NITROGEN - POTASSIUM RELATIONSHIPS IN BARLEY AND OATS AS INFLUENCED BY MODE OF FERTILIZATION

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ABSTRACT

The aim of this investigation was to study the effect of nitrogen forms and placements of nitrogen and potassium upon yield, potassium content and potassium uptake by oats and barley.

Generally, where potassium was applied, the ammonium sulfate carrier gave the highest yields for both crops on the calcareous soils while the ammonium nitrate resulted in the largest yields on the non-calcareous soil. For the treatments without potassium, the nitric acid form gave the lowest yields for both crops on both the calcareous and non-calcareous soils. Placing potassium separately at the soil surface gave the lowest yields as well as the lowest response to potassium fertilization for all soils.

Nitrogen and potassium contents of barley generally exceeded those of oats for comparable treatments. Placement of potassium at the surface invariably resulted in the lowest potassium and the highest nitrogen contents of barley regardless of soil used. For the potassium treatments largest nitrogen contents for oats and lowest for barley were obtained with the sodium nitrate form. The nitrogen content of barley was highest with use of the nitric acid form.

With potassium application on the calcareous soils the sodium nitrate source gave the lowest potassium uptake whereas the ammonium sulfate gave the largest of all nitrogen forms

used. The ammonium nitrate gave the largest potassium uptake for barley on the non-calcareous soil. Placement of potassium at the surface gave lower potassium uptake than placement below the seed. Regardless of crop grown or soil used, for all nitrogen forms, nitric acid gave the least variation in plant material yields, nitrogen content and uptake and potassium uptake with placement whereas the ammonium sulfate generally gave the most.

Phosphorus, calcium and magnesium contents were generally larger for barley than for oats. For comparable treatments phosphorus content of barley was larger while calcium and magnesium contents were less on the calcareous than on the non-calcareous soil. The sodium nitrate form gave the highest phosphorus and the lowest calcium and magnesium contents for all nitrogen forms used. For both soils with barley, higher calcium and sodium contents were obtained with the nitric acid than with the ammonium sulfate form for the potassium treatments. Magnesium contents followed no consistent trend with nitrogen form for either crop or soil. In all cases placement of potassium at the surface resulted in the largest phosphorus, sodium, calcium and magnesium contents.

For soils cropped to barley, placing nitrogen at the surface resulted in least fixation of potassium but gave the larger amount of fixation for soil cropped to oats. When employed, placement of potassium at the surface gave the largest potassium fixation for all nitrogen forms and soils, under both cropped and incubated conditions. For the incubated soils, the nitric acid form fixed more potassium than did the ammonium sulfate form. This was generally also true for the cropped soils.

For the potassium treatments for all soils regardless of placement the nitric acid form gave higher Ca:K and N:K ratios than did ammonium sulfate for both crops. The sodium nitrate form, when employed, gave higher N:K and lower Ca:K ratios than any other nitrogen form. Placement of potassium at the surface gave the largest Ca:K and N:K ratios for all soils. For both crops and for all soils, placing nitrogen at the surface gave lower N:K ratios than did placement of nitrogen below the seed.

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INTRODUCTION

Potassium is one of the essential elements in plant nutrition. It plays a role in both carbohydrate and nitrogen metabolism. Specifically, potassium catalyses transphosphorylation reactions and reactions culminating in the coupling of amino acids to form peptides and eventually proteins.

Work done on the assessment of the potassium status of Manitoba soils and potassium requirements and uptake by cereal crops has recently been intensified. Lately it has been estimated that over six hundred thousand acres of a total of twelve million cultivated acres in Manitoba may respond profitably to potassium fertilization of cereal crops. These potassium responsive soils are invariably coarse textured and/or fairly calcareous in nature.[1]

A greenhouse pot experiment with oats and barley was conducted on an Almasippi fine sandy loam at the University of Manitoba in 1965.[2] Using a blanket application of potassium and increasing rates of nitrogen and phosphorus applications, Gould[2] found that for any one level of phosphorus, the potassium content increased with increasing rates of nitrogen for barley. For oats, increases in potassium content with increasing nitrogen rates were observed only at the higher phosphorus levels.

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1. Unpublished data, Department of Soil Science, University of Manitoba.
2. Gould, E.M. (1965) B.S.A. thesis, University of Manitoba.

A second greenhouse experiment was conducted on a similar soil, i.e., Almasippi fine sandy loam, at the University of Manitoba, to investigate the effect of increasing potassium rates on the potassium content and uptake of barley fertilized with one level of nitrogen and phosphorus.[1] A variation of nitrogen placement was also employed at the highest potassium level. It was found that while potassium content of barley increased with increasing potassium, nitrogen content remained fairly constant. A slight increase in yield with a sharp depression in both nitrogen and potassium contents of barley was noted with the nitrogen placed separately from the potassium source, i.e., nitrogen banded at the surface.

The purpose of the investigation presented herein therefore, was to further study the effect of:

1) various nitrogen-potassium placements upon yield, potassium content and potassium uptake by oats and barley,

2) different forms of nitrogen on potassium content, potassium uptake and plant material yields of oats and barley and,

3) different nitrogen forms and nitrogen-potassium placements upon the soil potassium balance, by an incubation procedure.

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1. Unpublished data, Department of Soil Science, University of Manitoba.

LITERATURE REVIEW

A. Ion Uptake Mechanisms

Much work within the past few years has been directed towards elucidation of the mechanics of ion uptake by plants. The theories put forth have generally been largely hypothetical and fail to consider and to explain all aspects of the ion uptake and transport mechanisms of plants.

Fried and Shapiro (20) divided ion uptake by plants from a soil system into four steps, each of the transfer steps involving both rate constants and concentrations. The steps were:

1. release of the ion from the solid phase into the soil solution.
2. movement of the ion from any point in the soil solution to the vicinity of the root.
3. movement of the ion from the vicinity of the root into the root.
4. movement of the ion to the top of the plant.

The authors suggested that the replenishment of the solution ion at the solution-root interface may take place either by simple diffusion through the liquid phase or by bulk movement along with the water. Both active and passive processes describe the entry of ions into the root. The passive process involved is diffusion and if diffusion were rate limiting, ion uptake should be directly proportional to concentration.

Active entry is suggested by the rapidity of response to the outside solution by the accumulating mechanism of the root.

A division of modes of ion uptake into two main, different mechanisms was made by Epstein (18). These were:

1. Passive Ion Movements

a) cation exchange - there is evidence that roots act as cation exchangers and exhibit the lyotropic series of affinities common in such systems.

b) diffusion - ions permeate the 'apparent free space' in a reversible and non-metabolic process and tend to be in equilibrium with ions of the same ionic species in the external solution.

2. Active Transport

This theory involves the use of carriers which complex with the ions prior to permeation of the root membrane. Ionic 'antagonism' would thus involve ions recognized as being similar in chemical behaviour to act as metabolic analogs in the absorption process and to compete for identical sites on the carriers effectively active in transport.

Considerable controversy exists as to the mode of function of ion carriers and their importance in explaining ion selectivity in uptake by plants. Epstein and Hagen (19) explained selectivity of ion uptake on the basis of the existence of separate types of carrier molecules for each ion or group of ions. On the other hand, Sutcliffe (52) explains selectivity of ion uptake as a single type of carrier capable of transporting all or a number of ions but exhibiting distinct preferences when a choice is available.

Two factors to consider in regard to potassium nutrition in soil are maintained by Smith and Matthews (50) as being: a) intensity of potassium in the soil, i.e. the exchangeable potassium level which determines the concentration of potassium in the soil solution, and; b) the potassium supplying power, i.e. the amount and rate of release of non-exchangeable potassium.

Loehwing, as cited by (26) reported that early potassium absorption is generally in excess of current needs if the potassium concentration in the substrate is adequate. Luxury consumption during this period is usually followed by translocation of potassium in later stages of growth.

Williams (58) found that the potassium content of barley tops increased with increasing concentration of potassium in the nutrient medium.

Plants grown in a potassium concentration of 50 ppm absorbed more potassium than plants grown at lower concentration. Plants grown at the lower concentrations, however, were able to produce greater growth per unit of potassium absorbed than were the plants grown at higher concentrations.

Crop plants differ in their ability to take up potassium from potassium fixing soils. Åslander (6) reported a marked difference in this respect between oats and barley as well as between various strains of barley.

Lawton and Cook (26) state that barley requires a higher level of potassium than wheat or oats. Drake and Scarseth (14) working with a Crosby silty loam of pH 6.2, base exchange capacity of 9.4 me per 100 gm of air dried soil and with 0.267 gm of exchangeable potassium per pot, found that barley took up almost as much potassium as is held in the exchangeable form while oats could not obtain over one half of the potassium held in the exchangeable form.

B. Placement Effects.

McVickar, Bridger and Nelson (34) state that potassium placement shows greatest advantage when soils are high potassium fixers and when low rates of potassium are applied. When soils fix very little potassium and when high rates of fertilization are used, banded and broadcast placement of potassium give equal responses in crop yield.

Three experiments were conducted by Welch _et_ _al_. (56) in Illinois to determine the relative efficiency of broadcast versus banded potassium for corn. They suggested that broadcast potassium may not be as efficient as banded potassium because of a difference in chemical and/or positional availability between the two placement methods. Chemical unavailability refers to the fixation of potassium; fixation being enhanced by broadcast application of potassium. Positional unavailability refers to the placement of potassium in soil zones not permeated by corn roots, as is again the case in the broadcast placement. This positional unavailability is related to the very slow diffusion of potassium in the soil.

Work done in Holland by Prummel (42) indicates phosphorus and potassium fertilizers applied in bands near the seed to be more effective than broadcast application. The author attributed the rather small uptake of broadcast phosphorus and potassium to fixation; a localized concentration of fertilizer reduces fixation to a minimum and will therefore have a favourable influence on uptake.

C. Nitrogen Forms and their Influence on Nutrient Uptake

Pirschle, as cited by(41) grew a variety of agriculturally important plants in flowing culture solutions at various pH levels and found that with all plants except rice, considerably less potassium was adsorbed when ammonium salts were used as the nitrogen source. This was especially true at the higher pH values where the ammonium fertilized plants frequently contained only half as much potassium as the nitrate fertilized plants.

Exchangeable bases were removed from a sandy soil by a percolation procedure and potassium, sodium, magnesium, calcium in varying ratios were substituted by van Itallie (54). Oats were grown on the treated soil using both ammonium and nitrate forms as nitrogen sources. The author found that the groups receiving nitrate always produced better plant growth than those receiving ammonium. He also frequently found that under nitrate fertilization, normal healthy plants resulted with the same calcium and magnesium content as plants fertilized with ammonium, but the ammonium treated plants produced symptoms of magnesium deficiency and sometimes calcium deficiency. Van Itallie hypothesized that when the ammonium is taken up, the plants require more calcium and magnesium as protection against a strong hydrogen ion invasion which does not occur with the nitrate source.

The influence of form and mode of nitrogen fertilizer application on the availability of soil and fertilizer potassium to oats was studied by Acquaye and MacLean (1). They found that ammonium applied alone or two weeks after addition of potassium, the two week interval being a storage period with the soil held at 25 percent moisture holding capacity and then allowed to dry prior to addition of ammonium, depressed the uptake of potassium by oats grown in a sandy loam in the greenhouse. However, when ammonium was added first and potassium two weeks later at seeding, the ammonium increased potassium uptake. In the absence of potassium fertilizer, ammonium reduced the release of non-exchangeable potassium to the plants. When added prior to or at the same time as potassium at seeding, ammonium reduced potassium fixation. Nielsen and Cunningham as cited by (1) grew ryegrass with nitrogen applied in both the ammonium and nitrate forms. They attributed the superiority in yield with the ammonium form to better root distribution throughout the soil.

In a greenhouse experiment Axley and Legg (7) added 100 ppm nitrogen to each of three soils as ammonium sulfate or sodium nitrate with or without 100 ppm potassium as potassium sulfate. Two crops, oats and corn, were grown in succession. Where no potassium additions were made, nitrogen uptake from the sodium nitrate source was found to be significantly greater than from the ammonium sulfate source. The difference was explained on the basis of sodium substitution for potassium when no potassium was applied to the soil.

Two of the soils which possessed appreciable fixation capacities showed pronounced significant differences in nitrogen uptake between the sodium nitrate and the ammonium sulfate upon potassium application; the sodium nitrate being superior. For the third soil with the negligible fixation capacity nitrogen uptake values were similar for both sodium nitrate and ammonium sulfate when potassium was added.

The authors concluded that the amount of potassium required to reduce significantly nitrogen uptake by plants depends upon the ammonium fixation capacity and the initial potassium status of the soil. Previous work suggests that the effect of potassium inblocking nitrogen entry into the plant is primarily responsible for the reduced nitrogen uptake in the presence of excess potassium.

By fertilizing a sandy loam and a very fine sandy loam with urea, sodium nitrate and ammonium sulfate, Pearson (38) found that the use of physiologically acid nitrogen sources greatly increased downward potassium movement. Additions of lime in amounts required to neutralize the equivalent acidity reduced the amount of potassium leached by nearly fifty percent. He therefore concluded that there were no appreciable differences between nitrogen sources with respect to leaching providing that they were rendered physiologically neutral.

Wolcott, Falk and Davis (61) report that with repeated annual applications of 40 to 300 pounds nitrogen per acre to a moderately acid sandy loam, the acidifying effect to a depth of 15 inches was in the order:

$$(NH_4)_2\ SO_4 \quad NH_4Cl \quad NH_4NO_3 \quad \text{urea.}$$

Several workers (11, 21, 37, 44) found marked increases in phosphorus absorption with use of the ammonium form of nitrogen when the ammonium and phosphorus sources were intimately mixed together. The nitrate was found to be relatively ineffective in stimulating plant use of fertilizer phosphorus. Ammonium was rapidly absorbed by young cereal seedlings regardless of whether it was mixed with or separated from the phosphorus carrier, suggesting that the ammonium ion indirectly influences the plant's ability to take up phosphorus rather than altering in any way the availability of the applied phosphorus fertilizer by solubulizing or pH changes (21, 44). Olson and Dreier (37) suggested that the ammonium nitrogen played a physiological role in the absorption of fertilizer phosphorus by stimulating root activity.

D. Potassium-Nitrogen Relationship with a Consideration of Root Cation Exchange Capacity.

McVickar, Bridger and Nelson (34) state that researchers have reported increased potassium uptake, decreased potassium uptake and no effect on potassium uptake with nitrogen application. Phillips and Barber as cited by (34) have shown an interaction between the level of nitrogen and the level of potassium with respect to the influence of nitrogen on potassium uptake. At low levels of nitrogen and high potassium levels, adding nitrogen increased potassium uptake; at high levels of nitrogen and low potassium levels, addition of nitrogen depressed potassium uptake.

Mattson and Karlsson as cited by (13) reported that for a wide range of species of natural vegetation, there is a positive linear relationship between total nitrogen content and total cations. The general explanation offered is that total cations absorbed are initially balanced mainly by the nitrate absorbed which greatly exceeds the sum of the other inorganic anions. Crooke and Knight (13) balanced total cations - Ca, Mg, K, Na in me per unit weight against total anions - P, S, Cl - in me per unit weight and the difference was equal to excess bases. Excess bases were then found to be related to the total nitrogen content. However, at Rothamsted (45), workers studied H_2O, nitrogen and potassium interactions in ryegrass grown on a sand and a clay, with two levels of nitrogen, and four levels of potassium. They found that nitrate nitrogen accumulation seemed unrelated to the cation-anion balance in the grass. Total nitrogen taken up was the same at the different levels of applied potassium, whereas potassium uptake increased with the amount of potassium applied.

