured at each location in 1974 and 1975.

Tillering (1974) and boot stage (1975) measurements consisted of determining the number of plant culms, plant height, number of plants (stand counts), weight of roots, and weight of tops. This was conducted as follows. Two meter lengths of each of two rows of plants were removed from the respective plots. Samples were kept frozen until ready for measurement. After thawing, soil was washed from the plant roots and roots were separated from the rest of the plant at the base of the plant crown. Number of culms and number of plants were counted. Plant height was measured as the distance from the base of

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[1/]Large, E. C. 1954. Growth Stages in Cereals. Illustration of Feekes Scale. Plant Path. 3:128-129.

Table 6. Crop Response Variables Measured in 1974 and 1975.

Measured Variable	Experimental Location										
	14	24	34	44	15	25	35	45	55	65	75
Grain yield (kg/ha)	x	x		x	x	x	x	x	x	x	
Dry matter (kg/ha)	x	x		x	x	x	x	x	x	x	
Test weight (kg/hl)	x	x		x	x	x	x	x	x	x	
Protein percent	x	x		x	x	x	x	x	x	x	
P percent mature	x	x		x							
Total P uptake mature (kg/ha)	x	x		x							
Plump percent	x	x		x	x	x	x	x	x	x	
Straw:grain ratio	x	x		x	x	x	x	x	x	x	
Number of spikes/meter row	x		x	x	x	x	x	x	x	x	
Number of culms /meter row1/	x	x	x	x	x	x	x	x		x	x
Number of culms /meter row2/	x		x	x	x	x	x	x	x	x	
Plant height (cm)	x	x	x	x	x	x	x	x		x	x
Kernel weight (g/1000)	x	x		x	x	x	x	x	x	x	
Kernels /spike	x	x		x	x	x	x	x	x	x	
Stand count / meter row1/	x	x	x	x	x	x	x	x		x	x
Stand count / meter row2/	x		x	x							
Spikes/ plant	x	x		x	x	x	x	x	x	x	
Grain weight /spike (g)	x	x		x	x	x	x	x	x	x	
Root weight (g/ha)	x	x	x	x	x	x	x	x		x	x
Top weight (kg/ha)1/	x	x	x	x	x	x	x	x		x	x
Top weight (kg/ha)2/	x		x	x							
P percent roots	x	x	x	x							
P percent tops	x	x	x	x							
Total P roots (g/ha)	x	x	x	x							
Total P tops (kg/ha)	x	x	x	x							

1/ measured at tillering in 1974 and at boot in 1975.

2/ measured at harvest both years.

the plant crown to the tips of the longest leaf when straightened out. Roots and tops of plants were placed in separate sacks and dried for at least 48 hours at 82°C for determination of root and top dry weight.

Crop response measurements at maturity were number of spikes, number of culms, number of plants, and top weight in 1974. In 1975, only number of spikes and number of culms were counted so that the measurements could be made directly in the field. Procedures were the same as for the first counts in 1974. In 1975, sample size was reduced to one meter of two separate rows.

Three rows (5.0 to 5.6 m^2) of each plot were harvested for grain yields and associated data. Length of the rows harvested was dependent on points at which the drill stopped and started at the edge of each plot during planting. The rows were cut with a Jari mower modified with metal catch pans to hold the plants as they were being cut at ground level. At the end of each plot the bundles were removed from the pans, weighed, and the grain separated from the straw in a cylinder type plot thresher. Kernels per spike, spikes per plant, and grain weight per spike were calculated using variables measured in previous counts and at final harvest.

Location 55 provided no boot stage measurements because of a combination of rain and flood irrigation through this period. Location 75 was accidentally swathed by the cooperator prior to harvest and final measurements and therefore only the boot stage counts were made. Locations 24 and 34 were both damaged by hail just prior to harvest and have some data missing where damage was great enough to interfere with accuracy. Phosphorus uptake was not determined in 1975 due to a lack of time to analyze plant tissues for phosphorus.

Statistical Analysis

After all crop response variables had been measured and tabulated, data for each variable at each location were subjected to a standard analysis of variance. Where the F statistic indicated statistically significant treatment differences, treatment means were compared using the least significant difference (L.S.D.) at the 5% probability level. Table 7 lists the degrees of freedom for the crop response variables measured in 1974 and 1975.

Table 7. AOV degrees of freedom for crop response variables measured in 1974 and 1975.

	Degrees of Freedom					
	1974		1975			
Source	grain data	counts	grain data1/	grain data2/	counts1/	counts3/
Replications	2	2	2	2	2	2
Treatments	21	14	27	23	23	19
Error	42	28	54	46	46	38
Total	65	44	83	71	71	59

1/ locations 15, 25, 35, 45, 55
2/ location 65
3/ locations 65 and 75

To evaluate the effects of banded N rate, fertilizer source, and N rate x source interactions, crop response variables were regressed on N rate for each fertilizer source at each location. Because crop response to banded N is often curvilinear (Smith et al., 1969-1972 and Pairintra, 1973), quadratic equations relating the measured variables to banded N rate were fitted according to the method of least squares. Form of the fitted regression equation was $Y = a + b_1x + b_2x^2$; where Y is the predicted value of the measured variable, x is the banded nitrogen fertilizer rate, a is the intercept, and b_1 and b_2 are the partial regression coefficients. An F statistic was calculated to determine if regression lines for each of the fertilizer sources were significantly different from the regression line for all sources. Crop response variables analyzed in this manner were: grain yield, dry matter yield, straw/grain ratio, number of spikes, number of culms (both early season and harvest measurements), plant height, 1000 kernel weight, kernels/spike, stand counts (both early season and harvest measurements), spikes/plant, grain weight/spike, root weight, and top weight (both early season and harvest measurements where applicable).

To estimate the effect of soil $CaCO_3$ equivalent on ammonia damage, measured variables averaged over N rate or fertilizer source were linearly regressed on soil $CaCO_3$ means for each location within a crop year. This approach proved to be unsatisfactory since between location variation associated with other factors masked $CaCO_3$ effects.

In an attempt to remove some of the between location variation, relative values of the measured variables were calculated. Treatments receiving monoammonium phosphate at a rate of 11 kg/ha of N drill applied with the seed were assigned a value of 100 and relative values for other fertilizer sources and rates were calculated as follows:

$$\text{Relative value} = \frac{\text{Measured value for each fertilizer source and rate}}{\text{Measured value for monoammonium phosphate at 11 kg of N/ha}} \times 100.$$

The relative values averaged over N rates, or in separate analysis over fertilizer sources, were then linearly regressed on soil $CaCO_3$ means for each location within a crop year.

Preliminary analysis had shown that tillering or boot stage stand counts and top weight were among the better crop response variables for assessing ammonia damage to plants. These two response variables along with final grain yield were subjected to analysis of variance across locations within a year (1974 and 1975 analyzed separately). Because soil $CaCO_3$ effects were confounded with locations and not easily evaluated, use was made of the variation in $CaCO_3$ equivalent (see Table 3) between replications within location to assess the impact of this variable. Partitioning the sums of squares in this manner eliminated replications at each location and left no degrees of freedom for estimating error variance. To test the significance of some main effects and interactions, one main effect was used as a replication and the variance estimates from its two way and three way interactions with location were used as an "error" variance in calculating an F statistic. Repeating this process using a different main effect each time permitted testing the significance of all main effects and interactions as shown in Table 8.

The analysis of variance in Table 8 showed that the three way interaction location x rate x source was not significant. Therefore, in order to test the significance of all main effects and two way interactions with the same error variance, the analysis of variance was repeated using the variance estimate from the 3-factor interaction as an "error" variance in calculating the F statistics. Table 9 shows the degrees of freedom with the 3-factor interaction used as an error estimate.

Table 8. Degrees of freedom for analysis of variance with one main effect used as error estimate.