By using different levels of nitrogen on different crops, McLean (31) found that the percentage of potassium and sodium generally decreased with increased level of nitrogen. However, oat tops showed an increased sodium content and an almost constant potassium content with higher levels of nitrogen in the nutrient culture. He found that with cations, the relation is "increased uptake of divalent and a tendency towards decreased uptake of monovalent cations with increasing root cation exchange capacity".

Williams and Coleman (59) state that the plant root surfaces possess cation exchange capacities which may be measured by the adsorption and release of various cations. The entry of cations into the root double layer follows a lyotropic series listed in decreasing order of replacing abilities as follows:

$$H^{+} \quad Ba^{++} \quad Ca^{++} \quad Mg^{++} \quad NH_4^{+} \quad K^{+} \quad Na^{+} \quad Li^{+}$$

Bear (8) listed the following cation exchange capacities on an oven dry weight basis

Avena sativa	Spring oats	22.8 me per 100 gm
Hordeum vulgare	Barley	12.3 me per 100 gm

That root cation exchange capacity of a given plant species can be increased by 10 to 30 percent by increasing the level of nitrogen applied to the soil or supplied in a nutrient solution has been shown by Smith and Wallace as cited by (8). This increase in root cation exchange capacity was paralleled by a corresponding increase in nitrogen content of the root tissue. The authors suggest that the role of increased nitrogen in increasing root cation exchange capacity is by the synthesizing of additional protein-amino groups and possibly by stimulation of greater cell division and by reduction of non-pectic carbohydrate deposition in root cell walls. Observation of oat and barley roots under high magnification indicate the possibility of nitrogen induced cation exchange capacity increases by increased production of root hairs and by increased lateral root tip development. Theoretically, the effect of the increased root cation exchange capacity is to increase the ratio of divalent to monovalent cations attracted to the root surface according to Donnan's distribution. However, in their study, Drake and White (15) reported that increasing nitrogen increased the amount of potassium taken up by the oat plant and demonstrated that while root cation exchange capacity and the expressed Donnan distribution are important, the distribution is only one of several factors that influence uptake of cations and the monovalent : divalent cation ratio. The authors suggest that activity of cations, mechanisms of translocation and reactions of translocated cations with organic acids in the plant cell must also be considered.

McLean, Adams and Franklin (32) present results which indicate a correlation (R = 0.866) between cation exchange capacity of plant roots and their percentage of nitrogen. Generally, as more nitrogen was supplied to a given plant species, an increase in nitrogen content in the plant was obtained, accompanied by a corresponding increase in the cation exchange capacity of the plant roots.

McLean (31) grew oats in gravel cultures using three nitrogen levels. The oats were harvested fifteen days after seeding. He found that the root cation exchange capacity increased from 17.7 me per 100 gm to 24.4 me per 100 gm with increasing nitrogen level. Analyses carried out on the plant tops showed an increase in calcium and magnesium contents at higher nitrogen levels and generally, a decrease in phosphorus, potassium and sodium contents with greater nitrogen concentration of the medium. Heintze (24) found that high cation exchange capacities were associated with low potassium : calcium ratios of plant tops when comparisons were restricted within the same potassium level of the growing medium. Also, a correlation coefficient that was just significant was found in a number of comparisons for the relationship between the cation exchange capacity values of two species and the inverse ratio of the potassium contents of their plant tops.

Potassium uptake by three cereals of similar physical growth characteristics was studied by Drake and Scarseth (14). They found that at each of the three lower levels of soil potassium (0.095, 0.210, and 0.307 me per 100 gm); potassium uptake by wheat (9.0 me per 100 gm), barley (12.3 me per 100 gm) and oats (22.8 me per 100 gm) correlated well with root cation exchange capacity. At the higher increments of soil potassium (0.414 me per 100 gm to 1.158 me per 100 gm) the effect of root cation exchange capacity on potassium uptake vanished. The valence effect principle is consequently invalidated by greatly increasing the outside cation concentration. It is only when nearly all of the cations exist in an exchangeable state and the plant root colloids must compete with the soil colloids for these cations by exchange that the Donnan distribution will be reflected in the composition of the plants.

E. Relationship of Potassium to Calcium, Magnesium and Sodium in the Soil and Plant.

A review of literature reveals an uncertain and confused relationship existing between exchangeable cations in the soil and potassium absorption by plants. It has been shown by many investigators that when the concentration of calcium relative to that of potassium is low, the calcium actually favors potassium absorption by the plants, and it is only when the calcium is materially increased that potassium absorption is depressed (41).

Van Itallie (54) working with oats grown on a sandy soil with varying potassium:sodium:magnesium:calcium ratios and cation exchange capacities concluded that, for calcium, magnesium and sodium, the absolute amount present in exchangeable form is not primarily the determining factor for the uptake of these ions by the plant. With a constant potassium to sodium ratio however, potassium uptake is dependent only on the potassium concentration in the soil; it makes but little difference whether calcium or magnesium forms the greater part of the cations present.

The total amount of cations absorbed by a plant from different media tends to approach a constant, but the relative accumulation of potassium, calcium and magnesium is dependent upon the ratios of these ions in the nutrient medium according to Hanson and Kahn (23). These authors also report that high concentrations of potassium will tend to depress the accumulation of divalent cations and vice versa.

Different workers (9, 41) using increasing concentrations of potassium with corn have found that the calcium and magnesium contents of the leaf tissue were generally inversely related to the potassium content of the plant. They found that the sum of the percentages of potassium, calcium and magnesium was essentially a constant at all stages of growth. Barbier, as cited by (41) however, reported that amounts of calcium and magnesium absorbed by oats were little affected by potassium additions.

At Rothamsted (45), Italian ryegrass and kale were grown at 3 levels of 10 nutrients on a sandy loam and a clay loam. Nutrients used were: sodium, potassium, calcium, magnesium, ammonium nitrogen, nitrate nitrogen, phosphorus, chloride, sulfur and silica. Real negative interactions; i.e. antagonisms, were found between:

a) sodium with potassium and calcium.

b) potassium with sodium, calcium and magnesium.

c) ammonium nitrogen with potassium.

Real positive interactions; i.e. synergisms, were found between:

a) nitrate nitrogen with sodium, potassium and magnesium.

b) chloride with potassium.

Wallace (55) found nitrogen:potassium:magnesium ratios to be important in the nutrition of various crop plants. In the interactions between these elements, potassium exhibits antagonistic effects on the other two, whilst nitrogen appears to exert a synergistic effect on magnesium. Whether the effect of nitrogen on magnesium is a direct or an indirect effect through its antagonism towards potassium is not definitely known.

Sudangrass and ladino clover were grown by Adams and Henderson (2) on 7 soils in greenhouse experiments. They found that magnesium contents of plants at low potassium levels were greater than at adequate potassium levels for the same soil, regardless of soil pH. Decreased magnesium uptake from magnesium sufficient soils resulted at higher potassium levels in spite of increased plant growth because of the marked decrease in magnesium concentration of plants.

Stanford, Kelly and Pierre (51) found that with corn grown on a calcareous soil with a calcium carbonate equivalence of 18 percent, one effect of potassium fertilization was to reduce the amounts of calcium and magnesium per unit weight; potassium repressed absorption of these divalent cations. Total amounts of calcium and magnesium in the plant material decreased with heavier applications of potassium chloride to the soil; an observation which supports Lundegardh's contention that potassium:calcium and potassium:magnesium antagonism become dominant with increasing concentrations of potassium and causes a reduction in the absorption of the divalent cations.

Ratner, as cited by (41) stated that, depending upon the amount of exchangeable sodium, two different sodium - potassium interactions may occur in the soil.

a) where neutral sodium salts are applied to a soil low in exchangeable sodium, an increase in the availability of soil potassium to plants occurs due to an increase in the potassium concentration of the soil solution.

b) where the soil contains appreciable quantities of exchangeable sodium, addition of this cation decreases the availability of potassium to plants.

Pearson and Bernstein (39) report that increasing levels of exchangeable sodium in the soil resulted in decreasing potassium concentrations in all 6 crops studied including wheat, oats and barley, with increasing plant sodium. Calcium concentrations also decreased with increasing exchangeable sodium percentage.

F. Potassium Uptake as Influenced by Lime Content of the Soil.

Data from studies done on high lime soils and presented by Pierre and Bower (41) point to a depressing effect of calcium and magnesium on potassium absorption by corn as seen by a much higher calcium plus magnesium plant content and a much lower potassium content in corn grown on high lime soils. Kelly, as cited by (41), explains low absorption of potassium and poor corn growth on these soils as a result of the depressing effect of the high calcium concentration on potassium absorption by plants as well as the amount of exchangeable potassium that comes into solution. Allaway and Pierre, as cited by (40), showed that unproductive high lime soils of Iowa contained less exchangeable potassium, fixed more potassium into non-exchangeable form and showed a less rapid liberation of the non-exchangeable potassium than the adjacent normal soils.

York and Rogers (63) worked on the influence of lime on the solubility of potassium in soils and on its availability to plants. They found that the addition of calcium hydroxide to five acid soils increased the release of non replaceable potassium. High calcium levels in the soil were also found to either prevent absorption of potassium or to produce an unfavourable balance in the plant. The authors state the twofold influence of calcium on potassium uptake by plants as being:

a) increasing the release of non-exchangeable potassium.

b) repressing the absorption or efficient utilization of potassium by plants.

G. Some Aspects of Chemical Inhibition of Nitrification.

Turner, Warren and Andriesen (53) studied the control of nitrification of ammonium sulfate by 'N-Serve' on a loam receiving 100 pounds nitrogen per acre. They got a 62 percent recovery of ammonium nitrogen after four weeks when using a one percent concentration of 'N-Serve'. Recovery of the check treatment was 10 percent.

In a field experiment at Rothamsted (46) workers found that 'N-Serve' mixed with ammonium sulfate at one and at two percent of the weight of the nitrogen in the fertilizer only partially prevented nitrification.

Nielsen, Warder and Hinman (35) applied nitrogen in the ammonium form at 0, 7.5 and 30 ppm and 'N-Serve' at 0, 5, 15 and 30 ppm on a loam in a greenhouse experiment. The 'N-Serve' was dissolved in ethanol in the required amounts and then mixed with 300 grams of soil. The 300 grams of treated soil was then mixed with the remainder of the soil prepared for each pot, incubated for 22 days at 14°C and then sown to wheat. There was a general decrease in the nitrogen content of the tissue as 'N-Serve' increased. Nitrogen uptake decreased as rate of 'N-Serve' increased regardless of fertilizer treatment. Yields decreased at the 0 and 7.5 ppm nitrogen rates as the rate of 'N-Serve' increased. At 30 ppm nitrogen tissue yields were not significantly affected by 'N-Serve'.

H. Potassium Fixation and Release.

i) Clay Content and Clay Mineral Type

Merwin and Peech (35) studied the exchangeability of soil potassium in the sand, silt and clay fractions as influenced by the nature of the complementary exchangeable cation and found that the silts contributed from 15 to 50 percent of the potassium, the clays from 40 to 80 percent whereas the sands contributed very little of the potassium released by the four soils. Arnold (5) working with some British soils, reported similar observations.

The average amount of non-exchangeable potassium removed by H^+-resin and boiling 1 N nitric acid from the clay fraction in 11 Canadian soils was about twice that in the fine silt, about 4 times that in the medium silt and about 11 times that in the coarse silt and sand according to MacLean and Brydon (28).

ii) Effects of Wetting and Drying Temperature

Matthews and Sherrell (30) studied the effect of drying on the exchangeable potassium of Ontario soils, and the relation of exchangeable potassium to crop yield. They found that if the percent potassium saturation of the cation exchange capacity was 1.11 $\pm$ 0.2 percent, no change in amount of exchangeable potassium occurred during drying of the soil. Below this level of potassium saturation, exchangeable potassium increased upon drying; above this level, drying decreased the exchangeable potassium.

Drying different Iowa soils increased the exchangeable potassium in all of the profile samples according to Hanway and Scott (22). Generally the subsoils released more potassium on drying than the surface soils. No relation existed between the amount of potassium released on drying and the amount of released potassium that reverted to fixed form when the soils were subsequently stored under moist conditions.

Burns and Barber (10) studied the influence of temperature and moisture on the release of non-exchangeable potassium to the exchangeable form in the laboratory. They found that varying moisture from 60 to 100 percent of the moisture equivalent had no effect on the release of non-exchangeable potassium when incubated at temperatures from 1°C to 80°C. Increasing temperature caused increases in the level of exchangeable potassium in all but one case.

iii. Effects of Organic Matter and Crop Residues.

Åslander and Armolik (6) studying the influence of organic materials on potassium fixation in the soil found that organic materials did not fix potassium. Schuffelen and van der Marel (48) report that the decreased uptake of potassium sometimes observed as a result of added organic material is not brought about by a fixation reaction. The authors suggest that the reduction in potassium uptake is caused by competition between the mineral and organic matter for the exchangeable cations or by the uptake of potassium by microbes.

Addition of organic matter to soil has been reported to reduce fixation considerably. Jaffe and Lavine as cited by (6) explained this effect on the following basis: organic matter added to the soil will compete with the mineral or organic fraction of the soil for exchangeable potassium. Because of the organic matter's large exchange capacity considerable quantities of potassium from the mineral portion is diverted to it. Since organic matter is incapable of fixing potassium and since the quantity of potassium in the inorganic exchange complex has been materially lessened, fixation will be decreased. This explanation appears sound in the light of Worsham and Sturgis' (62) observation that organic matter markedly increased available potassium in soils and also increased the outgo of potassium in the leachate.

iv. Effects of Concentration of Added Potassium and pH on Potassium Fixation Release Rates.

Some factors influencing the capacity and the rate of fixation and release in a soil are discussed by Wiklander (57).

He assumes ion diffusion to be a rate determining factor in potassium fixation. Consequently, potassium fixation should be relatively rapid at the beginning and quite slow at the equilibrium point. Nutrient absorption in a cropped soil would lower the soluble potassium and exchangeable potassium fractions and consequently would allow for greater release than would occur in a fallow soil.

A second factor influencing the rate and capacity of fixation in a soil is the concentration effect. Both the capacity and rate of fixation increase with increasing concentration of the added potassium salts.

Lastly, pH affects the rate and capacity of fixation and release in a soil. Decreasing the soil pH reduces potassium fixation either as a result of H_3O^+ competition, which has a size similar to the potassium ion, for the interlayer exchange positions, or by a destruction of the lattice surface at very low pH.

Åslander and Armolik (6) state that fixation occurs fairly rapidly.

Extraction and leaching studies with dilute acid solutions varying in pH from 1 to 7 were carried out on a loam soil by Williams and Jenny (60). They found a correlation existed between pH and the amount of potassium removed from the soil. Potassium replaced with 0.1 N acid solutions with pH range between 3 and 7 was mostly from exchangeable forms, whereas that replaced at pH values below 3 included a large proportion of the non-exchangeable form.

McLean and Simon (33) expressed fixed potassium in the following form:

$$K_{fixed} = \text{applied K - increase in exchangeable K.}$$

The authors reported that if exchangeable potassium were removed by leaching or cropping, non-exchangeable potassium would become exchangeable.

v. Effects of Base Exchange Capacity and Complementary Ions on Potassium Fixation - Defixation Rates

Seatz and Winters (49) used eight soils with base exchange capacities varying from 9 to 24 me per 100 gm airdried soil and found no consistent relation between exchange capacity and potassium release. At lower potassium application rates more potassium was recovered where calcium rather than hydrogen was the complementary ion. At the highest rate, the complementary ion had little effect on the release of potassium.

Worsham and Sturgis (62) found base exchange capacity to be directly related to the amount of potassium fixed. The relationship was modified by the percentage base saturation. An increase in base saturation was associated with an increase in fixation until complete base saturation was reached.

Eleven Canadian soils ranging from a loamy sand to a silty clay loam in texture had potassium added as potassium chloride at a rate of 1.5 me per 100 gm oven dried soil by

MacLean (27). He reported that fixation in several samples increased with increase in their clay content. Samples exhibiting higher or lower fixing capacity than expected on the basis of their clay content were usually found to have correspondingly low or high degrees of potassium saturation.

Similarly Chaminade as cited by (8) related fixation of potassium to the exchange capacity of the soil and found that maximum fixation occurred if more than 4 percent of the exchange capacity was occupied by potassium.

Jenny and Ayers as cited by (43) concluded that the exchangeability of absorbed potassium decreased with decreasing degree of potassium saturation of the exchange complex, but that this effect is influenced by the nature of the complementary ion.

METHODS AND MATERIALS (General)

Soil Sampling and Preparation

a) Source

The first two greenhouse experiments were conducted on soil collected from the 0- to 6-inch depth from the Almasippi soil association in the Carman area (21). The Almasippi soils are meadow prairie and meadow soils developed on fine sandy textured deltaic and lacustrine deposits with imperfect drainage. The soils used in the remaining greenhouse experiments were collected from the same depth from a meadow and a calcareous meadow associate of the Pelan soil association located in the Grunthal district. The Pelan soil association is described as consisting of Grey-Black and associated soils developed in the Grey-Black zone on a thin mantle of reworked sandy sediments over strongly calcareous till (20).

b) Preparations

Each soil when brought into the laboratory from the field was immediately air dried, sieved through a 1/4 inch screen when dry and then mixed thoroughly. Representative samples of each soil were further passed through a 2 mm sieve and retained for analytical purposes.

Characteristics of the three soils employed are given in Tables 1 and 2.

Analytical Procedures for Soils

Exchangeable Cations

Duplicate ten-gram samples of soil were placed in one hundred ml 1 N NH_4Ac solution adjusted to pH 7.0 and containing 250 ppm Li^+ as $LiNO_3$ and shaken one hour. Calcium and magnesium in the soil extracts were determined by titration with EDTA (14); sodium and potassium by flame emission methods using a Baird-Atomic K Y 2 flame photometer (29).

Water Soluble Cations

Procedure was identical to that used for exchangeable cations except distilled water with 250 ppm Li^+ as $LiNO_3$ was used in place of 1 N NH_4Ac.

Total Potassium

Duplicate one-gram samples of air dried soil were passed through a 0.16 mm sieve and then decomposed in HF (29). The total potassium was determined by spectrochemical methods using a Beckman DU quartz spectrophotometer and suitable standards.

Potassium Supplying Power

Duplicate five-gram samples of air dried soil were extracted with boiling N HNO_3 for 10 minutes (53). The difference between the potassium extracted by this method and the exchangeable potassium is a measure of the potassium supplying power of the soil.

Analytical Procedure for Plant Material

Nitrogen

The Kjeldahl procedure as outlined by Jackson (29) was employed to determine the nitrogen content of the plant material samples.

Wet Ashing Procedure

The plant material samples were digested with a HNO_3-H_2SO_4-$HClO_4$ ternary acid mixture according to the procedure outlined by Jackson (29) except that the suggested pre-digestion with nitric acid was omitted.

Total Phosphorus

The total phosphorus content was determined colorimetrically by the vanadomolybdate yellow colour method using a suitable aliquot of the plant material digestate (29).

Calcium and Magnesium

Suitable aliquots of the plant material digestate with standard lanthanum chloride added were analyzed for calcium and magnesium by means of a Perkin-Elmer 707 atomic absorption spectrophotometer. The methods employed are outlined in Analytical Methods for Atomic Absorption Spectophotometry (3, 4).

Sodium and Potassium

A 0.2 gm sample of oven-dried, finely ground plant material was shaken on a reciprocal shaker for one hour with 100 ml 1 N NH_4Ac solution adjusted to pH 7.0 and containing 250 ppm Li^+ as $LiNO_3$. The potassium and sodium concentration of the filtrate was determined using a Baird-Atomic K Y 2 flame photometer and appropriate standard solutions.

General Seeding, Watering and Plant Handling Techniques

In all cases, 2 kgm of the specified air dried soil was placed in one-half gallon glazed porcelain pots. Phosphorus and sulfur, when applied, were banded in at the 1 inch depth in the pot. Ten seeds of the crop to be grown were sown at the 1/2 inch depth. Nitrogen and potassium when used were applied at the 1 inch depth or at the surface of the soil. Specific nitrogen and potassium fertilizer placements are discussed under the appropriate "Methods and Materials" sections of the following greenhouse experiments.

The seeded pots were brought to field capacity within 24 hours after seeding and the amount of water required to keep them at or near field capacity was estimated by weighing random pots. This was continued until growth was well advanced. Thereafter, the pots were watered daily.

The crops were thinned to six plants per pot approximately ten to twelve days after seeding and then to four plants per pot a week later. The four remaining plants represented the healthiest and best spaced plants in each individual pot. All pots were rotated on the greenhouse bench once a week.

For all greenhouse experiments conducted the plants were harvested at approximately 1/2 inch above the soil surface. The above ground portions were then clipped into 1/4- to 1/2-inch lengths, air dried for two days and placed in a forced draft oven at 70°C for 24 hours. All plants analyses were carried out on the above ground portions only.

Post Harvest Soil Treatment

Immediately after each greenhouse crop harvest, the soil from each pot was emptied and spread out to dry on a greenhouse bench. When dried, the soil from each pot was thoroughly mixed and a representative sample taken for exchangeable potassium determinations.

In the following tables and discussion, the symbols and abbreviations listed below have been used.

Nitrogen carrier abbreviations:

A.S. = $(NH_4)_2SO_4$ - Ammonium sulfate

N.A. = HNO_3 - Nitric acid

A.N. = NH_4NO_3 - Ammonium nitrate

S.N. = $NaNO_3$ - Sodium nitrate

Placement symbols

(1) N, P, K banded together 1/2 inch below seed

(2) P and K banded together 1/2 inch below seed; N added at the surface

(3) P and N banded together 1/2 inch below seed; K added at the surface

GREENHOUSE EXPERIMENTS

Experiment I

Materials and Methods

A greenhouse experiment was designed to study and compare the effects of increasing nitrogen application rates and varying nitrogen placement on yield and potassium content of oats and barley. Six fertilizer treatments for each crop with two different nitrogen placements at the two highest nitrogen levels were used. Each treatment was replicated four times.

Barley and oats were the crops grown on an Almasippi soil possessing some of the characteristics given in Tables 1 and 2. The fertilizer carriers, rates and placements employed in greenhouse experiment I are given in Table 3. A total of 64 pots were used.

Both oats and barley were harvested 46 days after seeding.

Results and Discussion

Yields of Plant Material

The data for yield of dried plant material are presented in Table 4. Oats outyielded barley for comparable treatments at all fertilizer rates. Neither barley nor oats gave a significant yield response to K only or to P-K only fertilizer applications. Increasing nitrogen resulted in significantly larger yields for oats. Barley, however, responded

TABLE 1

SOME CHARACTERISTICS OF THE SOIL

Soil type	Texture	pH	Conductivity of Sat'd extract (mmhos/cm)	Organic matter (%)	$CaCO_3$ equivalence (%)	$NaHCO_3$ extractable P (ppm)	Nitrate N (ppm)	Total N (%)	Total K (%)	K supplying power (me/100g)
Almasippi	VFSL	7.85	1.11	2.88	5.62	5.85	1.66	.124	1.42	1.10
Pelan calcareous meadow	LVFS	7.78	.42	2.15	10.89	5.02	.99	.104	1.148	.14
Pelan meadow	FS	7.73	.46	1.73	1.58	4.41	2.35	.083	1.20	.42

TABLE 2

CATION (EXCHANGEABLE AND WATER SOLUBLE) STATUS OF THE SOILS USED

Soil type	NH_4 Ac. Displaceable(me/100g)				H_2O Soluble(me/100g)				C.E.C. (me/100g)	%K Satn. of complex (%)
	K^+	Na^+	Ca^{++}	Mg^{++}	K^+	Na^+	Ca^{++}	Mg^{++}		
Almasippi	.30	.15	24.72	4.47	.10	.07	2.72	1.10	14.70	2.04
Pelan calcareous meadow	.12	.08	20.38	2.14	.06	.06	1.10	.18	8.09	1.48
Pelan meadow	.12	.11	7.64	2.00	.05	.09	.91	.23	9.95	1.21

TABLE 3. FERTILIZER CARRIERS, RATES AND PLACEMENTS USED IN GREENHOUSE EXPERIMENT I

Fertilizer Treatment	Carriers			Placements
$N-P_2O_5-K_2O$ lbs/acre	N	P	K	
0-0-0	-	-	-	
0-0-200	-	-	K_2SO_4	K banded 1/2 inch below seed
0-80-200	-	$NaH_2PO_4 \cdot H_2O$	K_2SO_4	K banded 1/2 inch below seed
40-80-200	NH_4NO_3	$NaH_2PO_4 \cdot H_2O$	K_2SO_4	N & K banded 1/2 inch below seed
(1) 80-80-200	"	"	"	N & K banded 1/2 inch below seed
(2) 80-80-200	"	"	"	K banded 1/2 inch below seed; N added at the surface
(1) 160-80-200	"	"	"	N & K banded 1/2 inch below seed
(2) 160-80-200	"	"	"	K banded 1/2 inch below seed; N added at the surface

TABLE 4. DRY WEIGHT OF PLANT MATERIAL (gms per pot)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley		Oats		Treatment average	
0-0-0	1.76	e_1	2.72	d_2	2.24	d
0-0-200	1.82	e_1	2.66	d_2	2.24	d
0-80-200	1.84	e_1	2.69	d_2	2.27	d
40-80-200	3.02	d_1	4.23	c_2	3.62	c
(1) 80-80-200	3.92	b_1c_1	4.74	b_2	4.33	b
(2) 80-80-200	4.51	a_1	4.60	b_2	4.56	a
(1) 160-80-200	3.69	c_1	5.28	a_2	4.48	ab
(2) 160-80-200	4.14	b_1	5.04	a_2	4.59	a
Crop average	3.09		4.00			

In this and all ensuing tables where Duncan's multiple range test was used, means with the same lower case letters indicate sets within which no significant differences were found ($p = 0.05$)

only to a maximum of 80 lbs nitrogen per acre; application of 160 lbs nitrogen per acre depressed barley yields. This depression was significant for placement 2.

For both the 80-80-200 and 160-80-200 fertilizer treatments larger yields obtained for oats with placement 1 but this yield response to placement 1 was not significant. Placement 2 for barley gave significantly higher yields than did placement 1.

Nitrogen and Potassium Content of Plant Material

Nitrogen and potassium contents are given in Table 5. Treatment means show a significant increase in nitrogen content of plant material with increasing nitrogen. The same trend is observed for each individual crop. No significant differences in nitrogen content of either crop with any of the placements used is noted. The initial 40 lbs nitrogen per acre produced a significant increase in nitrogen content of oats but not of barley. Regardless of placement used, nitrogen content of barley generally exceeded that of oats for comparable treatments.

Considering potassium contents, the 40-80-200 fertility level gave the lowest treatment average of all treatments used. This may be explained by the large yield response (Table 4) obtained with application of the initial 40 lbs nitrogen per acre, this increase in yield leading to a dilution of the plant potassium content. For oats no trends in potassium content

TABLE 5. NITROGEN AND POTASSIUM CONTENT OF PLANT MATERIAL (Percent)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Nitrogen			Potassium		
	Barley	Oats	Treatment average	Barley	Oats	Treatment average
0-0-0	1.25 c_1	1.06 d_2	1.16 d	3.29 c_1	2.96 b_2	3.12 cd
0-0-200	1.22 c_1	.97 d_2e_2	1.10 d	3.18 c_1d_1	3.17 a_2	3.17 bc
0-80-200	1.26 c_1	.92 e_2	1.09 d	3.26 c_1	3.16 a_2	3.21 bc
40-80-200	1.27 c_1	1.23 c_2	1.25 c	3.05 d_1	3.01 a_2b_2	3.03 d
(1) 80-80-200	1.58 b_1	1.59 b_2	1.59 b	3.35 b_1c_1	3.15 a_2b_2	3.25 abc
(2) 80-80-200	1.58 b_1	1.57 b_2	1.58 b	3.30 c_1	3.03 a_2b_2	3.16 bcd
(1) 160-80-200	2.40 a_1	2.20 a_2	2.30 a	3.52 a_1b_1	3.04 a_2b_2	3.28 ab
(2) 160-80-200	2.44 a_1	2.21 a_2	2.33 a	3.61 a_1	3.14 a_2b_2	3.38 a
Crop average	1.63	1.47		3.32	3.08	

with increasing rates of nitrogen or with use of different nitrogen placements can be established. Varying the placement of nitrogen appeared to bear little effect upon the potassium content of barley, although, unlike oats, increasing the nitrogen rate gave a significant increase in potassium content.

Nitrogen and Potassium Uptake by Barley and Oats

Nitrogen and potassium uptake by oats was generally larger than that by barley for comparable treatments (Table 6). Generally, both nitrogen and potassium uptake for both crops increased with increasing nitrogen. Recovery of applied nitrogen was calculated and the data are represented in Appendix I.

Regardless of crop grown or of fertilizer treatment used, both the potassium content and uptake were larger than the nitrogen content and uptake for comparable treatments.

Phosphorus, Sodium, Calcium and Magnesium Contents

Table 7 outlines the data for the phosphorus, sodium, calcium and magnesium contents of the plant material, For comparable treatments the phosphorus content of barley was greater than that of oats, the difference being most pronounced for the no nitrogen treatments. Increasing rates of applied nitrogen decreased the phosphorus content of barley but did not greatly affect that of oats.