				Degrees of Freedom					
				1974		1975			
	Factor	Stand count		Stand Count		Top Weight		Yield	
Source	Confounded	& Topweight	Yield	A	B	A	B	A	B
Location (L)		3	2	6	4	5	3	5	4
Fert. Rate (R)		2	2	3	3	3	3	3	3
$CaCO_3$ within locations (C)	Fert. Sources (S)	8	6	14	10	12	8	12	10
L x R		6	4	18	12	15	9	15	12
C x R		16	12	42	30	36	24	36	30
Error L x S		6	4	12	12	10	9	10	12
L x R x S		12	8	36	36	30	27	30	36
Location (L)		3	2	6	4	5	3	5	4
Fert. Source (S)		2	2	2	3	2	3	2	3
$CaCO_3$ with location (C)	Fert. Rate (R)	8	6	14	10	12	8	12	10
L x S		6	4	12	12	10	9	10	12
C x S		16	12	28	30	24	24	24	30
Error L x R		6	4	18	12	15	9	15	12
L x R x S		12	8	36	36	30	27	30	36
Location (L)		3	2	6	4	5	3	5	4
Fert. Rate (R)		2	2	3	3	3	3	3	3
Fert. Source (S)	$CaCO_3$	2	2	2	3	2	3	2	3

Table 8. (continued)

Source	Factor Confounded	Stand count & Topweight	Yield	Degrees of Freedom: 1974 Stand Count A	1974 Stand Count B	1975 Top Weight A	1975 Top Weight B	1975 Yield A	1975 Yield B
L x R	within	6	4	18	12	15	9	15	12
L x S	location (C)	6	4	12	12	10	9	10	12
R x S		4	4	6	9	6	9	6	9
L x R x S		12	8	36	36	30	27	30	36
Error C		8	6	14	10	12	8	12	10
C x R		16	12	42	30	36	24	36	30
C x S		16	12	28	30	24	24	24	30

A. Excludes urea and DAP as fertilizer source on locations 65 and 75.
B. Includes all four fertilizer sources on locations 15, 25, 35, 45, and 55.

Table 9. Degrees of freedom for analysis of variance with 3-factor interaction used to estimate error.

	Degrees of Freedom							
	1974		1975					
	Stand Count		Stand Count		Topweight		Yield	
Source	& Topweight	Yield	A	B	A	B	A	B
Location (L)	3	2	6	4	5	3	5	4
Fert. Rate (R)	2	2	3	3	3	3	3	3
Fert. Source (S)	2	2	2	3	2	3	2	3
$CaCO_3$ within location (C)	8	6	14	10	12	8	12	10
L x R	6	4	18	12	15	9	15	12
L x S	6	4	12	12	10	9	10	12
R x S	4	4	6	9	6	9	6	9
R x C	16	12	42	30	36	24	36	30
S x C	16	12	28	30	24	24	24	30
Error L x R x S	12	8	36	36	30	27	30	36

A. Excludes urea and DAP as a fertilizer source on locations 65 and 75

B. Includes all four fertilizer sources on locations 15, 25, 35, 45, and 55.

RESULTS AND DISCUSSION

While the main objective of the experiments was to determine the effects of banding ammonium phosphate fertilizers with the seed of irrigated barley, data showing responses to N, P, and K fertilizers were obtained. For this reason, this section is divided into two parts; the first is a brief summary of the kinds of N, P, and K responses obtained and the second is the main discussion of NH_3 damage.

Response to N, P, and K Fertilization

Table 10 shows grain yield as influenced by nitrogen fertilizer additions. Locations 34 and 75 produced no grain. Location 24

Table 10. Response of barley grain yield to nitrogen fertilization.

Nitrogen[1/] Fertilizer Rate	Grain Yield								
	Location Number								
	14	24	44	15	25	35	45	55	65
kg/ha	kg/ha								
11	2857	1712	3046	2272	3678	4226	4465	3781	2118
45	3397	1665	3529	3283	3187	4570	4478	3681	2502
90	4299	1906	4630	4287	3387	4357	4266	4450	3207
134	4480	2224	4711	4383	3167	4191	4244	4143	2794
179	4303	2110	4682	3648	3245	4376	4443	4095	2794
$LSD_{.05}$	633	339	918	720	510	629	783	879	553

1/Nitrogen fertilizer applied as follows: 11 kg/ha drill applied with the seed, as monoammonium phosphate (11-55-0), remainder broadcast as ammonium nitrate (34-0-0) to equal total shown in table.

2/Locations 14, 24, and 44 had 34 kg P/ha and 45 kg K/ha broadcast and incorporated before seeding plus 25 kg P/ha banded with the seed. Locations 15, 25, 35, and 55 had 39 kg P/ha and 45 kg K/ha broadcast was damaged by hail which resulted in low yields and location 65 had bad weed infestations which reduced yields. Most locations had a significant response to additions of nitrogen fertilizer. Location 25 had a total NO_3^--N content to a 122 cm depth of 161 kg/ha which was high enough that no response was expected. It is not certain why location 45 did not respond to N fertilizer. Soil test NO_3^--N and organic matter % were low and responses were expected. Table 11 shows the relationships between total NO_3^--N and O.M.%, recommended N fertilizer rates, and the applied N fertilizer rate at which highest yields were obtained.

Table 11. Comparison of total measured NO_3^--N and organic matter to recommended N rates and N rates at which highest yields were obtained.

Location Number	Total NO_3^--N to 122 cm	Organic Matter	N fertilizer[1/] Recommendation	Fert. rate with highest yield
	kg/ha	%	kg/ha	kg/ha of N
44	9	2.06	134-168	134
15	11	2.63	134-168	134
55	26	2.84	134-168	90
65	24	2.19	106-134	90
14	46	3.03	106-134	134
24	50	3.41	106-134	134
35	66	2.60	106-134	45
45	76	2.00	78-106	45
25	161	3.83	11-45	11

1/ Based on Fertilizer Guide for Irrigated Cereal Grain. Montana Cooperative Extension Service. 1974.

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and incorporated before seeding plus 25 kg P/ha banded with seed. Locations 45 and 65 had 78 kg P/ha and 45 kg K/ha broadcast and incorporated before seeding plus 25 kg P/ha banded with seed.

Most responses correlated well with recommended rates based on soil test information. Highest yields were obtained at most locations with 90 to 134 kg/ha of N. Those that produced their highest yields at lower rates were also highest in soil test NO_3^--N. If any inconsistency exists, it is that the recommended rates tended to be slightly higher than the actual highest yielding rates.

Additions of phosphorus fertilizer were made by broadcasting and drill application at increasing rates. Table 12 shows response of grain yield to phosphorus fertilization.

Table 12. Response of barley grain yield to phosphorus fertilization.

Phosphorus Fert. Rate[1/]		Grain Yield								
		Location Number								
Bdc[2/]	Dr	14	24	44	15	25	35	45	55	65
--kg/ha--		kg/ha								
0	0	3942	1637	4140	2682	3263	2921	4229	3876	2657
0	13	4547	1902	4210	3800	3148	4127	4551	4060	2626
0	25	3893	2127	4417	3763	3068	3973	4293	4287	2990
34-78	0	3820	1914	3714	3653	3236	3908	4656	3889	2653
34-78	25	4299	1906	4630	4287	3387	4357	4266	4450	3176
LSD.05		633	339	918	720	519	629	783	879	553

1/ P broadcast and incorporated before seeding as treble superphosphate (0-45-0) and banded as monoammonium phosphate (11-55-0). All treatments received 89 kg N/ha.

2/ Locations 14, 24, and 44 had 34 kg P/ha broadcast, locations 15, 25, 35, and 55 had 39 kg P/ha broadcast, locations 45 and 65 had 78 kg P/ha broadcast.

Locations 14, 24, 15 and 35 had statistically significant differences between treatment means. Most locations had highest yields with drill applied or a combination of drill applied and broadcast P as opposed to broadcast P alone. Soils at all locations tested low to very low in available phosphorus and responses were expected.

Soil tests revealed that extractable potassium levels were high at all locations in 1974 and 1975. Even so, responses to additions of 45 kg/ha of K were obtained at most locations as shown in Table 13. Location 24 was the only one not showing increased grain yield due to K fertilization. It is possible that hail damage may be the reason for this lack of response. Locations 25, 45 and 55 had increased yields which were not statistically significant at the 5% probability level. Increases in kernel plumpness with potassium were evident at several locations as shown in Table 13. Locations 14, 45, and 55 did not show increases in kernel plumpness with additions of K fertilizer. It is possible that factors, particularly climatic ones, were responsible for this. Also, location 14 was planted to a feed grain barley variety as opposed to malting barley varieties at the other locations.

Complete data and least significant difference values at the 5% probability level for all treatments at each location are listed in appendix tables. It is hoped that this data will be of value in refining soil test corrleations for irrigated barley.

Table 13. Response of barley grain yield and kernel plumpness to potassium fertilization.

Potassium Fert. Rate[1/]	Location Number								
	14	24	44	15	25	35	45	55	65
kg/ha	Grain Yield (kg/ha)								
0	3920	2023	4236	3887	2972	3985	4085	3820	2834
45	4299	1906	4630	4287	3387	4357	4266	4450	3707
$LSD_{.05}$	633	339	918	720	519	629	783	879	553
	Kernel Plumpness (%)								
0	93.1	89.5	91.4	90.3	70.3	78.9	70.4	79.2	75.8
45	92.0	92.5	93.6	94.3	73.8	83.8	69.6	78.5	79.8
$LSD_{.05}$	3.9	5.2	3.8	3.0	8.9	4.5	13.6	4.9	4.5

1/ K broadcast before seeding as muriate of potash (0-0-60). All locations received 89 kg N/ha and from 34 to 78 kg P/ha broadcast plus 25 kg P/ha banded with seed.