The sodium content of both barley and oats increased

TABLE 6. NITROGEN AND POTASSIUM UPTAKE BY BARLEY AND OATS (mgs per pot)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Nitrogen			Potassium		
	Barley	Oats	Treatment average	Barley	Oats	Treatment average
0-0-0	22.1 f_1	28.9 d_2	25.5 e	57.9 d_1	80.7 e_2	69.3 e
0-0-200	21.9 f_1	25.9 d_2	23.9 e	57.2 d_1	84.3 e_2	70.7 e
0-80-200	23.1 f_1	24.8 d_2	23.9 e	60.0 d_1	85.2 e_2	72.6 e
40-80-200	38.2 e_1	52.9 c_2	45.6 d	91.9 c_1	128 d_2	110 d
(1) 80-80-200	61.9 d_1	75.4 b_2	68.7 c	131 b_1	149 b_2	140 c
(2) 80-80-200	70.7 c_1	72.0 b_2	71.4 c	149 a_1	139 c_2	144 b
(1) 160-80-200	88.6 b_1	116 a_2	102 b	130 b_1	160 a_2	145 b
(2) 160-80-200	101 a_1	112 a_2	106 a	149 a_1	158 a_2	154 a
Crop average	53.4	63.5		103	123	

TABLE 7. PHOSPHORUS, SODIUM, CALCIUM AND MAGNESIUM CONTENTS OF PLANT MATERIAL (Percent)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Phosphorus		Sodium		Calcium		Magnesium	
	barley	oats	barley	oats	barley	oats	barley	oats
0-0-0	.72	.41	.75	.15	.42	.42	.36	.26
0-0-200	.73	.44	.60	.18	.42	.39	.30	.25
0-80-200	.86	.66	1.00	.26	.43	.30	.36	.26
40-80-200	.73	.42	1.25	.49	.35	.54	.32	.26
(1) 80-80-200	.66	.41	1.35	.60	.40	.37	.30	.32
(2) 80-80-200	.64	.42	1.30	.60	.39	.39	.32	.25
(1) 160-80-200	.47	.41	1.44	1.08	.49	.39	.35	.28
(2) 160-80-200	.48	.40	1.42	1.23	.46	.32	.32	.26
Crop average	0.66	0.45	1.14	0.57	0.42	0.39	0.33	0.27

with increasing nitrogen, the increase being much larger for oats than for barley. This may possibly be explained by better plant growth at the higher fertilizer rates and consequently more absorption of sodium by the plants. The phosphorus carrier employed, $NaH_2PO_4 \cdot H_2O$, provided a source of available sodium to the plant. The sodium content in barley was much larger than that of oats for comparable treatments. No significant differences were noted in phosphorus and sodium contents of either crop with different placements.

The calcium and magnesium contents of barley are generally larger than those of oats for comparable treatments. Neither barley nor oats appear to show any consistent trend in calcium or magnesium content with fertilizer rate. Placement 2 led to depressed calcium and magnesium contents of both crops at the 160-80-200 fertility level. Generally for any one crop the calcium content tended to be larger than the magnesium content for comparable treatments.

Potassium Uptake

Data for potassium uptake (Table 8) reveal generally larger uptake for oats than for barley when comparable treatments are considered. For similar placements, potassium uptake increased significantly with increasing nitrogen. For barley, potassium uptake increases with use of placement 2 are significant at both the 80-80-200 and 160-80-200 fertilizer rates. With oats use of placement 2 lowered the uptake of potassium.

TABLE 8. POTASSIUM UPTAKE (Percent of added potassium)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley	Oats	Treatment average
40-80-200	46.0 c_1	64.1 d_2	55.1 d
(1) 80-80-200	65.6 b_1	74.6 b_2	70.1 c
(2) 80-80-200	74.5 a_1	69.5 c_2	72.0 bc
(1) 160-80-200	64.9 b_1	80.1 a_2	72.5 b
(2) 160-80-200	74.7 a_1	79.1 a_2	76.9 a
Crop average	65.1	73.5	

Release and Fixation of Potassium

The data for potassium released and fixed are outlined in Table 9. For all fertilizer treatments with the exception of the 160-80-200 rate, regardless of placement, soil cropped to oats fixed greater quantities of applied potassium than soil cropped to barley. Greater potassium fixation occurred at the no nitrogen treatments or at low application rates of nitrogen than at the higher levels of nitrogen. This would be expected since plant utilization of potassium is less for these treatments than for the treatments receiving high nitrogen rates of application and consequently more available potassium may be subjected to fixation. Potassium uptake data (Table 6) confirm this observation.

Ca:K and N:K Ratios of Plant Material

These ratios (Table 10) are quite similar for both crops. Little consistent difference in Ca:K ratios appears with increasing nitrogen for either of the crops. On the other hand, N:K ratios increased with increasing nitrogen.

TABLE 9. RELEASE (+) AND FIXATION (-) OF POTASSIUM IN SOIL CROPPED TO OATS AND BARLEY (ppm)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley	Oats	Treatment average
0-0-0	+29.1	+30.6	+29.9
0-0-200	-26.8	-35.5	-31.2
0-80-200	-26.1	-28.2	-27.2
40-80-200	-17.6	-34.6	-26.1
(1) 80-80-200	-12.8	-18.2	-15.5
(2) 80-80-200	-11.6	-25.4	-18.5
(1) 160-80-200	-16.4	-15.2	-15.8
(2) 160-80-200	-21.6	-16.7	-19.2
Crop average	-13.0	-17.9	

1. Potassium released (+) or fixed (-) = potassium content of crop - (Initial potassium + fertilizer potassium - residual potassium).

TABLE 10. Ca:K AND N:K RATIOS OF PLANT MATERIAL

(Calculated on basis of eqvt.wt. per unit wt.)*

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Ca:K ratio		N:K ratio	
	barley	oats	barley	oats
0-80-200	.26	.19	1.08	.81
40-80-200	.22	.35	1.16	1.15
(1) 80-80-200	.23	.23	1.32	1.41
(2) 80-80-200	.23	.25	1.34	1.44
(1) 160-80-200	.27	.25	1.91	2.03
(2) 160-80-200	.25	.20	1.89	1.97
Crop average	0.24	0.25	1.45	1.47

* N assumed to have a valence of one.

Experiment II

Materials and Methods

Greenhouse experiment II was conducted to study and compare yield, potassium content and uptake from native and applied potassium sources by oats and barley using different nitrogen forms and placements. Basically, greenhouse experiment II was similar to the first greenhouse experiment, but differed from it in that three nitrogen forms were employed in combination with two nitrogen placements.

A total of 104 one-half gallon porcelain pots were prepared with Almasippi soil. Both oats and barley were grown. Table 11 outlines the different fertilizer rates, carriers and placements used in greenhouse experiment II. Each treatment was replicated four times.

Both crops were harvested 50 days after seeding.

Results and Discussion

Yields of Plant Material

Plant material yields (Table 12) for the 0-0-0 treatment of both crops were significantly lower than those of any one of the remaining fertilizer treatments. Fertilized barley with or without added potassium gave larger yields than fertilized oats for comparable treatments except when A.S. was the nitrogen form used. In this case oats and barley gave approximately equivalent plant yields. The only consistent increase

TABLE 11. FERTILIZER CARRIERS, RATES AND PLACEMENTS USED IN GREENHOUSE EXPERIMENT II

Fertilizer Treatment	Carriers			Placements
$N-P_2O_5-K_2O$ lbs/acre	N	P	K	
0-0-0	-	-	-	
(1) 160-100-0	$(NH_4)_2SO_4$	$NaH_2PO_4 \cdot H_2O$	-	N banded 1/2 inch below seed
(1) 160-100-0	HNO_3	"	-	" "
(1) 160-100-0	$NaNO_3$	"	-	" "
(2) 160-100-0	$(NH_4)_2SO_4$	"	-	N added at the surface
(2) 160-100-0	HNO_3	"	-	" "
(2) 160-100-0	$NaNO_3$	"	-	" "
(1) 160-100-140	$(NH_4)_2SO_4$	K_2HPO_4	K_2HPO_4	N & K banded 1/2 inch below seed
(1) 160-100-140	HNO_3	"	"	" "
(1) 160-100-140	$NaNO_3$	"	"	" "
(2) 160-100-140	$(NH_4)_2SO_4$	"	"	K banded 1/2 inch below seed; N added at the surface
(2) 160-100-140	HNO_3	"	"	" "
(2) 160-100-140	$NaNO_3$	"	"	" "

TABLE12 . DRY WEIGHT OF PLANT MATERIAL (gms per pot)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley	Oats	Treatment average
0-0-0	.79 f_1	.96 f_2	.88 g
(1) 160-100-0 A.S.	2.75 $b_1c_1d_1$	2.77 $b_2c_1d_1$	2.76 c
(1) 160-100-0 N.A.	2.57 d_1e_1	2.30 d_2e_2	2.44 ef
(1) 160-100-0 S.N.	2.59 $c_1d_1e_1$	2.47 d_2	2.53 de
(2) 160-100-0 A.S.	3.08 a_1	3.01 a_2b_2	3.05 a
(2) 160-100-0 N.A.	2.58 $c_1d_1e_1$	2.30 d_2e_2	2.44 ef
(2) 160-100-0 S.N.	2.90 a_1b_1	2.52 c_2d_2	2.71 cd
(1) 160-100-140 A.S.	2.87 $a_1b_1c_1$	3.06 a_2	2.96 ab
(1) 160-100-140 N.A.	2.84 $a_1b_1c_1d_1$	2.17 e_2	2.51 e
(1) 160-100-140 S.N.	2.74 $b_1c_1d_1$	2.13 e_2	2.44 ef
(2) 160-100-140 A.S.	2.83 $a_1b_1c_1d_1$	2.80 $a_2b_2c_2$	2.82 b
(2) 160-100-140 N.A.	2.39 e_1	2.19 e_2	2.29 f
(2) 160-100-140 S.N.	2.45 e_1	2.17 e_2	2.31 f
Crop average	2.57	2.37	

in yield with potassium application occurred with placement 1 for barley only. For this crop and placement yield increases, although not significant, were recorded for all three nitrogen forms.

Treatment means show a significant increase in yield with use of the A.S. form over the other two nitrogen sources. This is in close agreement with previous work (1) which attributed the increased yield to better root distribution and root growth of the plant fertilized with the NH_4^+ form of nitrogen.

Regardless of placement or fertilizer rate used the A.S. form gave significantly larger oat yields than did the N.A. or S.N. forms. For barley, yield increases with use of the A.S. form were less pronounced. Placement effects on yield, as seen by treatment means, do not follow a definite trend. For all nitrogen forms used application of potassium depressed yields of both crops with placement 2. The amount of this depression was calculated and is presented in Appendix II. This yield depression with potassium fertilization was significant only for the S.N. source and indicates a significant sodium-potassium interaction in the nutrition of both crops.

For all three forms of nitrogen used, barley plant yields are larger for placement 1 than for placement 2 at the 160-100-140 fertilizer rate, and larger for placement 2 than for placement 1 at the 160-100-0 level. Oat yields responded similarly to placement and fertility level only for the A.S. form; the N.A. and S.N. forms of nitrogen showing little response to either placement at any fertility level.

Of all three nitrogen forms used, N.A. resulted in the lowest yields for both crops, regardless of placement, at the 160-100-0 fertilizer rate. Except for barley with placement 2 at the 160-100-0 level there were no significant crop yield differences between the S.N. and N.A. forms.

Nitrogen and Potassium Content of Plant Material

From the data presented in Table 13 it is observed that nitrogen content of barley generally exceeds that of oats, the exceptions being the A.S. form with placement 2 at both the 160-100-0 and 160-100-140 fertility levels. Nitrogen contents of both crops at the 0-0-0 level are significantly lower than for the fertilized treatments.

For all three nitrogen forms, at the 160-100-0 level, nitrogen contents of both crops are lower for placement 2 than for placement 1 except for oats fertilized with S.N. However, the difference in nitrogen content between placements is significant only for the A.S. form.

Of all three nitrogen forms used, the nitrogen content of barley was highest with the A.S. carrier for both the 160-100-0 and 160-100-140 fertilizer rates when placement 1 was employed. At the same fertilizer rates with placement 2 the same carrier gave the lowest nitrogen contents for barley. Generally, the nitrogen content of barley is higher though not significantly so, with the N.A. form than with S.N.

TABLE 13. NITROGEN AND POTASSIUM CONTENT OF PLANT MATERIAL (Percent)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre		Nitrogen			Potassium		
		Barley	Oats	Treatment average	Barley	Oats	Treatment average
0-0-0		1.81 f_1	1.78 d_2	1.80 f	4.44 b_1c_1	3.70 a_2	4.07 bc
(1) 160-100-0	A.S.	3.83 a_1	3.53 a_2	3.68 a	3.34 g_1	3.24 c_2d_2	3.29 fg
(1) 160-100-0	N.A.	3.49 b_1	3.18 b_2c_2	3.34 bc	4.07 d_1e_1	3.30 c_2d_2	3.68 e
(1) 160-100-0	S.N.	3.26 b_1c_1	3.07 b_2c_2	3.17 cde	3.44 g_1	2.88 e_2	3.16 g
(2) 160-100-0	A.S.	2.81 e_1	3.14 b_2c_2	2.97 e	3.49 g_1	2.99 e_2	3.24 g
(2) 160-100-0	N.A.	3.47 b_1	3.04 c_2	3.25 bcd	4.36 b_1c_1	3.43 b_2c_2	3.89 d
(2) 160-100-0	S.N.	3.13 c_1d_1	3.12 b_2c_2	3.13 de	3.73 f_1	3.12 d_2	3.42 f
(1) 160-100-140	A.S.	3.41 b_1c_1	3.11 b_2c_2	3.26 bcd	4.37 b_1c_1	3.71 a_2	4.04 bcd
(1) 160-100-140	N.A.	3.39 b_1c_1	3.15 b_2c_2	3.27 bcd	4.23 c_1d_1	3.70 a_2	3.96 cd
(1) 160-100-140	S.N.	3.29 b_1c_1	3.37 a_2b_2	3.33 bcd	3.99 e_1	3.31 c_2d_2	3.65 e
(2) 160-100-140	A.S.	2.96 d_1e_1	3.05 c_2	3.00 e	4.58 b_1	3.75 a_2	4.16 b
(2) 160-100-140	N.A.	3.49 b_1	3.25 $a_2b_2c_2$	3.37 bc	5.15 a_1	3.77 a_2	4.46 a
(2) 160-100-140	S.N.	3.53 a_1b_1	3.32 $a_2b_2c_2$	3.43 b	4.33 c_1	3.63 a_2b_2	3.98 cd
Crop average		3.22	3.09		4.12	3.43	

For oats at the 160-100-140 fertilizer rate, regardless of placement used, A.S. gave the lowest nitrogen contents of the three nitrogen forms. However, none of these differences in nitrogen content with different nitrogen forms had any statistical significance with the exception of the A.S. form at the 160-100-0 fertilizer level.

Potassium content of both crops (Table 13) increased with application of potassium. Potassium content of barley invariably exceeds that of oats for comparable treatments. Also, for similar treatments for both crops, potassium content is larger with placement 2 than with 1. This difference in potassium content with placement is significant for both crops with the S.N. form at both the 160-100-0 and 160-100-140 fertilizer rates.

The lower plant potassium content associated with placement 1 may be attributed partly to yield differences and partly to the increased concentration of nitrogen in the soil solution immediate to the plant root. Previous workers (31) report decreased phosphorus, potassium and sodium contents with higher nitrogen concentration of the solution.

Considering the 160-100-140 fertilizer rate, the depression in potassium content of both crops fertilized with S.N. suggests a K^+-Na^+ interaction (39). This depression is significant for placement 1 where the two interacting cations are more intimately associated.

For both placements at the 160-100-0 fertilizer rate, and for both crops with the exception of oats with placement 1, potassium content is significantly larger for the N.A. form than for any of the other two forms used.

The larger K content with the N.A. form reflects yield differences as well as a shift in equilibrium between non-exchangeable and exchangeable potassium resulting from disruption of the soil mineral lattices by the strong acid carrier (57, 60).

At the 160-100-140 fertility level with placement 2, N.A. gave significantly larger potassium contents than did any of the other nitrogen sources for barley, and larger, though not significantly so, for oats as well.

Nitrogen and Potassium Uptake by Barley and Oats

The data for nitrogen and potassium uptake by barley and oats are outlined in Table 14. Nitrogen uptake parallels nitrogen content in that barley uptake of nitrogen exceeded that of oats for all treatments except the A.S. form with placement 2. Treatment means of nitrogen uptake indicate that for any one fertilizer rate and placement the A.S. form with the exception of the 160-100-140 level with placement 2, gave significantly larger uptake than either of the other nitrogen forms. The larger nitrogen uptake associated with the A.S. form results from a combination of higher plant yields and higher nitrogen contents derived from this nitrogen form.

With oats, the A.S. gave significantly higher nitrogen

TABLE 14. NITROGEN AND POTASSIUM UPTAKE BY BARLEY AND OATS (mgs per pot)

Fertilizer treatment $N-P_2O_5-K_2O$		Nitrogen			Potassium		
		Barley	Oats	Treatment average	Barley	Oats	Treatment average
0-0-0		14.3 e_1	17.1 e_2	15.7 g	35.1 e_1	35.5 e_2	35.3 f
(1) 160-100-0	A.S.	106 a_1	97.6 a_2	101 a	91.8 d_1	89.4 b_2	90.6 d
(1) 160-100-0	N.A.	89.5 $b_1c_1d_1$	73.1 c_2d_2	81.3 def	105 c_1	75.8 c_2d_2	90.2 d
(1) 160-100-0	S.N.	84.4 d_1	75.2 c_2d_2	80.1 def	88.9 d_1	71.0 d_2	80.0 e
(2) 160-100-0	A.S.	86.5 d_1	94.4 a_2	90.5 c	108 c_1	89.8 b_2	98.8 bc
(2) 160-100-0	N.A.	89.4 c_1d_1	70.0 d_2	79.7 def	112 b_1c_1	78.7 c_2d_2	95.6 bcd
(2) 160-100-0	S.N.	90.6 $b_1c_1d_1$	78.1 b_2c_2	84.4 d	108 c_1	78.4 c_2d_2	93.2 cd
(1) 160-100-140	A.S.	97.7 a_1b_1	95.2 a_2	96.4 a	125 a_1	114 a_2	119 a
(1) 160-100-140	N.A.	96.4 b_1c_1	69.9 d_2	83.2 de	120 a_1b_1	82.1 b_2c_2	101 b
(1) 160-100-140	S.N.	90.2 $b_1c_1d_1$	71.7 c_2d_2	80.9 def	109 c_1	70.5 d_2	90.0 d
(2) 160-100-140	A.S.	83.8 d_1	85.5 b_2	84.6 d	130 a_1	105 a_2	117 a
(2) 160-100-140	N.A.	83.5 d_1	71.3 c_2d_2	77.4 f	123 a_1	82.8 b_2c_2	103 b
(2) 160-100-140	S.N.	86.5 d_1	72.2 c_2d_2	79.3 def	106 c_1	78.8 c_2d_2	92.4 cd
Crop average		84.5	74.7		105	80.9	

uptake than either of the other two nitrogen forms, regardless of placement or fertilizer rate used. Data on the recovery of applied nitrogen presented in Appendix III reflects this. For barley, only the 160-100-0 fertility level with placement 1 had the A.S. form giving nitrogen uptake significantly higher than for the other nitrogen forms. No significant trend between placement and nitrogen uptake can be established for either crop.

Treatment means (Table 14) indicate potassium uptake to be significantly larger, regardless of nitrogen form, for the 160-100-140 than for the 160-100-0 fertility level. The one exception is the S.N. form with placement 2. Also, potassium uptake of barley is larger than that of oats for equivalent treatments with the exception of the 0-0-0 treatment. The difference between the two crops, which agrees with literature previously cited (6, 14, 26),is particularly large for the N.A. form, irrespective of placement or fertility rate.

Generally, placement 2 led to larger potassium uptake for both crops than did placement 1 regardless of fertilizer rate or nitrogen form used. None of the enhanced potassium uptake with use of placement 2 is significant in the case of the oat crop; however, for barley, for both the A.S. and S.N. forms at the 160-100-0 fertility level, placement 2 gave significantly larger potassium uptake than placement 1.

Phosphorus, Sodium, Calcium and Magnesium Content of Plant Material

The phosphorus, sodium, calcium and magnesium contents of oats and barley are outlined in Table 15. The phosphorus content of barley was higher than that of oats for comparable treatments with the exception of the 0-0-0 treatment.

For barley, regardless of placement or fertilizer rate used, the S.N. carrier gave consistently higher phosphorus contents than either of the two other nitrogen forms.

The 160-100-140 fertilizer rate, irrespective of placement or nitrogen form and for comparable treatments gave considerably lower phosphorus contents than did the 160-100-0 fertilizer rate for barley. This is also true for oats, the difference between the two fertility levels being less pronounced than for barley.

Plant material yields for the two fertility levels were not significantly different. Consequently the above reults suggest possible differences in the efficiency of the two phosphorus carriers utilized, i.e., $NaH_2PO_4.H_2O$ for the 160-100-0 level and K_2HPO_4 for the 160-100-140 level.

For both the N.A. and A.S. carriers, for comparable treatments, oats possessed larger sodium contents than did barley. With the S.N. carrier sodium content of barley exceeded that of oats for both placements and fertility rates. Thus, it would appear that given a readily available source of sodium, barley will absorb more sodium than will oats.

As would be expected, use of the S.N. carrier led to the highest sodium content for both crops.

Sodium content of both crops decreased with potassium fertilization. The reason for the depression is mainly related

TABLE 15 . PHOSPHORUS, SODIUM, CALCIUM AND MAGNESIUM CONTENTS OF PLANT MATERIAL (Percent)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Phosphorus		Sodium		Calcium		Magnesium	
	barley	oats	barley	oats	barley	oats	barley	oats
0-0-0	.14	.36	.17	.10	.62	.21	.30	.26
(1) 160-100-0 A.S.	.39	.34	.88	.96	1.05	.43	.46	.37
(1) 160-100-0 N.A.	.41	.27	.67	.74	.34	.35	.43	.33
(1) 160-100-0 S.N.	.47	.24	1.36	1.17	.48	.25	.38	.28
(2) 160-100-0 A.S.	.35	.25	.63	.85	.73	.51	.45	.34
(2) 160-100-0 N.A.	.43	.26	.66	.69	1.02	.49	.43	.34
(2) 160-100-0 S.N.	.44	.25	1.25	1.10	.72	.42	.36	.32
(1) 160-100-140 A.S.	.30	.22	.27	.33	.65	.33	.42	.25
(1) 160-100-140 N.A.	.32	.25	.32	.46	.66	.32	.39	.28
(1) 160-100-140 S.N.	.33	.23	1.06	.86	.55	.29	.37	.27
(2) 160-100-140 A.S.	.28	.22	.22	.32	.85	.93	.40	.37
(2) 160-100-140 N.A.	.35	.26	.29	.35	.86	.79	.42	.42
(2) 160-100-140 S.N.	.37	.25	1.19	.84	.61	.70	.36	.35
Crop average	0.35	0.26	0.69	0.67	0.74	0.46	0.40	0.32

to the phosphorus and potassium carriers employed.

Generally, sodium content of both crops was larger for placement 1 than for placement 2 considering comparable treatments. At the 160-100-140 fertility level the N.A. form gave higher sodium contents for both crops than did the A.S. carrier regardless of placement used. Perhaps an explanation for this observation would involve a comparison of the NH_4^+ and NO_3^- forms; the cationic form, i.e., NH_4^+ exerting a depressive effect upon the uptake of sodium by both crops. This observation does not hold true for the 160-100-0 fertility level in which case the phosphorus is supplied as $NaH_2PO_4 \cdot H_2O$.

From Table 15 it may be seen that the calcium and magnesium contents of barley were generally larger than those of oats for similar treatments. Also for any one crop, generally calcium contents were larger than magnesium contents for comparable treatments. With few exceptions, the calcium contents of both crops regardless of carrier or fertilizer rate used, were larger for placement 2 than for the alternate placement for similar treatments.

Unlike calcium, placement of fertilizer did not have much effect upon the magnesium content of either crop. Application of potassium had a depressing effect upon the magnesium content of both crops having placement 1. This observation held true regardless of nitrogen form and may be attributed to magnesium-potassium antagonism. Similar observations have previously been reported by several workers (2, 9, 23, 41).

The S.N. carrier generally depressed both the calcium and magnesium contents of both crops for both placements at the 160-100-0 and 160-100-140 fertilizer rates. This is in close agreement with previously reported work (39, 45).

Potassium Recovery

Barley had larger potassium recoveries (Table 16) than did oats for comparable treatments. Treatment means of potassium recoveries show no significant differences between placements for any of the nitrogen forms; the highest potassium recoveries being made with the A.S. form and the least with the S.N. form.

For barley, regardless of placement used, the A.S. form gave the highest potassium recovery values. The S.N. form gave significantly lower potassium recoveries, for both placements used, than either of the two other nitrogen forms.

For oats, irrespective of placement, potassium recoveries were significantly larger for the A.S. form than for either of the other two nitrogen forms used.

Potassium Released or Fixed

From the data recorded in Table 17 it may be seen that the release characteristics of the soil cropped to oats and to barley were quite similar for the 160-100-0 treatment. For both crops regardless of placement, release of potassium from non-exchangeable forms was greatest generally for the A.S. carrier

TABLE 16. POTASSIUM RECOVERY (percent)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley		Oats		Treatment average	
(1) 160-100-140 A.S.	94.3	a_1b_1	85.5	a_2	89.9	a
(1) 160-100-140 N.A.	90.3	b_1	61.9	b_2	76.1	b
(1) 160-100-140 S.N.	82.5	c_1	53.1	c_2	67.8	c
(2) 160-100-140 A.S.	97.7	a_1	79.3	a_2	88.5	a
(2) 160-100-140 N.A.	92.7	a_1b_1	62.3	b_2	77.5	b
(2) 160-100-140 S.N.	79.9	c_1	59.4	b_2	69.6	c
Crop average	89.6		66.9			

1. Percent potassium recovery = $\frac{\text{yield of potassium}}{\text{potassium applied}} \times 100$

TABLE 17. RELEASE (+) AND FIXATION (-) OF POTASSIUM IN SOIL CROPPED TO OATS AND BARLEY (ppm)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre		Barley	Oats	Treatment average
0-0-0		+23.3	+28.1	+25.7
(1) 160-100-0	A.S.	+47.2	+49.0	+48.1
(1) 160-100-0	N.A.	+39.2	+38.5	+38.9
(1) 160-100-0	S.N.	+31.3	+39.8	+35.6
(2) 160-100-0	A.S.	+46.0	+43.9	+45.0
(2) 160-100-0	N.A.	+45.5	+38.0	+41.8
(2) 160-100-0	S.N.	+47.0	+37.5	+42.3
(1) 160-100-140	A.S.	-12.1	- 9.6	-10.8
(1) 160-100-140	N.A.	-11.4	-17.4	-14.4
(1) 160-100-140	S.N.	-16.4	-10.1	-13.3
(2) 160-100-140	A.S.	- 2.2	-12.2	- 7.2
(2) 160-100-140	N.A.	- 4.2	-17.6	-10.9
(2) 160-100-140	S.N.	- 6.5	-14.7	-10.6
Crop average		+17.4	+14.9	

1. Potassium released (+) or fixed (-) = potassium content of crop - (Initial potassium + fertilizer potassium - residual potassium).

at the 160-100-0 fertility level. At the 160-100-140 fertility level use of placement 2 gave a smaller amount of fixation for the soil cropped to barley and a larger amount for that cropped to oats than did placement 1. This was true of all three nitrogen forms used.

Ca:K and N:K Ratios of Plant Material

The Ca:K and N:K ratios of both crops are presented in Table 18. Regardless of placement, fertilizer rate or nitrogen form used, the Ca:K ratios were generally larger and the N:K ratios smaller, for barley than for oats. However, for the 160-100-140 fertilizer level with placement 2, oats gave larger Ca:K ratios than did barley regardless of nitrogen form employed.

Generally, for both crops grown and for all three nitrogen forms within each fertility level, the Ca:K ratios were larger for placement 2 than for placement 1. Also, irrespective of placement or nitrogen form used, for barley, addition of potassium, lowered the Ca:K ratios.

For oats the A.S. form generally gave higher Ca:K ratios than any of the other two nitrogen forms no matter what placement or fertility level was used. Regardless of placement or fertilizer used, for both crops the S.N. form led to the lowest Ca:K ratios. This may be due to the fact that the depressive effect of sodium upon calcium is greater than that upon potassium therefore leading to a lower Ca:K ratio. The greatest depression of the Ca:K ratio with the S.N. occurs with placement

TABLE 18 . Ca:K AND N:K RATIOS OF PLANT MATERIAL

(Calculated on basis of eqvt.wt. per unit wt.)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre		Ca:K ratio		N:K ratio	
		barley	oats	barley	oats
(1) 160-100-0	A.S.	.61	.26	3.21	3.05
(1) 160-100-0	N.A.	.40	.21	2.40	2.70
(1) 160-100-0	S.N.	.27	.17	2.65	2.98
(2) 160-100-0	A.S.	.41	.33	2.24	2.93
(2) 160-100-0	N.A.	.45	.28	2.22	2.48
(2) 160-100-0	S.N.	.38	.26	2.34	2.80
(1) 160-100-140	A.S.	.29	.17	2.18	2.34
(1) 160-100-140	N.A.	.30	.17	2.24	2.38
(1) 160-100-140	S.N.	.27	.17	2.30	2.84
(2) 160-100-140	A.S.	.36	.48	1.80	2.27
(2) 160-100-140	N.A.	.32	.41	1.89	2.41
(2) 160-100-140	S.N.	.27	.37	2.28	2.56
Crop average		0.36	0.27	2.31	2.65

N assumed to have a valence of one.

1 N assumed to have a valence of one.

1 for the 160-100-0 fertilizer rate and with placement 2 for the 160-100-140 rate.

Considering N:K ratios at the 160-100-0 fertility level, the N.A. form gave the lowest N:K ratios of all nitrogen forms and, generally, the A.S. gave the highest regardless of placement employed for both crops.

These results may be explained as a compound effect of the larger yields associated with the A.S. form and the higher K contents derived from the N.A. form. Also at the same fertility level placement 2 gave lower N:K ratios than placement 1 for comparable treatments and for all nitrogen forms.

At the 160-100-140 fertility level however, the highest N:K ratios for both crops considering comparable treatments, were associated with the S.N. form and the lowest were obtained with the A.S. form regardless of placement used. Again, generally lower ratios resulted from use of placement 2 than from placement 1 for both crops.