Ammonia Damage

The remainder of this section consists of discussion of the effects of banding different rates and sources of ammonium phosphate fertilizers with the seed of irrigated barley at 11 locations. For the purpose of organization and simplification this section is divided into subsections based upon the different factors taken into consideration during the course of this study. Some repetition of the results was necessary because some data provided information for more than one factor.

Moisture Differences

In field experiments of this type, climatological factors can be of the utmost importance. Recent studies have shown that the effects of soil moisture on ammonia volatilization are both profound and complicated (Fenn and Escarzaga, 1976). Since ammonia damage occurs in the first few days after planting (Pairintra 1973), it can be assumed that precipitation a few days prior to and just after planting will have an important effect. Subsequent rainfall during the growing season could influence compensation, if any, by the barley plant to earlier damage. Table 14 lists rainfall amounts at all locations in 1974 and 1975 during April 1 to September 30.

Numbers shown are the weekly total precipitation in centimeters. Rainfall data were collected at the nearest National Oceanic and Atmospheric Administration meterological station.[5/] In 1974, data for location 14 was obtained from Belgrade, Montana; locations 24 and 34 from Townsend; location 44 from Fairfield, Montana. In 1975, location 15 rainfall was obtained from the Agricultural Experiment Station at Bozeman; locations 25 and 35 from Manhattan, Montana; locations 45 from the Dillon airport; locations 55 and 65 from Townsend, Montana; and locations 75 from 6 miles north of Helena, Montana. Differences

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5/ Climatological Data. Montana. Vol. 77 and 78. U.S. Dept. of Commerce. National Oceanic and Atmospheric Administration. 1974 and 1975.

Table 14. Total weekly rainfall from April 1 to September 30 at selected locations in 1974 and 1975.

		Rainfall (cm)							
		Location Number							
Date		14	24&34	44	15	25&35	45	55&65	75
April	1-7	0.25	0.15	0.10	0.43	0.79	0.51	0.86	1.14
	8-14	0.18	0.08	0.10	0.43	0.46	0.28	----	0.25
	15-21	0.05	0.13	----	0.46	0.58	0.38	----	0.03
	22-30	0.74	0.38	0.25	1.85	1.27	4.09	3.35	6.55
	Total	1.22	0.74	0.45	3.17	3.10	5.26	4.21	7.97
May	1-7	0.05	----	----	6.58	6.15	4.62	3.28	2.64
	8-14	0.69	1.02	1.91	2.01	1.45	0.03	0.94	0.58
	15-21	2.24	0.81	----	1.35	0.69	----	0.20	0.58
	22-31	3.23	1.78	0.66	0.41	0.28	----	0.64	0.30
	Total	6.21	3.61	2.57	10.35	8.57	4.65	5.06	4.10
June	1-7	0.38	----	0.25	0.71	0.18	0.89	0.56	----
	8-14	0.08	0.13	1.07	2.79	3.30	0.15	1.30	1.17
	15-21	0.18	0.69	----	0.94	1.70	4.72	4.34	4.37
	22-30	0.05	----	----	2.46	2.01	0.18	1.37	0.20
	Total	0.69	0.82	1.32	6.90	7.19	5.94	7.57	5.74
July	1-7	1.60	0.46	----	----	----	0.03	0.76	0.86
	8-14	0.69	0.74	1.32	0.15	----	1.60	0.81	0.08
	15-21	0.28	----	0.25	2.01	1.40	0.71	0.91	2.54
	22-31	0.08	----	----	4.24	2.95	3.53	4.65	3.40
	Total	2.65	1.20	1.57	6.40	4.35	5.87	7.13	6.88
Aug.	1-7	1.50	0.86	1.78	1.22	----	----	----	2.27
	8-14	2.03	1.60	3.38	0.56	0.76	0.58	0.05	0.51
	15-21	0.94	4.88	3.05	1.12	1.02	0.25	0.53	2.31
	22-31	----	----	----	1.07	0.41	0.10	1.45	1.09
	Total	4.47	7.34	8.21	3.97	2.19	0.93	2.03	6.18
Sept.	1-7	0.79	1.04	1.75	1.27	0.64	0.08	1.07	0.71
	8-14	1.60	0.51	0.48	----	----	----	----	----
	15-21	----	----	0.05	1.35	0.97	0.46	0.58	0.61
	22-30	0.79	----	----	----	----	----	----	0.10
	Total	3.18	1.55	2.28	2.62	1.61	0.54	1.65	1.42
Season Total		18.42	15.26	16.40	33.41	27.01	23.19	27.65	32.29

between actual rainfall at the experimental sites and measured rainfall at the given stations could exist, but conclusions as to rainfall patterns and differences between the two years can be reached.

It is evident from Table 14 that considerably more precipitation occurred in 1975 as compared to 1974 at all locations. To further verify this, Table 15 shows the departure from mean monthly precipitation for both years at selected locations. These data were not available for locations 44, 25 and 35.

Table 15. Departure from mean monthly precipitation for 1974 and 1975.

	Departure from Mean Monthly Precipitation (cm)					
	Location Number					
Month	14	24&34	15	45	55&65	75
April	-1.73	-1.42	-0.02	+3.18	+2.06	+5.26
May	+0.86	-1.04	+5.61	+0.43	+0.41	+0.48
June	-6.22	-5.44	+0.61	+0.25	+1.32	+1.14
July	-0.10	-1.55	+0.66	+3.68	+4.39	+7.44
August	+1.55	+4.62	-0.61	-1.17	-0.69	+3.78
September	-0.36	-1.50	-0.23	-1.83	-1.40	-1.27
Season Totals	-6.00	-6.33	+6.02	+4.54	+6.09	+16.38

Comparison of locations 24 and 34 to locations 55 and 65 (which were measured at the same station in both years) serves to point out the differences between the years. In 1974, the two locations were 6 cm below normal precipitation. The same locations in 1975 received

6 cm above normal precipitation. Location 75 was over 16 cm above normal precipitation. Every location in 1974, except location 14 in May, had below normal average precipitation during the first four months measured, while every location in 1975, except location 15 in April, had above average precipitation.

In 1974, all locations were planted between April 26 and May 6 (see Table 1) but in 1975 planting was not feasible until the period of May 27 to June 3. This delay of almost a month was due to inclement weather during April and May 1975. During the month of April 1974, the three stations received 1.22, 0.74, and 0.45 cm of precipitation, respectively. During the month prior to planting in 1975 (May), the stations received 10.35, 8.57, 4.65, 5.06, and 4.10 cm of precipitation, respectively (see Table 14). In the month following planting (May 1974 and June 1975) the locations in 1975 again received more precipitation than those measured in 1974, except location 14 which had 6.21 cm of precipitation for the month of May.

Precipitation differences between the two years were great enough to rule out grouping data from the two years for analysis. Above normal precipitation in 1975 could minimize the effects of volatilized NH_3 on barley plants. For this reason, the two years were analyzed and treated separately throughout the remainder of this discussion.

Crop Response Variables and Year Effect

Quadratic regression equations describing crop response to banded N rate for each fertilizer source were calculated for 16 crop response variables measured over four locations in 1974 and seven locations in 1975. An F test and subsequent p values were used to determine if regression equations for sources were statistically different. Fertilizer sources were monoammonium phosphate, diammonium phosphate, urea ammonium polyphosphate, and, in 1975, a 1:1 ratio $N:P_2O_5$ of urea + diammonium phosphate at rates of 11, 22, 33, and, in 1975, 44 kg/ha of N drill applied with barley seed. Table 16 shows the p values obtained.

The differences between the two years are readily apparent in Table 16. Although the p values do not necessarily indicate any patterns of ammonia damage, they do indicate where there were significant differences between fertilizer sources as N rates with the seed increased. The differences in the p values and the number of significant p values in 1974 as compared to 1975 must be considered. It is obvious from the table that for almost all crop response variables measured, lower p values and a larger number of statistically significant p values were obtained for 1974 data as compared to 1975 data. The reason for the differences between the two years would seem to be precipitation amounts as discussed in the previous subsection. Since 1975 experiments received a much greater amount of precipitation

Table 16. Quadratic regression p values calculated for 16 crop response variables at all locations in both years.

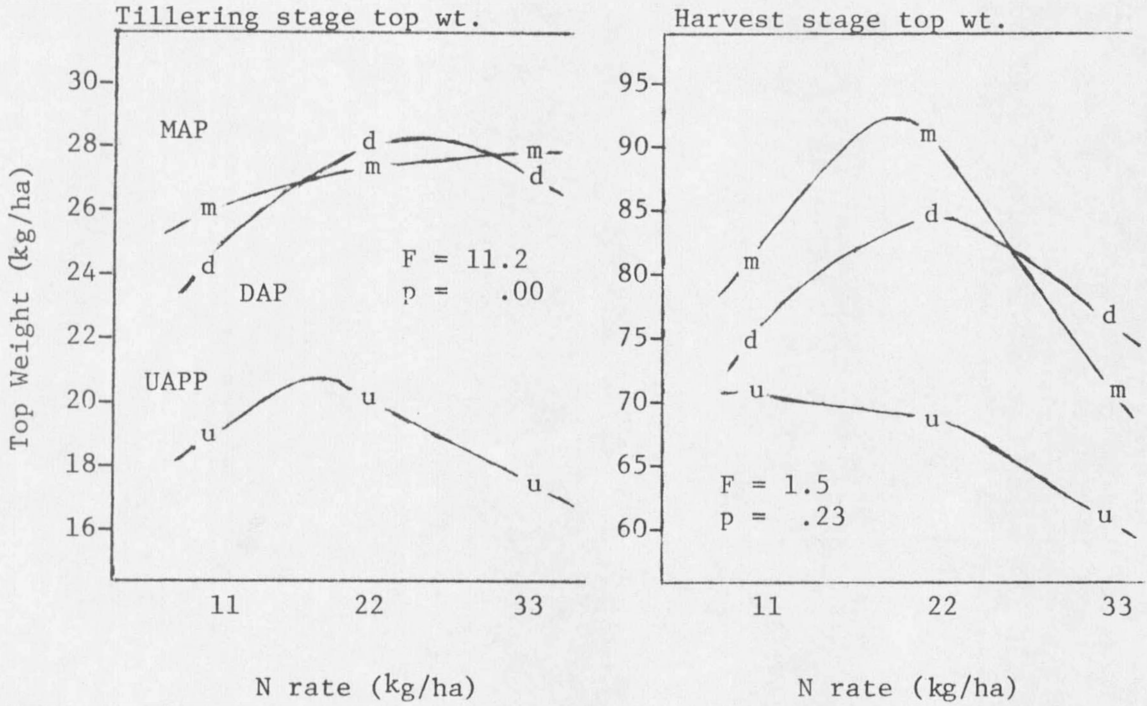
Crop Response Variable	p-value										
	Location Number										
	1974				1975						
	14	24	34	44	15	25	35	45	55	65	75
Grain yield	.21	.26		.46	.18	.34	.02	.74	.70	.43	
Dry matter	.01*	.81		.87	.82	.45	.42	.08	.68	.73	
Straw/grain ratio	.21	.60		.03*	.23	.37	.91	.63	.52	.56	
Spikes/meter row	.00*		.03*	.11	.82	.31	.08	.76		.53	
Culms/meter row 1/	.01*	.00*	.09	.00*	.25	.27	.59	.50		.49	.28
Culms/meter row 2/	.00*		.01*	.05*	.94	.57	.06	.83	.99	.87	
Plant height	.26	.08	.00*	.08	.05*	.35	.16	.02*		.07	.14
1000 kernel wt.	.00*		.06	.83	.06	.55	.42	.95	.49	.23	
Kernels/spike	.04*			.21	.77	.24	.68	.52	.55	.63	
Stand count 1/	.00*	.00*	.06	.02*	.70	.34	.37	.39	.82	.91	.41
Stand count 2/	.01*		.01*	.05*							
Spikes/plant	.79		.96	.21	.99	.42	.36	.74	.74	.49	
Grain wt./spike	.01*			.20	.84	.33	.49	.65	.54	.70	
Root weight	.05*	.08	.07	.03*	.92	.76	.19	.60		.98	.38
Top weight 1/	.00*	.00*	.00*	.00*	.16	.37	.08	.49		.03*	.61
Top weight 2/	.23			.70							

* p-values $\leq$ .05 considered statistically significant.
1/measured at tillering in 1974 and boot stage in 1975.
2/measured at harvest both years.

throughout the growing season, it would be expected that the amount of ammonia damage incurred would be less than the dryer 1974 experiments.

Another factor that could have resulted in differences between the two years is that certain crop response variables were measured at tillering stage in 1974 but not until boot stage in 1975. This might be expected to influence p values if large discrepancies existed between the measurements made first as compared to the harvest measurements within a given location. If, for instance, the number of culms/meter of row measured at tillering stage revealed a greater difference between different fertilizer sources or rates as compared to measurements made at harvest, then it is possible that by waiting until boot stage to make the initial measurements, early evidence of ammonia damage could be missed. As seen in Table 16, no particular difference exists in the p values obtained for culms per meter of row or stand count per meter of row whether measured at tillering or harvest in 1974. Previous studies (Pairintra, 1973) found measurable ammonia damage at early stages of measurement, but early stage measurements tended to point out treatment differences more dramatically. One of the crop response variables in Table 16 which shows differences between early and late measurements is top weight. Although it was only measured at harvest in 1974 and then only at two locations, the results are of interest. Figure 1 shows early and late top weight measurements made at location 14.

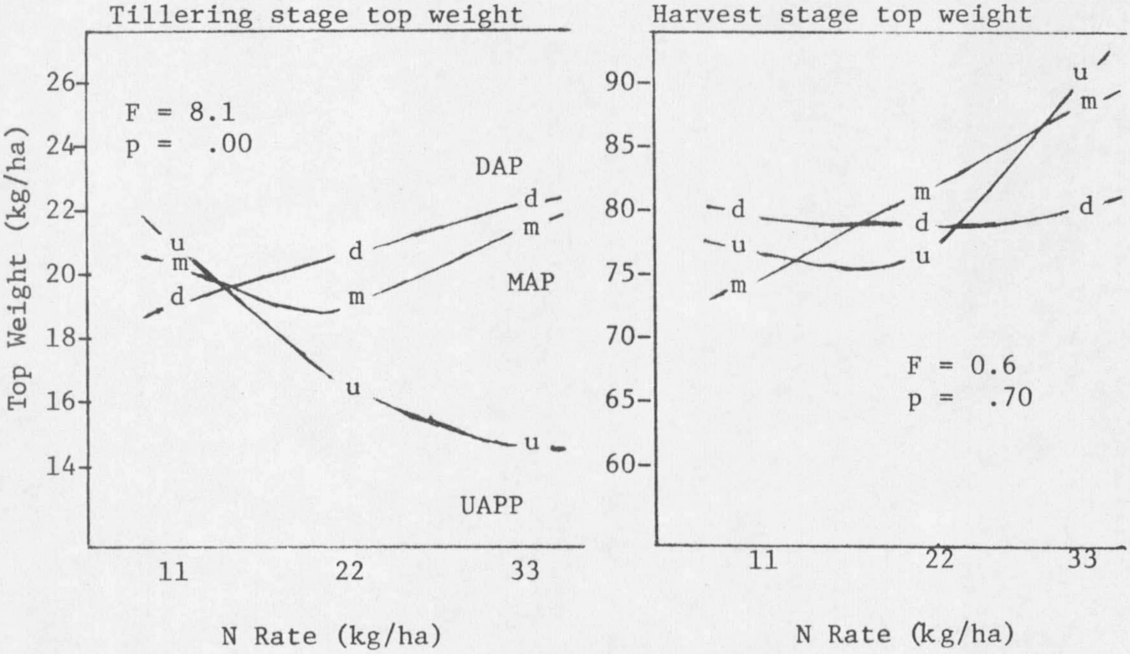
Even though trends of ammonia damage are shown in both figures, the tillering stage measurement is much more dramatic. While the F value for the harvest stage measurement is greater than 1.0, the probability level (p) is too high for differences to be considered statistically significant. An even greater difference exists between tillering and harvest stage top weight measurement for location 44, as is seen in Figure 2.



MAP = monoammonium phosphate (11-55-0)
DAP = diammonium phosphate (18-46-0)
UAPP = urea ammonium polyphosphate (28-28-0)

Figure 1. Plant top weight measured at tillering and harvest as influenced by three fertilizer sources at three nitrogen rates for location 14.

In Figure 2, the difference between the two times of measurement is much more evident. Tillering stage measurement showed statistically significant differences between the fertilizer sources (note UAPP), but no trends of ammonia damage were evident in measurements made at the same location at harvest. Therefore, delaying measurement of crop response variables until the boot stage in 1975 could be at least



MAP = monoammonium phosphate (11-55-0)
DAP = diammonium phosphate (18-46-0)
UAPP = urea ammonium polyphosphate (28-28-0)

Figure 2. Plant top weight measured at tillering and harvest as influenced by three fertilizer sources at three nitrogen rates for location 44.

partly responsible for the differences between the two years. However, differences between the times of measurement did not result in different crop injury trends for all response variables measured. The extreme differences in precipitation between the two years must have played a significant role in the amount of ammonia damage incurred and this along with the delayed measurement in 1975 could have resulted in less ammonia damage in 1975 and a minimizing of the researchers ability to detect it.