Experiment III

The experiments reported earlier showed the existence of differences in yields, potassium content and uptake by oats and barley with different nitrogen forms and placements. Since only small yield increases were obtained with potassium fertilization in greenhouse experiment II, it was decided to extend the study of the effects of varying nitrogen form and placement to include soils known to be responsive to potassium. Thus greenhouse experiment III was initiated to study and compare the effect of different nitrogen forms and nitrogen-potassium placements on yield, potassium content and uptake by barley grown on a calcareous and a non-calcareous soil of low exchangeable potassium status. Barley was chosen as the test crop because of its interesting behaviour and response to nitrogen form and placement variations.

The soils used for this study were a Pelan meadow - and a Pelan calcareous meadow soil. Some of their characteristics are given in Tables 1 and 2.

Twenty fertilizer carrier-placement treatments replicated four times each were used in greenhouse experiment III for a total of 160 pots. A blanket application of 20 mgm S per pot as $MgSO_4$ was made at 1/2 inch below the seed depth. The fertilizer rates, carriers and placement employed in this greenhouse experiment are given in Table 19.

The barley was harvested 41 days after seeding.

TABLE 19 FERTILIZER CARRIERS, RATES AND PLACEMENTS USED IN GREENHOUSE EXPERIMENT III

Fertilizer treatment	Carriers				Placements
$N-P_2O_5-K_2O-S$ lbs/acre	N	P	K	S	
0-0-0-20	-	-	-	$MgSO_4$	
(1) 0-0-200-20	-	-	KCl	"	K banded 1/2 inch below seed
(3) 0-0-200-20	-	-	"	"	K added at the surface
(1) 0-400-200-20*	-	H_3PO_4	"	"	K banded 1/2 inch below seed
(3) 0-400-200-20	-	"	"	"	K added at the surface
(1) 160-400-0-20	$(NH_4)_2SO_4$	"	-	"	N banded 1/2 inch below seed
(2) 160-400-0-20	"	"	-	"	N added at the surface
(1) 160-400-0-20	HNO_3	"	-	"	N banded 1/2 inch below seed
(2) 160-400-0-20	"	"	-	"	N added at the surface
(1) 160-400-0-20	$(NH_4)NO_3$	"	-	"	N banded 1/2 inch below seed
(2) 160-400-0-20	"	"	-	"	N added at the surface
(1) 160-400-200-20	$(NH_4)_2SO_4$	"	KCl	"	N & K banded together 1/2 inch below seed
(2) 160-400-200-20	"	"	"	"	K banded 1/2 inch below seed; N added at the surface
(3) 160-400-200-20	"	"	"	"	N banded 1/2 inch below seed; K added at the surface
(1) 160-400-200-20	HNO_3	"	"	"	N & K banded together 1/2 inch below seed
(2) 160-400-200-20	"	"	"	"	K banded 1/2 inch below seed; N added at the surface
(3) 160-400-200-20	"	"	"	"	N banded 1/2 inch below seed; K added at the surface
(1) 160-400-200-20	$(NH_4NO_3$	"	"	"	N & K banded together 1/2 inch below seed
(2) 160-400-200-20	"	"	"	"	K bandedv1/2 inch below seed; N added at the surface
(3) 160-400-200-20	"	"	"	"	N banded 1/2 inch below seed; K added at the surface

* The higher P_2O_5 rate in this experiment was due to a miscalculation.

Results and Discussion

Yield of Plant Material

Data for yield of dried plant material are recorded in Table 20. Barley plant material yields on the calcareous soil are invariably larger than those on the non-calcareous soil for comparable treatments at the 160-400-0-20 and 160-400-200-20 fertilizer rates. This difference in plant yields with the two soils is most pronounced for the A.S. form at both fertility levels and regardless of placement used. For treatments receiving no nitrogen, barley yields for both soils were comparable considering similar placement and fertility levels.

Treatment means of both soils show no significant differences in barley plant yields amongst treatments receiving no-nitrogen. However, the 0-400-200-20 level irrespective of placement used, outyielded any of the other no-nitrogen treatments. Considering each soil individually it is noted that the non-calcareous soil benefitted most from phosphorus application. This observation may be explained by the higher initial NO_3^-N or by the more serious phosphorus deficiency of the non-calcareous soil.

Considering treatment means of the 160-400-0-20 fertilizer treatment, placement 2 generally outyielded placement 1. For both soils and both placements at the 160-400-0-20 level, the N.A. form gave the lowest plant yields of all nitrogen carriers used.

TABLE 20. DRY WEIGHT OF BARLEY (gms. per pot)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Pelan non-calcareous	Treatment average
0-0-0-20		1.14 f_1	1.08 f_2	1.11 i
(1) 0-0-200-20		1.13 f_1	1.10 f_2	1.12 i
(3) 0-0-200-20		1.14 f_1	1.26 f_2	1.20 i
(1) 0-400-200-20		1.27 f_1	1.48 f_2	1.37 i
(3) 0-400-200-20		1.27 f_1	1.44 f_2	1.36 i
(1) 160-400-0-20	A.S.	4.01 d_1e_1	2.60 e_2	3.30 gh
(2) 160-400-0-20	A.S.	4.34 d_1	2.69 e_2	3.41 g
(1) 160-400-0-20	N.A.	3.67 e_1	2.53 e_2	3.10 h
(2) 160-400-0-20	N.A.	4.08 d_1e_1	2.57 e_2	3.38 gh
(1) 160-400-0-20	A.N.	4.00 d_1e_1	2.79 e_2	3.40 g
(2) 160-400-0-20	A.N.	4.08 d_1e_1	2.69 e_2	3.39 gh
(1) 160-400-200-20	A.S.	6.42 a_1b_1	4.76 a_2b_2	5.59 a
(2) 160-400-200-20	A.S.	6.61 a_1	4.08 c_2d_2	5.34 ab
(3) 160-400-200-20	A.S.	5.45 c_1	3.73 d_2	4.60 f
(1) 160-400-200-20	N.A.	5.84 c_1	4.48 $a_2b_2c_2$	5.16 cd
(2) 160-400-200-20	N.A.	5.93 b_1c_1	4.50 $a_2b_2c_2$	5.22 bc
(3) 160-400-200-20	N.A.	5.49 c_1	3.94 c_2d_2	4.71 ef
(1) 160-400-200-20	A.N.	6.15 a_1b_1	5.03 a_2	5.59 a
(2) 160-400-200-20	A.N.	5.57 c_1	4.32 $b_2c_2d_2$	4.95 cde
(3) 160-400-200-20	A.N.	5.55 c_1	4.26 $b_2c_2d_2$	4.90 de
Soil average		4.16	3.07	

An examination of the treatment mean yields of all nitrogen forms used at the 160-400-200-20 fertilizer rate reveals that with the exception of the A.N. form placement 3 gave plant yields significantly lower than either one of the other two placements. Placement 1 tended to give yields greater than either of the other placements.

Considering each soil individually, at the 160-400-200-20 fertility level, placement 3 gave lower plant yields for both soils regardless of nitrogen form.

Regardless of soil used, for the A.N. form at the 160-400-200-20 level, placement 1 resulted in significantly greater yields than either one of the other two placements. For the N.A. form placements 1 and 2 gave approximately equivalent yields.

Disregarding placement and comparing nitrogen forms at the 160-400-200-20 fertilizer rate, for the calcareous soil the A.S. form gave the highest yields and the N.A. and A.N. forms gave approximately equivalent yields. For the non-calcareous soil both N.A. and A.N. gave approximately equivalent yields, both these carriers being better than A.S. in this respect.

The greatest response to application of potassium is obtained with use of placement 1 regardless of nitrogen form or soil. Banding of the nitrogen-potassium fertilizer near the seed appears to be the more effective placement. This is in agreement with previously reported results (34, 42). Data for the increase in yield due to potassium are presented in Appendix IV.

Considering placement 1 for all nitrogen carriers at the 160-400-200-20 fertility level, lowest yields were obtained with the N.A. carrier regardless of soil used. With placement 3 lowest yields for both soils were obtained with the A.S. form.

Nitrogen Content of Plant Material

The 0-400-200-20 level resulted in lower nitrogen content (Table 21), significant for the calcareous soil, than for the 0-0-200-20 treatment and both these fertilizer treatments irrespective of placement or soil used, gave lower plant nitrogen contents than did the 0-0-0-20 fertility level.

Except for the A.S. form with placement 2, at the 160-400-0-20 and 160-400-200-20 fertilizer rates plant nitrogen contents were invariably larger for the non-calcareous than for the calcareous soil regardless of nitrogen form or placement. Also, as seen from an examination of soil treatment means, of all nitrogen forms used at both these fertilizer rates, the N.A. form provided the largest nitrogen contents. These differences in nitrogen contents with use of the N.A. form were significant for all placements at both fertility levels. Significance was attained for all nitrogen forms with the calcareous soil only.

For both soils at the 160-400-0-20 and 160-400-200-20

TABLE 21. NITROGEN CONTENT OF BARLEY (percent)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre	Pelan calcareous	Pelan non-calcareous	Treatment average
0-0-0-20	1.75 $h_1i_1j_1k_1$	1.89 g_2h_2	1.82 g
(1) 0-0-200-20	1.63 K_1	1.57 h_2i_2	1.60 h
(3) 0-0-200-20	1.65 j_1k_1	1.52 i_2	1.59 h
(1) 0-400-200-20	1.47 l_1	1.30 i_2	1.38 i
(3) 0-400-200-20	1.44 l_1	1.38 i_2	1.43 hi
(1) 160-400-0-20 A.S.	2.56 b_1	3.56 a_2	3.07 b
(2) 160-400-0-20 A.S.	2.06 d_1e_1	2.03 $e_2f_2g_2$	2.05 ef
(1) 160-400-0-20 N.A.	2.90 a_1	3.66 a_2	3.28 a
(2) 160-400-0-20 N.A.	2.61 b_1	3.62 a_2	3.12 ab
(1) 160-400-0-20 A.N.	2.36 c_1	3.49 a_2	2.93 b
(2) 160-400-0-20 A.N.	2.14 d_1	3.03 b_2	2.59 c
(1) 160-400-200-20 A.S.	1.80 $g_1h_1i_1$	2.12 $e_2f_2g_2$	1.96 fg
(2) 160-400-200-20 A.S.	1.46 l_1	1.40 i_2	1.43 hi
(3) 160-400-200-20 A.S.	1.89 $f_1g_1h_1$	2.29 $d_2e_2f_2$	2.09 ef
(1) 160-400-200-20 N.A.	1.96 e_1f_1	2.38 d_2e_2	2.17 de
(2) 160-400-200-20 N.A.	1.93 $e_1f_1g_1$	2.53 d_2	2.23 de
(3) 160-400-200-20 N.A.	2.17 d_1	2.82 b_2c_2	2.50 c
(1) 160-400-200-20 A.N.	1.78 $g_1h_1i_1j_1$	2.14 $e_2f_2g_2$	1.96 fg
(2) 160-400-200-20 A.N.	1.71 $i_1j_1k_1$	1.97 f_2g_2	1.84 g
(3) 160-400-200-20 A.N.	1.97 e_1f_1	2.60 c_2d_2	2.29 d
Soil average	1.96	2.37	

fertilizer rates, placement 2 gave significantly larger barley nitrogen content with the N.A. carrier than did similar placement with either the A.S. or A.N. forms.

At the 160-400-0-20 fertility level, placement 2 gave significantly lower nitrogen contents than placement 1 for the A.S. and A.N. forms for both soils.

Placement 3 involved a surface application of potassium which generally resulted in lower plant material yields (Table 20) thus increasing the nitrogen content. Differences between placement 3 and placements 1 or 2 were significant for the N.A. and A.N. forms for both soils at the 160-400-200-20 fertility level. Placement 2 caused greater depression of nitrogen content with the A.S. form than with any of the other two nitrogen forms used. For both fertilizer rates the plant nitrogen contents with this placement and nitrogen form are lower for the non-calcareous than for the calcareous soil. The lower availability of nitrogen to the plant resulted from surface application of all the nitrogen as the less mobile NH_4^+ ion.

Potassium Content of Plant Material

The plant potassium contents (Table 22) of the 0-0-0-20, 0-0-200-20 and 0-400-200-20 treatments are generally higher for the calcareous than for the non-calcareous soil for comparable treatments with the exception of the 0-0-200-20 treatment with placement 1. The 0-400-200-20 fertilizer rate, irres-

TABLE 22. POTASSIUM CONTENT OF BARLEY (percent)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Pelan non-calcareous	Treatment average
0-0-0-20		3.69 b_1c_1	3.17 $d_2e_2f_2$	3.43 bc
(1) 0-0-200-20		3.84 a_1b_1	4.27 a_2	4.06 a
(3) 0-0-200-20		3.92 a_1	3.88 b_2	3.90 a
(1) 0-400-200-20		3.66 b_1c_1	3.56 b_2c_2	3.61 b
(3) 0-400-200-20		3.53 c_1	3.25 c_2d_2	3.39 cd
(1) 160-400-0-20	A.S.	1.14 g_1	1.12 h_2	1.13 jk
(2) 160-400-0-20	A.S.	1.35 f_1	1.17 h_2	1.26 j
(1) 160-400-0-20	N.A.	1.06 g_1	1.23 h_2	1.15 jk
(2) 160-400-0-20	N.A.	1.07 g_1	1.17 h_2	1.12 jk
(1) 160-400-0-20	A.N.	1.04 g_1	1.19 h_2	1.11 jk
(2) 160-400-0-20	A.N.	1.05 g_1	1.03 h_2	1.04 jk
(1) 160-400-200-20	A.S.	2.86 d_1	3.04 $d_2e_2f_2$	2.95 f
(2) 160-400-200-20	A.S.	2.85 d_1	3.53 b_2c_2	3.19 de
(3) 160-400-200-20	A.S.	2.34 e_1	2.53 g_2	2.44 i
(1) 160-400-200-20	N.A.	2.42 e_1	2.88 $e_2f_2g_2$	2.65 h
(2) 160-400-200-20	N.A.	2.48 e_1	2.87 $e_2f_2g_2$	2.68 gh
(3) 160-400-200-20	N.A.	2.44 e_1	2.61 g_2	2.53 i
(1) 160-400-200-20	A.N.	2.84 d_1	2.86 f_2g_2	2.85 fg
(2) 160-400-200-20	A.N.	2.85 d_1	3.23 $c_2d_2e_2$	3.04 h
(3) 160-400-200-20	A.N.	2.44 e_1	2.83 f_2g_2	2.64 ef
Soil average		2.44	2.57	

pective of placement used, gave lower potassium contents than did the 0-0-200-20 level. The differences were significant for both soils with placement 3.

Considering the 160-400-0-20 fertility level, the A.S. form resulted in larger plant potassium content than any of the other two nitrogen forms for the calcareous soil regardless of placement used. With the non-calcareous soil at the same fertility level and for both placements, plant potassium contents are similar for all three nitrogen forms.

Considering plant potassium content at the 160-400-200-20 fertilizer rate, values were invariably larger for the non-calcareous than for the calcareous soil for similar treatments. The difference between the two soils generally was largest with placement 2. At the 160-400-200-20 fertility level, greatest variation in potassium content with placement was obtained with the A.S. carrier and, least with the N.A. carrier.