One of the objectives of this study was to determine which measures of plant growth and development are the best indicators of ammonia damage. Table 16 serves as a basis for this determination. As was pointed out earlier, measurements made at earlier stages of plant development seem to be better indicators of plant damage. As can be seen, certain crop response variables tended to have lower p values than others, particularly in 1974.

Those crop response variables included as possible measures of ammonia damage which tended to have lower p values were culms/meter of row (both times of measurement), plant height, stand count/meter of row (both times of measurement), and early top weight. Since it is assumed that less ammonia damage occurred in 1975, much of this information will be reliant on 1974 results with the assumption that in years of normal to below normal precipitation these crop measurements will be more indicative of volatilized ammonia damage.

Spikes/meter of row showed significant differences between sources for locations 14 and 34, but in all other locations for both years this crop response variable was not influenced by ammonia damage. Figure 3 shows the number of spikes/meter of row for locations 14 and 34. It should be noted that for this crop response variable, monoammonium phosphate (MAP), and diammonium phosphate (DAP) produced more heads/meter

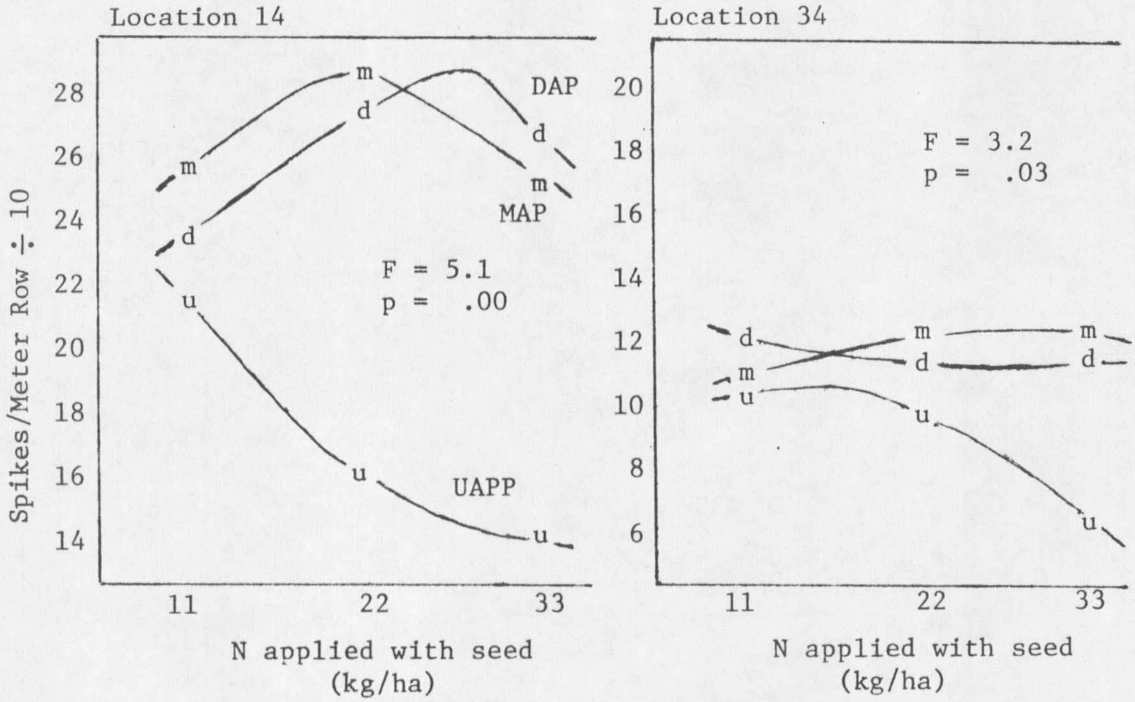


Figure 3. Number of spikes/meter of row as influenced by three fertilizer sources at three nitrogen rates for locations 14 and 34.

of row at all fertilizer rates that did urea ammonium polyphosphate (UAPP). Data from location 15, fairly indicative of the other locations, are shown in Figure 4. No trends or differences between the different fertilizer sources or rates are evident.

Plant height proved rather ineffective as an indicator of ammonia damage. At location 14, which was probably the best overall location for showing evidence of ammonia damage, plant height was not measureably affected by volatilized ammonia. All three of the

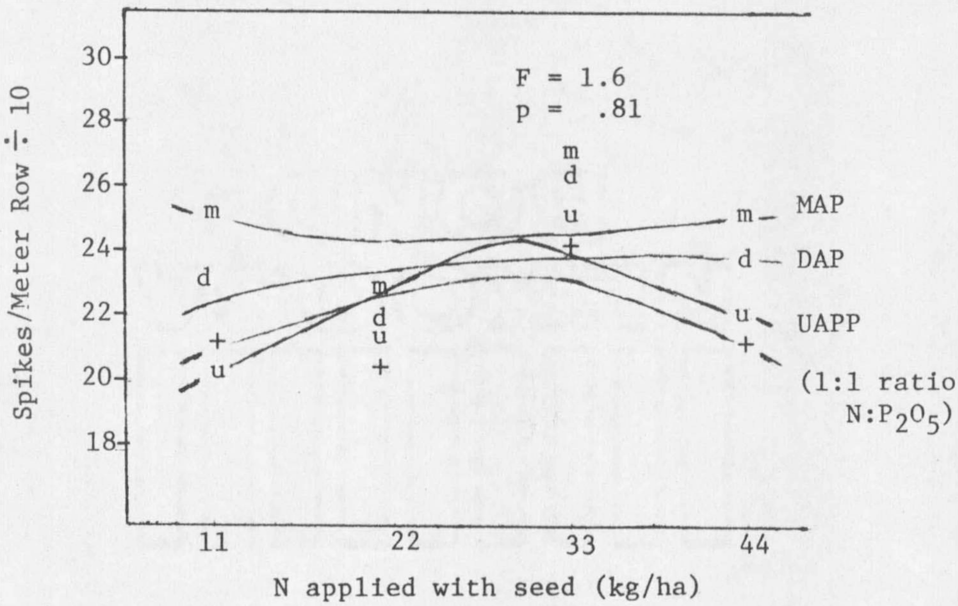


Figure 4. Number of spikes/meter of row as influenced by four fertilizer sources at four nitrogen rates for location 15.

other locations in 1974 and several in 1975 did show some evidence that plant height was affected by volatilized NH_3. Table 17 lists plant height for specific treatments for all locations in 1974 and 1975.

Location 34 provides evidence of the effects of volatilized NH_3 on plant height. Urea ammonium polyphosphate had lower plant height with 33 kg/ha of N drill applied with barley seed. Although all locations in 1975 were statistically significant to either the 1% or 5% level, the results were inconsistent as far as the development of a pattern of ammonia damage is concerned. Location 25 had

Table 17. Plant height of all locations in 1974 and 1975 as affected by fertilizer source and rate.

	N	Plant Height									
		Location Number /1									
Fert.	applied	1974				1975					
Source	w/ seed	14	24	34	44	15	25	35	45	65	75
	kg/ha	cm									
MAP	11	53	54	48	40	64	81	66	70	62	68
	22	53	52	49	40	71	85	73	65	67	64
	33	53	54	52	44	67	81	67	68	65	61
	44					67	85	68	67	61	64
DAP	11	56	53	46	40	65	83	66	61	57	70
	22	53	53	47	41	69	88	68	64	60	67
	33	54	56	52	41	63	81	64	69	61	70
	44					68	79	69	62	64	60
UAPP	11	51	52	42	39	64	84	63	65	58	67
	22	55	49	41	38	63	84	67	66	60	63
	33	54	51	32	38	66	86	63	57	61	68
	44					67	79	64	64	57	65
U+DAP	11					66	85	62	64	57	64
	22					65	78	63	65		
	33					64	84	60	68	59	65
	44					64	80	64	59		
Significance			*	**	**	**	**	**	**	**	*
$LSD_{.05}$		3.0	4.0	8.4	3.0	5.7	5.7	6.5	6.6	6.0	9.3

*, ** Treatment means significantly different at the 5% and 1% probability level, respectively.

1/ Location 55 not measured.

decreases in plant height with drill application of 44 kg/ha of N as diammonium phosphate (DAP), urea ammonium polyphosphate (UAPP), and a mixture of urea and DAP in 1:1 ratio $N:P_2O_5$. Locations 45 and 65 also showed some evidence of lower plant heights with higher N rates. It is possible that under certain conditions plant height could be used as a measure of ammonia damage (Parintra 1973), but the results from this experiment are inconclusive. The inconsistencies between the different locations could possibly be caused by precipitation differences, planting dates, or possibly even varietal differences. For example, plant height could be affected differently in tall varieties as compared to shorter ones.

Culms/meter row (both times of measurement), stand count/meter of row (both times of measurement in 1974), and early top weight all proved to be fairly reliable measures of ammonia damage, particularly in 1974. Tables 18 and 19 present culms/meter of row, stand count/meter of row, and top weight as influenced by fertilizer source and banded N rate for all locations in 1974 and 1975. Number of culms/meter row was not measured early at location 55, nor at harvest at locations 24 and 75. Stand counts were not made early at location 55 and were made at harvest only at locations 14, 34, and 44. Top weight was not measured at location 55.

Culms/meter row (Table 18) appears to be a more effective damage indicator at early stages of growth than at harvest. Urea ammonium polyphosphate had fewer culms/meter of row with 33 (1974) or 44 (1975) kg/ha of N applied with the seed as compared to lower rates of N when measured at early stages of growth at all locations

Table 18. Culms/meter of row as affected by fertilizer source and rate in 1974 and 1975

	N	Early Culms/meter row										Harvest Culms/meter row								
		Location Number																		
Fert.	Applied	1974				1975						1974			1975					
Source	w/seed	14	24	34	44	15	25	35	45	65	75	14	34	44	15	25	35	45	55	65
	kg/ha																			
MAP	11	198	250	174	213	278	324	207	443	282	286	267	133	187	262	338	422	329	238	326
	22	190	252	197	209	276	322	297	312	296	265	303	138	216	236	364	469	283	239	389
	33	209	270	190	222	254	307	279	299	322	173	264	134	208	270	366	414	318	261	353
	44					255	319	277	318	326	268				265	395	380	327	236	353
DAP	11	196	256	171	191	273	286	245	290	277	354	255	135	196	241	321	386	276	239	332
	22	192	254	176	203	276	323	248	305	345	225	289	142	199	231	356	351	337	223	392
	33	180	260	193	215	273	282	283	338	347	294	272	140	196	268	350	416	270	229	358
	44					242	262	234	268	291	186				245	317	352	274	228	372
UAPP	11	179	234	160	236	256	349	214	349	275	236	224	132	186	222	408	438	324	224	389
	22	144	193	164	188	254	354	252	316	293	263	178	129	181	228	294	414	282	227	367
	33	119	186	146	174	247	304	220	238	353	212	149	95	196	252	314	373	237	232	307
	44					258	281	208	249	261	290				231	370	428	270	235	342
U+DAP	11					214	338	232	373	335	194				215	389	342	372	215	358
	22					300	290	274	294						220	293	379	292	208	
	33					258	281	210	332	285	218				253	364	361	334	243	359
	44					235	275	256	213						212	327	419	276	232	
Significance		**	**		**	*						**	**	**	**		*			
LSD .05		34	31	37	24	55	70	83	128	85	130	57	23	25	56	84	93	122	60	88

*, ** Treatment means significantly different at the 5% and 1% probability levels, respectively.

Table 19. Stand count/meter row and early top weight as affected by fertilizer source and rate.

		Stand Counts/meter row																						
		Early										Harvest			Early Top Weight (kg/ha)									
	N applied w/seed	Location Number																						
		1974				1975						1974			1974				1975					
Source	kg/ha	14	24	34	44	15	25	35	45	65	75	14	34	44	14	24	34	44	15	15	25	35	65	75
MAP	11	59	77	61	58	98	106	115	80	132	81	46	47	47	26	30	18	21	43	35	23	30	23	17
	22	63	81	54	62	103	109	87	49	116	63	56	44	51	27	29	19	19	48	35	27	24	26	19
	33	55	79	57	61	100	97	97	38	126	30	43	50	58	27	33	21	21	42	33	33	33	27	11
	44					122	112	98	51	121	54								45	32	29	22	25	18
DAP	11	64	78	55	59	108	104	101	48	123	79	52	51	56	24	30	17	19	44	27	24	20	18	27
	22	56	80	54	63	97	111	93	58	116	47	46	47	47	28	28	17	21	42	35	25	23	21	16
	33	54	76	56	63	133	104	95	49	126	64	45	50	57	27	32	21	21	44	35	21	24	20	17
	44					115	110	70	39	101	40								46	31	23	20	20	16
UAPP	11	45	66	56	60	99	121	118	58	106	47	43	45	41	19	29	13	21	42	35	24	24	17	17
	22	32	54	52	48	89	118	92	41	104	63	29	43	43	21	21	15	16	43	36	21	18	19	17
	33	31	48	41	45	99	95	70	30	120	46	23	31	39	18	22	8	14	42	31	19	17	23	16
	44					106	96	71	33	107	40								45	32	18	15	20	13
U+DAP	11					95	120	104	81	119	58								38	31	20	22	18	18
	22					107	109	100	46										45	31	20	21		
	33					112	118	79	52	120	39								42	32	17	23	20	17
	44					95	94	85	43										34	28	20	16		
Significance		**	**	*	*	**		*				**	**	**	**	**	*	**	**		**		**	*
LSD .05		8	9	10	11	22	21	30	29	43	36	15	10	12	14	6	6	3	7	7	7	9	5	10

*, ** Treatment means significantly different at the 5% and 1% probability levels, respectively.

except 15 and 45. Harvest culms were lower with higher N rates on locations 14, 34, and 15 only. Stand counts/meter row and early top weight (Table 19) were both effective measures of NH_3 damage, especially in 1974. Higher rates of N applied with seed frequently produced lower stand counts and top weight than lower rates. Because these two crop response variables were relatively effective measures of ammonia damage, early stand counts and early top weight were statistically analyzed in greater depth in order to obtain a more thorough evaluation of the effects of the fertilizer treatments. Grain yields were analyzed in the same manner in order to estimate the effects of volatilized ammonia (if any) on final yield of barley grain. These three crop response variables are discussed in more depth in subsequent subsections.

Thousand kernel weight, kernels/spike, spikes/plant, and grain weight/spike were measured in order to determine if grain plants compensated for earlier ammonia damage. These response variables are discussed in the compensation subsection. Plant dry matter, straw: grain ratio, and root weight resulted in variable and inconsistent data. Root weight was shown to be an effective measure of NH_3 damage by Pairintra (1973) in laboratory and greenhouse studies, but these field studies could not duplicate his findings. The method in which the root weight of the plants was determined was probably at fault. Removal of the root systems from the soil and subsequent washing of the soil from the roots probably damaged the fibrous root system of the barley plant. If the effects of volatilized ammonia are to be evaluated in field studies using plant root measurements, a more precise method of removing and cleaning the roots should be developed.

Fertilizer Source and Rate

One of the major objectives of this study was to determine the magnitude of damage by several ammonium phosphate fertilizers and to determine at what rates these fertilizers could be safely applied with barley seed under irrigated conditions. In 1974, three ammonium phosphate fertilizers (monoammonium phosphate - MAP, diammonium phosphate - DAP, and urea ammonium polyphosphate - UAPP) were drill applied with barley seed at three rates (11, 22, and 33 kg/ha of N). In 1975, MAP, DAP, and UAPP were drill applied at 11, 22, 33, and 44 kg/ha of N. A mixture of urea and diammonium phosphate (U + DAP) in a 1:1 ratio $N:P_2O_5$ was also applied at these four rates at all 1975 locations except 65 and 75. At these two locations, U + DAP was applied at 11 and 33 kg/ha of N only. A mixture of ammonium nitrate and monoammonium phosphate (AN + MAP) in a 1:1 ratio $N:P_2O_5$ was applied at 22 and 44 kg/ha of N at locations 15, 25, 35, 45, and 55. Due to the total number of treatments studied, the mixture of AN + MAP was not included in much of the statistical analysis but data will be included where appropriate.

a. Analysis of variance across locations with one main effect confounded.

The F and p values obtained from analysis of variance across locations in 1974 with one main effect confounded each time are listed in Table 20. Stand counts/meter row at tillering stage of growth, plant top weight at tillering, and final grain yield were the crop response variables analyzed. Final grain yield was measured on only three of the four locations.

Table 20. Analysis of variance degrees of freedom, F, and p values across locations in 1974 with one main effect confounded.