For the calcareous soil at the 160-400-200-20 fertility level, plant potassium contents for both placements 1 and 2 were very similar for comparable nitrogen forms. In general, for the non-calcareous soil, placement 2 gave the larger plant potassium content. This was particularly true for the A.S. and A.N. forms where differences in potassium content between placements 1 and 2 were significant.

Discussing only placements 1 and 2, the N.A. source resulted in the lowest plant potassium content whereas both the A.N. and A.S. forms provided approximately similar significantly larger potassium contents for the calcareous soil. For the non-calcareous soil the N.A. carrier gave the lowest plant potassium content while the A.S. source provided potassium contents larger than either one of the other two nitrogen sources for placements 1 and 2.

For both soils at the 160-400-200-20 fertilizer level, of all three placements considered, placement 3 gave the lowest plant potassium content. This indicates that surface applied potassium is lower in availability than potassium applied below the seed and agrees with results* indicating low mobility of potassium even in sandy soils.

Nitrogen Uptake by Barley

The data for nitrogen uptake by barley are presented in Table 23. There were no significant differences in nitrogen uptake of the 0-0-0-20, 0-0-200-20, and 0-400-200-20 fertilizer rates irrespective of placement or soil used. For these treatments the non-calcareous soil tended to give slightly higher nitrogen uptake than did the calcareous soil.

Generally at both the 160-400-0-20 and 160-400-200-20 fertility levels and for all placements and nitrogen forms, nitrogen uptake was larger for the calcareous than for the non-calcareous soil for comparable treatments.

For both soils at the 160-400-0-20 fertility level place-

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* Errol Lewis - Unpublished B.S.A. thesis, Dept. of Soil Science, U. of M., 1967.

TABLE 23. NITROGEN UPTAKE BY BARLEY (mgs per pot)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Pelan non-calcareous	Treatment average
0-0-0-20		19.8 h_1	20.3 h_2	20.1 h
(1) 0-0-200-20		18.5 h_1	17.4 h_2	17.9 h
(3) 0-0-200-20		18.8 h_1	19.1 h_2	18.4 h
(1) 0-400-200-20		18.6 h_1	19.2 h_2	18.9 h
(3) 0-400-200-20		18.4 h_1	20.3 h_2	19.3 h
(1) 160-400-0-20	A.S.	103 $d_1e_1f_1$	92.6 $c_2d_2e_2f_2$	97.6 cd
(2) 160-400-0-20	A.S.	89.5 g	54.6 g_2	72.0 g
(1) 160-400-0-20	N.A.	106 $b_1c_1d_1$	93.4 $d_2e_2f_2$	99.2 c
(2) 160-400-0-20	N.A.	105 $c_1d_1e_1$	96.4 $b_2c_2d_2e_2$	101 bc
(1) 160-400-0-20	A.N.	94.6 f_1g_1	97.2 $b_2c_2d_2e_2$	95.7 cd
(2) 160-400-0-20	A.N.	86.9 g_1	81.0 f_2	84.0 ef
(1) 160-400-200-20	A.S.	115 a_1b_1	100 $a_2b_2c_2d_2$	108 ab
(2) 160-400-200-20	A.S.	96.1 $e_1f_1g_1$	56.9 g_2	76.5 fg
(3) 160-400-200-20	A.S.	103 $d_1e_1f_1$	87.5 $d_2e_2f_2$	95.2 cd
(1) 160-400-200-20	N.A.	114 $a_1b_1c_1$	106 $a_2b_2c_2$	110 a
(2) 160-400-200-20	N.A.	114 $a_1b_1c_1$	113 a_2	114 a
(3) 160-400-200-20	N.A.	119 a_1	111 a_2	115 a
(1) 160-400-200-20	A.N.	109 $b_1c_1d_1$	107 a_2b_2	108 ab
(2) 160-400-200-20	A.N.	95.2 f_1g_1	84.8 e_2f_2	90.0 de
(3) 160-400-200-20	A.N.	109 $b_1c_1d_1$	110 a_2	110 a
Soil average		82.7	74.2	

ment 2 generally gave lower nitrogen uptake than did placement 1 for all nitrogen forms. This difference was significant with both soils for the A.S. form. The N.A. form gave significantly higher nitrogen uptake than either one of the other two nitrogen sources for both soils with placement 2.

Considering the 160-400-200-20 fertility level, the N.A. form generally gave the highest nitrogen uptake for both soils regardless of placement used. Within the N.A. form there were no significant differences in nitrogen uptake with placement for either soil. Comparing nitrogen forms, with placement 2, the N.A. form gave nitrogen uptake values significantly larger than these of the A.S. or A.N. forms. This trend in nitrogen uptake may be explained by the higher nitrogen content of barley fertilized with the N.A. carrier. The fact that placement of nitrogen as N.A. at the surface did not depress its uptake by barley on either soil may be related to the high mobility of the nitrate ion. Data for the recovery of applied nitrogen presented in Appendix V confirm this observation. Again, comparing nitrogen forms at placement 3, the N.A. form gave nitrogen uptake values significantly higher than those of A.N. and A.S. in the case of the calcareous soil and, for the non-calcareous soil, significantly larger than that of the A.S. form only. For placement 1 for both soils there were no significant differences in nitrogen uptake with different nitrogen forms.

Potassium Uptake by Barley

With the exception of the 0-0-0-20 fertilizer treatment, potassium uptake values (Table 24) for the non-calcareous soil exceed those for the calcareous soil for all the no-nitrogen treatments. For comparable treatments at the 160-400-0-20 and 160-400-200-20 fertilizer rates potassium uptake was invariably larger for the calcareous than for the non-calcareous soil. The difference between soils, disregarding placement, was largest for the A.S. form.

At the 160-400-0-20 fertility level the N.A. and A.N. forms gave approximately equivalent potassium uptake, both being lower for comparable placements than that of the A.S. form for the calcareous soil. There were no significant differences or definite trends established between potassium uptake and placement or nitrogen form at the 160-400-0-20 fertility level for the non-calcareous soil.

At the 160-400-200-20 fertility level for both soils with placements 1 and 2, comparing potassium uptake associated with the three different nitrogen forms, uptake values are largest for the A.S. and least for the N.A. form. Significance is attained for all comparisons between these two nitrogen carriers for the calcareous soil with placements 1 and 2. For the non-calcareous soil, none of the above comparisons are significant.

The lower potassium uptake values obtained are related to the lower plant material yields and lower potassium contents

TABLE 24. POTASSIUM UPTAKE BY BARLEY (mgs per pot)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Belan non-calcareous	Treatment average
0-0-0-20		41.6 h_1	34.2 $e_2f_2g_2$	37.9 gh
(1) 0-0-200-20		43.6 h_1	47.2 $d_2e_2f_2$	45.4 fg
(3) 0-0-200-20		44.7 h_1	48.9 d_2e_2	46.8 fg
(1) 0-400-200-20		46.3 h_1	52.6 d_2	49.5 f
(3) 0-400-200-20		45.0 h_1	46.8 $d_2e_2f_2$	45.9 fg
(1) 160-400-0-20	A.S.	45.6 h_1	29.0 g_2	37.3 gh
(2) 160-400-0-20	A.S.	58.5 g_1	31.4 f_2g_2	44.9 fgh
(1) 160-400-0-20	N.A.	38.7 h_1	31.0 f_2g_2	34.8 h
(2) 160-400-0-20	N.A.	43.7 h_1	31.2 f_2g_2	37.4 gh
(1) 160-400-0-20	A.N.	41.5 h_1	32.9 $e_2f_2g_2$	37.2 gh
(2) 160-400-0-20	A.N.	42.5 h_1	27.8 g_2	35.1 h
(1) 160-400-200-20	A.S.	183 a_1b_1	144 a_2	163 a
(2) 160-400-200-20	A.S.	188 a_1	144 a_2	166 a
(3) 160-400-200-20	A.S.	128 f_1	97.4 c_2	113 e
(1) 160-400-200-20	N.A.	141 d_1e_1	127 a_2b_2	134 c
(2) 160-400-200-20	N.A.	147 c_1d_1	129 a_2b_2	138 c
(3) 160-400-200-20	N.A.	134 e_1f_1	103 c_2	118 de
(1) 160-400-200-20	A.N.	174 b_1	143 a_2	159 ab
(2) 160-400-200-20	A.N.	159 c_1	139 a_2	149 b
(3) 160-400-200-20	A.N.	135 $d_1e_1f_1$	120 b_2	127 cd
Soil average		94.0	77.9	

of the barley fertilized with N.A. Nitrate nitrogen has been reported by other workers (31, 34) to depress potassium content while increasing the nitrogen content (Table 21).

Placement 3, regardless of nitrogen form used at the 160-400-200-20 fertility level for both soils, generally gave significantly lower potassium uptake than either of the other two placements. This is a reflection of both lower potassium content and yields of plant material associated with placement 3. For placement 3, with both soils, the lowest potassium uptake was obtained with the A.S. source and the highest uptake with the A.N. carrier.

These results parallel the plant yield and nitrogen uptake data presented earlier in the discussion in that of all nitrogen forms employed, the A.S. appears to be most critical with respect to placement. They also indicate chemical and positional availability differences amongst the nitrogen sources utilized as proposed by (56).

Phosphorus, Sodium, Calcium and Magnesium Contents of Plant Material.

From Table 25 it may be seen that regardless of placement, fertility level, or nitrogen form used, phosphorus contents were invariably larger for the calcareous than for the non-calcareous soil. With the calcareous soil a fairly large depression of plant phosphorus content occurred upon addition of potassium. No such trend was observed for the non-calcareous

TABLE 25. PHOSPHORUS, SODIUM, CALCIUM AND MAGNESIUM CONTENTS OF BARLEY (Percent)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre	Phosphorus		Sodium		Calcium		Magnesium	
	Pelan calc.	Pelan non-calc.	Pelan calc.	Pelan non-calc.	Pelan calc.	Pelan non-calc.	Pelan calc.	Pelan non-calc.
0-0-0-20	1.04	.92	.32	.40	.70	.66	.41	.38
(1) 0-400-200-20	1.41	.90	.19	.16	.50	.43	.33	.28
(3) 0-400-200-20	1.41	.89	.20	.22	.45	.63	.33	.36
(1) 160-400-0-20 A.S.	1.29	.89	.84	.57	.76	1.72	.46	.71
(2) 160-400-0-20 A.S.	1.09	.86	.73	.54	.57	.91	.40	.54
(1) 160-400-0-20 N.A.	1.11	.90	.86	.60	1.05	1.76	.47	.55
(2) 160-400-0-20 N.A.	1.09	.86	.77	.56	.95	.77	.53	.38
(1) 160-400-200-20 A.S.	1.14	.94	.39	.32	.45	.76	.33	.68
(2) 160-400-200-20 A.S.	.93	.88	.37	.30	.40	.64	.31	.29
(3) 160-400-200-20 A.S.	1.14	1.00	.52	.41	.49	.98	.36	.65
(1) 160-400-200-20 N.A.	.94	.85	.25	.33	.64	1.06	.36	.40
(2) 160-400-200-20 N.A.	.98	.85	.51	.36	.58	1.03	.36	.39
(3) 160-400-200-20 N.A.	.99	.88	.60	.46	.68	1.17	.41	.44
Soil average	1.12	0.89	0.50	0.40	0.63	0.96	0.39	0.47

soil, in spite of a significant increase in yield of barley for this soil with addition of potassium.

With placement 1 at both the 160-400-0-20 and 160-400-200-20 fertility levels, for the calcareous soil, the A.S. form gave higher phosphorus contents than did the N.A. form. This was also the case for the non-calcareous soil at the 160-400-200-20 fertilizer rate only. The forementioned observation is in close agreement with the literature (11, 21, 37, 44) where intimate mixing of the NH_4^+ form with the phosphorus source was found to enhance phosphorus uptake. With placement 2 no consistent differences exist between the two nitrogen sources for either of the fertility levels or soils used.

Placement 3 gave larger phosphorus contents with the A.S. form than with the N.A. form for both soils at the 160-400-200-20 fertilizer rate. Placement 3 involves surface addition of potassium with the nitrogen and phosphorus sources being intimately associated below the seed. Phosphorus contents with placement 3 are equivalent to - or slightly larger than - phosphorus contents obtained with placement 1 for all nitrogen forms and soils.

Generally calcium contents were larger than either magnesium or sodium contents for comparable treatments for both soils used. Regardless of soil or placement used, the 160-400-0-20 level gave the largest calcium, magnesium and sodium contents of all fertilizer treatments used. Application of potassium, depressed calcium, magnesium and sodium contents for comparable treatments with both soils. This may be explained by an increase in plant material with potassium application as well as the antagonism between the potassium ion and the calcium, magnesium and sodium ions(19, 23, 39, 41, 45, 51).

Placement 1 invariably gave higher calcium contents for both soils and for all nitrogen forms at both the 160-400-0-20 and 160-400-200-20 fertilizer rates than did placement 2. This was generally true for the sodium and magnesium contents as well although for these the differences between placements were not as pronounced.

As noted earlier, for both soils and all nitrogen forms, placement 1 resulted in larger nitrogen content and nitrogen uptake by barley than did placement 2. This indicates a positive relation between total nitrogen content and total cations as has been previously reported (13, 28, 31).

For the 160-400-200-20 fertility level, placement 3, in which the potassium was added to the surface, resulted in generally higher calcium, magnesium and sodium contents for both soils than either of the other two placements for comparable treatments. This may be attributed mainly to the lower plant yields with placement 3.

For both soils considering similar treatments and placements larger calcium contents were generally obtained for the N.A form than for the A.S. form. Work done previously (28) on the effect of nitrogen form, i.e., NO_3^- vs NH_4^+, on calcium uptake gave similar results. This trend is not as distinct for magnesium, particularly for the non-calcareous soil where the A.S. generally gave higher magnesium contents than did the N.A. form for comparable treatments.

Calcium contents showed greater variation with placement and nitrogen forms than did magnesium contents, and variations were larger for the non-calcareous than for the calcareous soil. The calcareous soil gave generally larger barley sodium contents for both the 160-400-0-20 and 160-400-200-20 fertilizer rates than did the non-calcareous soil.

Potassium Recovery

Potassium recovery data are presented in Table 26. Generally, potassium recoveries are larger for the calcareous than for the non-calcareous soil considering comparable placements and nitrogen forms. Regardless of soil used, potassium recoveries of all three nitrogen forms are lowest for placement 3. This decrease in recovery with placement 3 is significant when compared to the other two placements, for the calcareous soil with the A.S. and A.N. carriers. In the case of the non-calcareous soil significance is attained for both A.S. and N.A. forms. Neither for soils nor nitrogen placements was there a significant difference in potassium recoveries between placements 1 and 2.

For placements 1 and 2 irrespective of soil used, the potassium recovery values are lowest for the N.A. form and highest for the A.S. source.