Source	Factor Confounded	Stand Counts			Top Weight			Grain Yield		
		df	F	p	df	F	p	df	F	p
Location (L)		3	44.3	.00	3	176.7	.00	2	438.9	.00
Rate (R)		2	10.3	.00	2	0.6	.58	2	0.8	.47
$CaCO_3$ (C)	Fert.	8	0.3	.95	8	0.2	.99	6	1.5	.20
L x R	Source	6	0.7	.69	6	2.5	.06	4	1.7	.21
C x R		16	0.2	.99	16	0.3	.99	12	1.5	.14
Error L x S		6			6			4		
L x R x S		12			12			8		
Location		3	44.3	.00	3	176.7	.00	2	438.9	.00
Source (S)		2	68.0	.00	2	38.9	.00	2	7.0	.01
$CaCO_3$	Fert.	8	0.9	.51	8	0.4	.90	6	1.3	.26
L x S	Rate	6	4.5	.01	6	1.0	.45	4	0.4	.84
C x S		16	0.9	.60	16	1.2	.27	12	0.8	.69
Error L x R		6			6			4		
L x R x		12			12			8		
Location		3	56.3	.00	3	107.0	.00	2	623.1	.00
Rate		2	9.6	.00	2	0.5	.61	2	1.2	.31
Source	$CaCO_3$	2	82.6	.00	2	68.9	.00	2	6.5	.00
L x R	within	6	0.6	.72	6	2.3	.04	4	2.5	.05
L x S	location	6	5.4	.00	6	1.7	.13	4	0.3	.89

Table 20. (continued)

Source	Confounded	Stand Counts df	F	p	Top weight df	F	p	Grain Yield df	F	p
R x S		4	6.9	.00	4	8.3	.00	4	1.3	.28
L x R x S		12	.06	.84	12	1.0	.47	8	0.6	.79
Error		8			8			6		
C x R		16			16			12		
C x S		16			16			12		

$p \leq .05$ considered statistically significant.

Location effects were always highly significant regardless of which main effect was confounded. Because of differences in management and unmeasured soil and climatic variables, it was expected that location would have a profound effect in field tests of this type. Fertilizer rate significantly influenced stand counts but had no effect on top weight or grain yield. Fertilizer source significantly affected all three crop response variables. The fertilizer rate x source interaction was significant for stand counts and top weight when within location $CaCO_3$ levels (originally intended replications) were used to estimate error variance.

The analysis of variance with one main effect confounded for 1975 was divided into two parts: one across all locations with three fertilizer sources (MAP, DAP, and UAPP), the other across locations (15, 25, 35, 45, and 55) with four fertilizer sources (MAP, DAP, UAPP, and U + DAP). Table 21 lists analysis of variance F and p values for 1975 with three fertilizer sources. Table 22 lists analysis of variance F and p values for 1975 with four fertilizer sources. As in 1974, location was the most significant variable with both three and four fertilizer sources. With three fertilizer sources, fertilizer rate main effect significantly affected stand counts when fertilizer source or $CaCO_3$ level was confounded and grain yield when $CaCO_3$ level was confounded. With three fertilizer sources, the fertilizer source main effect significantly influenced top weight and grain yield when rate was confounded and all three crop response variables when $CaCO_3$ levels were confounded. With four fertilizer sources, the fertilizer rate main effect significantly affected stand count and grain yield when source was confounded and all three crop response variables when $CaCO_3$ level was confounded. Fertilizer source main effect significantly influenced top weight when rate was confounded and top weight and grain yield when calcium carbonate level was confounded. In 1975, none of the crop responses were significantly influenced by fertilizer rate x source interactions.

The initial AOVs point out the impact of fertilizer rate and source on crop growth, particularly in 1974. Since confounding main effects to estimate error resulted in some main effects and interactions being tested for significance with different estimates of error variance, the AOVs were conducted again but this time the three-factor interaction variance estimate was used to calculate the F statistic.

Note that this interaction was not statistically significant in the previous AOV's. The following subsection details the results of this analysis.

Table 21. Analysis of variance degrees of freedom, F, and p values across locations in 1975 with one main effect confounded for three fertilizer sources.

Source	Factor ignored	Stand counts df	Stand counts F	Stand counts p	Top weight df	Top weight F	Top weight p	Grain Yield df	Grain Yield F	Grain Yield p
Location (L)		6	75.5	.00	5	124.0	.00	5	40.5	.00
Rate (R)		3	3.2	.03	3	1.8	.16	3	2.3	.10
$CaCO_3$ (C)	Fert.	14	1.0	.51	12	1.0	.39	12	2.3	.01
L x R	Source	18	1.3	.22	15	1.4	.19	15	0.6	.82
C x R		42	1.3	.13	36	1.0	.43	36	1.5	.04
Error L x S		12			10			10		
L x R x S		36			30			30		
Location		6	75.5	.00	5	124.0	.00	5	40.5	.00
Source (S)		2	2.5	.10	2	5.0	.01	2	4.1	.03
$CaCO_3$	Fert.	14	0.9	.61	12	1.1	.39	12	2.1	.02
L x S	Rate	12	0.5	.88	10	1.2	.36	10	0.6	.77
C x S		28	1.2	.21	24	1.2	.23	24	1.1	.38
Error L x R		18			15			15		
L x R x S		36			30			30		
Location		6	66.5	.00	5	132.8	.00	5	79.1	.00
Rate		3	3.8	.01	3	2.0	.12	3	3.0	.03
Source	$CaCO_3$	2	3.2	.04	2	6.1	.00	2	4.2	.02
L x R	Level	18	1.6	.07	15	1.5	.10	15	0.8	.62
L x S		12	0.7	.77	10	1.4	.18	10	0.6	.78
R x S		6	1.6	.15	6	0.5	.79	6	1.5	.20
L x R x S		36	0.7	.90	30	0.9	.56	30	0.9	.60
Error C		14			12			12		
C x R		42			36			36		
C x S		28			24			24		

$P \leq .05$ considered and statistically significant.

Table 22. Analysis of variance degrees of freedom, F, and p values across locations in 1975 with one main effect confounded for four fertilizer sources.

		Stand Counts			Top weight			Grain Yield		
Source	ignored	df	F	p	df	F	p	df	F	p
Location (L)		4	119.4	.00	3	160.6	.00	4	120.0	.00
Rate (R)		3	3.3	.03	3	2.7	.06	3	3.4	.03
$CaCO_3$ (C)	Fert.	10	0.8	.67	8	1.1	.34	10	0.4	.94
L x R	Source	12	1.8	.10	9	1.1	.39	12	0.6	.82
C x R		30	1.5	.07	24	1.1	.30	30	1.3	.13
Error L x S		12			9			12		
L x R x S		26			27			36		
Location		4	119.4	.00	3	160.6	.00	4	120.0	.00
Source (S)		3	1.1	.37	3	5.7	.00	3	2.6	.07
$CaCO_3$	Fert.	10	0.6	.79	8	1.2	.30	10	0.4	.95
L x S	Rate	12	0.9	.68	9	0.7	.71	12	0.8	.65
C x S		30	1.1	.39	24	1.3	.21	30	1.2	.24
Error L x R		12			9			12		
L x R x S		36			27			36		
Location		4	83.8	.00	3	194.2	.00	4	49.9	.00
Rate		3	4.4	.01	3	3.3	.02	3	4.6	.00
Source	$CaCO_3$	3	1.3	.29	9	7.1	.00	3	3.2	.02
L x R	Level	12	2.4	.01	9	1.4	.22	12	0.8	.63
L x S		12	0.9	.54	9	0.9	.56	12	1.0	.45
R x S		9	1.7	.09	9	1.1	.39	9	1.6	.12
L x R x S		36	0.7	.90	27	0.9	.57	36	0.9	.63
Error C		10			8			10		
C x R		30			24			30		
C x S		30			24			30		

$p \leq .05$ considered statistically significant.

b. Analysis of variance across locations with 3-factor interactions confounded.

Table 23 lists analysis of variance F and p values across locations using the three-factor interaction as an estimate of error variance. The table is in three parts: 1974 with all four locations, 1975 with three fertilizer sources (all seven locations), and 1975 with four fertilizer sources (all locations except 65 and 75). As was expected, location differences were highly significant in each analysis. Calcium carbonate main effects were generally non-significant and will be discussed in the next subsection.

In 1974, fertilizer rate main effects significantly affected stand counts/meter row only, while fertilizer source main effects significantly affected stand counts, top weight, and grain yield. The rate x source interaction was significant for stand counts and top weight. In 1975 with three fertilizers, fertilizer rate main effect was statistically significant only for final grain yield. Fertilizer source main effect had a significant effect on all three crop response variables. The rate x source interaction approached significance only for stand counts/meter row. In 1975 with four fertilizer sources, the inclusion of a mixture of urea + diammonium phosphate in 1:1 ratio $N:P_2O_5$ had a noticeable effect on the analysis of variance. Fertilizer rate main effect was significant only for grain yield, and the importance of fertilizer source main effect was not as evident as it was statistically significant only for top weight and possibly for grain yield. The rate x source interaction was significant for stand counts.

Table 23. Analysis of variance degrees of freedom, F, and p values measured across locations with three-factor interactions used to estimate error for all locations in 1974, all locations in 1975 with 3 fertilizer sources, and 5 locations in 1975 with 4 fertilizer sources.

Source	Stand counts			Top weight			Grain Yield		
	df	F	p	df	F	p	df	F	p
--1974 Complete--									
Location (L)	3	95.5	.00	3	108.1	.00	2	108.9	.00
Fertilizer Rate (R)	2	15.7	.00	2	0.2	.81	2	0.5	.66
Fertilizer Source (S)	2	15.2	.01	2	38.3	.00	2	22.7	.01
$CaCO_3$ Level (C)	8	1.5	.20	8	0.8	.64	6	1.9	.13
L x R	6	1.0	.45	6	2.3	.10	4	4.4	.04
L x S	6	9.2	.00	6	1.7	.19	4	0.5	.74
R x S	4	11.8	.00	4	8.4	.00	4	2.3	.15
R x C	16	1.1	.40	16	1.2	.36	12	1.9	.08
S x C	16	1.4	.19	16	2.1	.03	12	1.1	.41
Error L x R x S	12			12			8		
--1975 w/ 3 fertilizer sources--									
Location	6	94.5	.00	5	142.5	.00	5	87.1	.00
Fertilizer Rate	3	2.4	.10	3	1.3	.31	3	3.6	.04
Fertilizer Source	2	4.7	.03	2	4.3	.04	2	6.6	.01
$CaCO_3$ Level	14	1.1	.41	12	1.2	.29	12	2.9	.00
L x R	18	2.3	.02	15	1.6	.12	15	0.9	.54
L x S	12	1.0	.50	10	1.5	.18	10	0.7	.72
R x S	6	2.3	.06	6	0.6	.77	6	1.6	.18
R x C	42	1.4	.08	36	1.2	.24	36	2.0	.01
S x C	28	1.5	.07	24	1.4	.15	24	1.5	.09
Error L x R x S	36			30			30		
--1975 w/ 4 fertilizer sources--									
Location	4	121.3	.00	3	208.7	.00	4	55.6	.00
Fertilizer Rate	3	1.9	.19	3	2.5	.13	3	5.6	.01
Fertilizer Source	3	1.4	.29	3	8.3	.01	3	3.3	.06
$CaCO_3$ Level	10	0.8	.61	8	1.5	.18	10	0.5	.90
L x R	12	3.5	.00	9	1.5	.22	12	0.9	.55
L x S	12	1.3	.26	9	0.9	.52	12	1.1	.38

Table 23. (continued)

Source	Stand counts			Top weight			Grain Yield		
	df	F	p	df	F	p	df	F	p
R x S	9	2.5	.03	9	1.2	.36	9	1.8	.10
R x C	30	1.6	.05	24	1.5	.10	30	1.6	.05
S x C	30	1.4	.13	24	1.5	.08	30	1.4	.10
Error L x R x S	36			27			36		

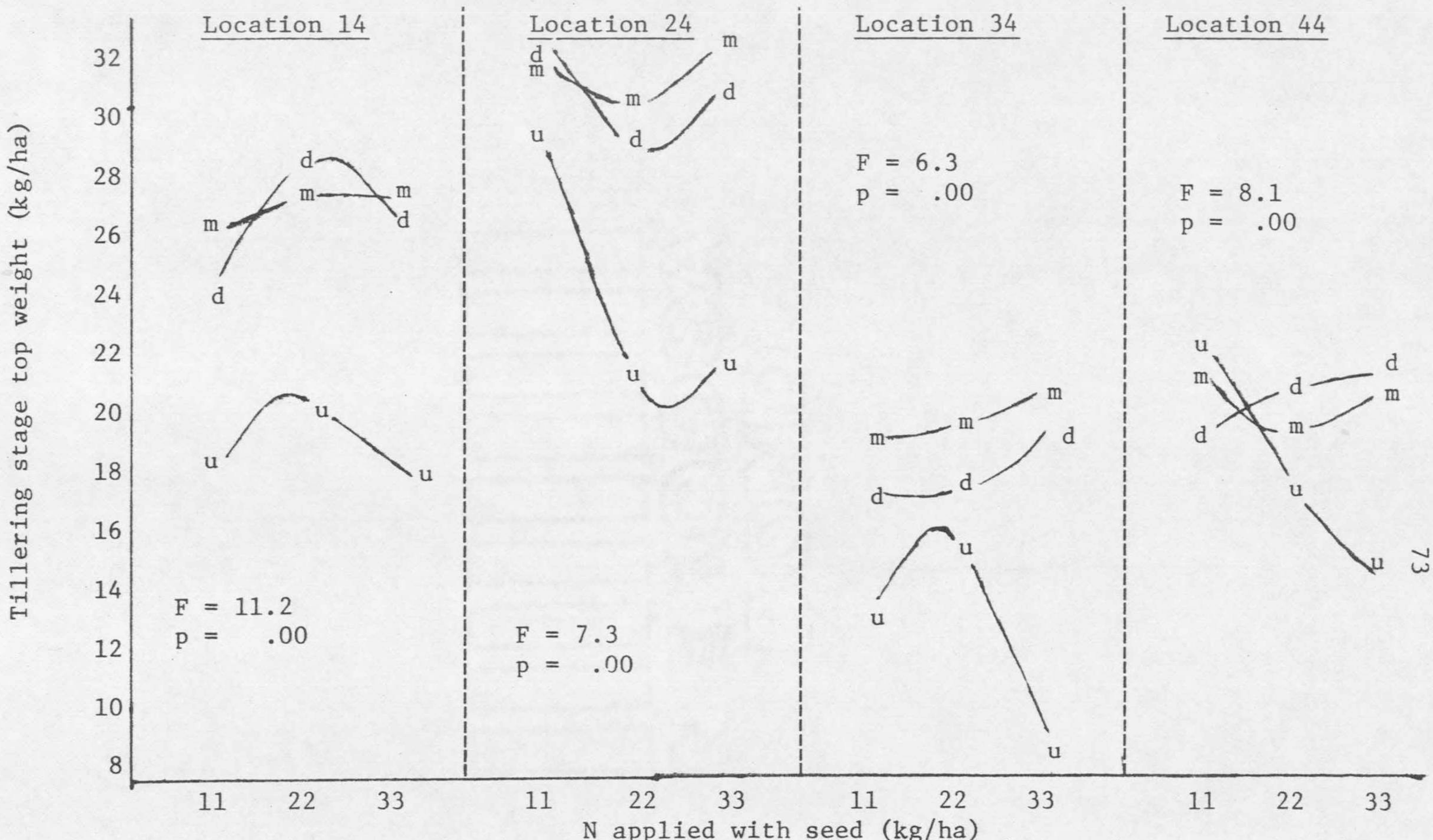
$P \leq .05$ considered statistically significant.

c. Comparison of individual fertilizer sources and rates.

1974 Results

The previous analysis of variance revealed that fertilizer source main effect was significant for all three crop response variables measured in 1974, while fertilizer rate main effect was significant only for stand counts/meter row. Figure 5 graphically illustrates the effect of fertilizer source and rate on tillering stage top weight for the four individual locations in 1974. All four locations are shown in the same figure for purposes of comparison.

As can be seen from Figure 5, monammonium phosphate (MAP) and diammonium phosphate (DAP) had greater top weights at higher N rates than did urea ammonium polyphosphate (UAPP). At locations 14, 24, and 34 UAPP had lower top weights at tillering stage of growth than either MAP or DAP at all rates of N applied with the seed. No particular difference is evident between MAP and DAP. The effect of fertilizer



m=monoammonium phosphate (11-55-0); d=diammonium phosphate (18-46-0); u=urea ammonium polyphosphate (28-28-0) p ≤ .05 considered statistically significant.

Figure 5. Tillering stage top weight as affected by three ammonium phosphate fertilizers at three rates of N applied with barley seed at four locations in 1974.

rate main effect was not significant (see Table 23) but UAPP had decreasing top weights with N rates greater than 22 kg/ha applied with barley seed at locations 14 and 34. It produced decreased top weights at fertilizer rates greater than 11 kg/ha of N on locations 24 and 44. The rate x source interaction was significant and is shown by the fact that MAP and DAP had little or no effect on tillering stage top weight as N rates with barley seed increased while top weights generally decreased with increasing N rate when UAPP was the fertilizer source.

Figure 6 shows graphically the effect of fertilizer source and rate on tillering stage stand counts/meter row for the four locations in 1974. MAP and DAP are again seen to be superior to UAPP at rates greater than 11 kg/ha of N applied with the seed. UAPP fertilizer resulted in fewer plants with increasing rates at all four locations. The fertilizer rate x source interaction was highly significant and is shown by the different effect of rate of N application on tillering stage plant stand counts for UAPP as opposed to MAP and DAP. Again no particular difference between MAP and DAP is evident. Any evidence that rates of 22 kg/ha of N applied with seed as UAPP were superior to lower rates did not exist with stand counts as it did with top weight for locations 14 and 34. The statistical significance of the rate x source interaction at location 34 is questionable, but UAPP produced fewer plants at 33 kg/ha of N applied with barley seed than did MAP or DAP.