TABLE 26. POTASSIUM RECOVERY (percent)[1]

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre	Pelan calcareous	Pelan non-calcareous	Treatment average
(1) 0-400-200-20	23.2 f_1	26.3 c_2	24.7 g
(3) 0-400-200-20	22.6 f_1	23.4 c_2	22.9 g
(1) 160-400-200-20 A.S.	91.3 a_1	71.9 a_2	81.6 a
(2) 160-400-200-20 A.S.	94.1 a_1	72.0 a_2	83.3 a
(3) 160-400-200-20 A.S.	64.2 e_1	48.7 b_2	56.4 f
(1) 160-400-200-20 N.A.	70.7 d_1e_1	63.7 a_2	67.2 d
(2) 160-400-200-20 N.A.	73.3 c_1d_1	64.3 a_2	68.8 cd
(3) 160-400-200-20 N.A.	67.0 d_1e_1	51.4 b_2	59.1 ef
(1) 160-400-200-20 A.N.	87.2 a_1b_1	71.5 a_2	79.3 ab
(2) 160-400-200-20 A.N.	79.4 b_1c_1	69.5 a_2	74.4 bc
(3) 160-400-200-20 A.N.	67.3 d_1e_1	60.2 a_2b_2	63.7 de
Soil average	67.3	56.6	

1. Percent potassium recovery = $\frac{\text{yield of potassium}}{\text{potassium applied}} \times 100$

Release and Fixation of Potassium

Regardless of placement, nitrogen form or fertilizer rate used, the non-calcareous soil invariably fixed more added potassium and released less non-exchangeable potassium than did the calcareous soil (Table 27).

This observation could be related to two main factors; 1) crop removal of potassium, i.e., potassium uptake by barley was larger for the calcareous soil than for the non-calcareous soil. Thus one would expect less soluble potassium and a larger shift in the equilibrium between exchangeable and non-exchangeable potassium for the calcareous soil (57); 2) exchangeability of absorbed potassium decreases with decreasing degree of potassium saturation of the exchange complex (43). Table 2 indicates that the calcareous soil had a higher potassium saturation than did the non-calcareous soil.

At the 160-400-200-20 fertility level with both soils, placement 3 gave the largest fixation of applied potassium. In this placement potassium was added to the soil surface and presumably such an arrangement would theoretically increase the number of fixation sites, consequently more of the potassium ion is fixed (6, 56).

The A.S. form gave the largest variation in fixation with placement at the 160-400-200-20 level.

Ca:K and N:K Ratios of Plant Material

Both Ca:K and N:K ratios (Table 28) behave similarly to

TABLE 27. RELEASE (+) AND FIXATION (-) OF POTASSIUM IN SOILS CROPPED TO BARLEY (ppm)[1]

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Pelan non-calcareous	Treatment average
0-0-0-20		+16.6	+ 1.8	9.2
(1) 0-0-200-20		-53.8	-63.3	-58.6
(3) 0-0-200-20		-60.5	-64.0	-62.3
(1) 0-400-200-20		-60.1	-62.5	-61.3
(3) 0-400-200-20		-62.4	-64.3	-63.4
(1) 160-400-0-20	A.S.	+17.4	- 0.2	+ 8.6
(2) 160-400-0-20	A.S.	+21.4	+ 0.9	+11.2
(1) 160-400-0-20	N.A.	+16.3	+ 1.3	+ 8.8
(2) 160-400-0-20	N.A.	+14.9	+ 3.2	+ 9.1
(1) 160-400-0-20	A.N.	+14.5	+ 2.8	+ 8.7
(2) 160-400-0-20	A.N.	+14.5	+ 0.1	+ 7.3
(1) 160-400-200-20	A.S.	-14.6	-34.6	-24.6
(2) 160-400-200-20	A.S	- 8.8	-36.6	-22.7
(3) 160-400-200-20	A.S.	-39.2	-55.5	-47.4
(1) 160-400-200-20	N.A.	-32.4	-43.9	-38.2
(2) 160-400-200-20	N.A.	-25.6	-39.4	-32.5
(3) 160-400-200-20	N.A.	-32.1	-44.0	-38.1
(1) 160-400-200-20	A.N.	-12.1	-32.4	-22.3
(2) 160-400-200-20	A.N.	-22.4	-35.6	-29.0
(3) 160-400-200-20	A.N.	-28.2	-38.4	-33.3
Soil average		-16.8	-30.2	

1. Potassium released (+) or fixed (-) = potassium content of crop - (Initial potassium + fertilizer potassium - residual potassium.

TABLE 28. Ca:K AND N:K RATIOS OF BARLEY (Calculated on basis of eqvt. wt. per unit wt.)[1]

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Ca:K Ratio		N:K Ratio	
		Pelan calc.	Pelan non-calc.	Pelan calc.	Pelan non-calc.
0-0-0-20				1.32	1.66
(1) 0-400-200-20		.27	.24	1.12	1.02
(3) 0-400-200-20		.25	.38	1.31	1.21
(1) 160-400-0-20	A.S.	1.30	2.99	6.28	8.89
(2) 160-400-0-20	A.S.	.83	1.51	4.32	5.30
(1) 160-400-0-20	N.A.	1.92	2.79	7.65	8.31
(2) 160-400-0-20	N.A.	1.72	1.28	6.79	8.63
(1) 160-400-0-20	A.N.			6.35	8.22
(2) 160-400-0-20	A.N.			5.70	8.16
(1) 160-400-200-20	A.S.	.31	1.16	1.78	1.95
(2) 160-400-200-20	A.S.	.27	.36	1.43	1.10
(3) 160-400-200-20	A.S.	.41	1.52	2.26	2.53
(1) 160-400-200-20	N.A.	.51	.72	2.26	2.31
(2) 160-400-200-20	N.A.	.45	.70	2.17	1.92
(3) 160-400-200-20	N.A.	.54	.87	2.48	2.78
(1) 160-400-200-20	A.N.			1.75	2.08
(2) 160-400-200-20	A.N.			1.67	1.71
(3) 160-400-200-20	A.N.			2.18	2.57
Soil average		0.73	1.21	3.27	3.91

1 N assumed to have a valence of one.

placement in that regardless of nitrogen form used, placement 3 generally gave the highest, and placement 2 the lowest ratios for both soils and fertilizer rates. Generally the values of both ratios are larger for the non-calcareous than for the calcareous soil. Also, as would be expected, both ratios at the 160-400-0-20 fertility level are considerably larger than at the 160-400-200-20 level for similar treatments.

For the calcareous soil at the 160-400-0-20 fertility level the N.A. form generally resulted in larger N:K and Ca:K ratios than did either one of the other nitrogen forms.

Generally at the 160-400-200-20 fertilizer rate, the A.N. and A.S. forms gave approximately equivalent N:K ratios for both soils. The N.A. form at this fertility level gave N:K ratios larger than either of these carriers for both soils.

Experiment IV

Materials and Methods

In the previous greenhouse experiments conducted to study and compare yield and nutrient uptake of barley and oats with different nitrogen forms and placements both NH_4^+ and NO_3^- were used. Greenhouse experiment IV was an attempt to study the effect of the NH_4^+ form, with and without a nitrification inhibitor, on yield and potassium content of barley grown on a calcareous and a non-calcareous soil.

The Pelan calcareous and non-calcareous soils, whose characteristics are given in Tables 1 and 2, were used for this greenhouse experiment.

Technical grade 'N-Serve', a trade mark of Dow Chemical Company* for 2-chloro-6-(trichloromethyl)pyridine, was the nitrification inhibitor used. After a review of literature (1, 36, 46, 53), a concentration of 2 percent of the weight of nitrogen in the nitrogen solution was decided upon as being the most favorable concentration. Thus, for greenhouse experiment IV, a weight of 'N-Serve' equivalent to 2 percent the weight of nitrogen in the $(NH_4)_2SO_4$ solution used was dissolved in acetone and added to the nitrogen solution.

A total of 88 one-half gallon porcelain pots were prepared. One crop only, barley was grown. $(NH_4)_2SO_4$ was the only nitrogen form used. All pots received 20 mgm S as $MgSO_4$

* Obtained from Prof. E. Paul, Dept. of Soil Science, Univ. of Saskatchewan.

placed 1/2 inch below the seed. The fertilizer rates and placements employed in greenhouse experiment IV are outlined in Table 29. A total of eleven fertilizer treatments were used; each treatment being replicated four times.

The barley was harvested 44 days after seeding. Samples of the moist soil from certain selected pots were then taken and stored in the cold room for a period of time not exceeding one week. Exchangeable NH_4-N determinations were carried out on these moist samples within a week after sampling. The purpose of these determinations was to assess the effectiveness of the 'N-Serve' in controlling nitrification.

The remaining soil in the pots was air dried and collected as described under "General Methods and Materials".

Results and Discussion

Since average nitrogen recovery in the plants ranged from about one-half to two-thirds of the nitrogen applied, depending on placement, one would expect a difference in ammonium nitrogen levels at the end of the experiment if 'N-Serve' had been effective in blocking nitrification. This was not the case (Table 30) and hence it seems improbable that nitrification was prevented by 'N-Serve' in this experiment. In any case the results with respect to plant yields, nitrogen and potassium content, uptake and recovery of nitrogen and potassium are similar to those obtained in Experiment III. Therefore, results of this experiment are not presented.

TABLE 29. FERTILIZER RATES AND PLACEMENTS USED IN GREEN-HOUSE EXPERIMENT IV

Fertilizer treatment $N-P_2O_5-K_2O-S$	Inhibitor treatment	Placements
0-0-0-20		
(1) 160-100-0-20	+'N-Serve'	N banded 1/2 inch below seed
(1) 160-100-020	-'N-Serve'	" "
(2) 160-100-0-20	+'N-Serve'	N added at the surface
(2) 160-100-0-20	-'N-Serve'	" "
(1) 160-100-200-20	+'N-Serve'	N and K banded together 1/2 inch below seed
(1) 160-100-200-20	='N-Serve'	" "
(2) 160-100-200-20	+'N-Serve'	K banded 1/2 inch below seed; N added at the surface
(2) 160-100-200-20	-'N-Serve'	" "
(3) 160-100-200-20	+'N-Serve'	N banded 1/2 inch below seed; K added at the surface
(3) 160-100-200-20	-'N-Serve'	" "

TABLE 30. AMMONIUM NITROGEN CONTENT OF CROPPED SOIL (lbs/acre)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre	Pelan calcareous	Pelan non-calcareous
0-0-0-20	5.07	5.26
(1) 160-100-0-20 (B)	6.68	-
(2) 160-100-200-20 (A)	5.12	9.90
(1) 160-100-200-20 (A)	5.33	6.35
(1) 160-100-200-20 (B)	5.57	5.26

Experiment V

Methods and Materials

Experiment V was designed to study the potassium release and fixation characteristics of both native and applied potassium sources when associated with different nitrogen forms and placements. It was felt that a knowledge of such characteristics would be beneficial in explaining the plant uptake and yield response to potassium with different forms and placements of nitrogen.

Experiment V was conducted in two parts. Part (a) utilized similar nitrogen, phosphorus and potassium forms and rates of application, and similar nitrogen placements as were used in greenhouse experiment II. The Almasippi soil, with characteristics given in Tables 1 and 2, was used for both greenhouse experiment II and the present experiment. A total of 15 one-half gallon pots comprising five fertilizer treatments, each replicated three times, were used. An outline of the fertilizer rates, carriers and placements used in this greenhouse experiment is given in Table 31.

Part (b) in Experiment V utilized nitrogen, phosphorus and potassium forms and rates of application, as well as nitrogen-potassium placements, similar to those of greenhouse experiment III. Part (b) was conducted on the same soils as used for greenhouse experiment III, i.e., Pelan calcareous and non-calcareous meadow soils.

TABLE 31. FERTILIZER RATES, CARRIERS AND PLACEMENTS USED IN EXPERIMENT V, Part (a)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Carriers			Placements
	N	P	K	
0-0-0-	-	-	-	
(1) 160-100-140	$(NH_4)_2SO_4$	K_2HPO_4		N and K banded 1 inch below soil surface
(2) 160-100-140	" "	"	"	K banded 1 inch below soil surface; N added at the surface
(1) 160-100-140	HNO_3	"	"	N and K banded 1 inch below soil surface
(2) 160-100-140	"	"	"	K banded 1 inch below soil surface; N added at the surface

A total of 78 one-half gallon pots representing thirteen fertilizer treatments, each replicated three times, was used. Table 32 outlines the fertilizer rates, carriers and placements used in greenhouse experiment V, Part (b). An application of 20 mgm S per pot as $MgSO_4$ was made to all pots one inch below the surface of the soil.

The water content of all pots used in experiment V was maintained at close to field capacity by weekly additions of water. After one week several pots were weighed to determine the average amount of water needed to bring them to field capacity. After two weeks each pot was weighed individually and the water required to bring it to field capacity added. The process was continued throughout the incubation period. Each pot in series (a) received about 1300 ml and each pot in series (b) about 1250 ml of water during the seven week period.

After the incubation period the pots were immediately emptied and the soil spread to dry on the greenhouse benches. When dried, the soil from each pot was thoroughly mixed and a representative sample collected for exchangeable potassium determinations.

Results and Discussion (Part (a))

Release and Fixation of Potassium

The 0-0-0 treatment (Table 33) of the Almasippi soil released more potassium than the 0-0-0-20 treatment (Table 34) of the Pelan calcareous and non-calcareous soils. Regardless

TABLE 32. FERTILIZER RATES, CARRIERS AND PLACEMENTS USED IN EXPERIMENT V, Part (b)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre	Carriers			Placements
	N	P	K	
0-0-0-20	-	-	-	
(1) 0-100-200-20	-	H_3PO_4	KCl	K banded 1 inch below soil surface
(3) 0-100-200-20	-	"	"	K added at the surface
(1) 160-100-0-20	$(NH_4)_2SO_4$	"	-	N banded 1 inch below soil surface
(2) 160-100-0-20	"	"	-	N added at the surface
(1) 160-100-0-20	HNO_3	"	-	N banded 1 inch below soil surface
(2) 160-100-0-20	"	"	-	N added at the surface
(1) 160-100-200-20	$(NH_4)_2SO_4$	"	KCl	K and N banded 1 inch below soil surface
(2) 160-100-200-20	"	"	"	K banded 1 inch below soil surface; N added at the surface
(3) 160-100-200-20	"	"	"	N banded 1 inch below soil surface; K added at the surface
(1) 160-100-200-20	HNO_3	"	"	K and N banded 1 inch below soil surface
(2) 160-100-200-20	"	"	"	K banded 1 inch below soil surface; N added at the surface
(3) 160-100-200-20	"	"	"	N banded 1 inch below soil surface; K added at the surface

TABLE 33. POTASSIUM FIXED[1] (-) OR RELEASED[2] (+) UPON INCUBATION OF ALMASIPPI SOIL IN MOIST STATE FOR SEVEN WEEKS (ppm or percent of potassium added)

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre		Release or fixation ppm.	percent	
0-0-0		+12.3	-	
(1) 160-100-140	A.S.	-29.8	42.6	b
(2) 160-100-140	A.S.	-28.3	40.4	b
(1) 160-100-140	N.A.	-41.9	59.8	a
(2) 160-100-140	N.A.	-36.4	52.0	ab

1. Fixed potassium = Applied potassium - Increase in exchangeable potassium.
2. Potassium released = Initial potassium - Residual potassium.

of placement used, the A.S. form fixed less of the applied potassium than did the N.A. form and, for both nitrogen forms, placement 1 resulted in more fixation than did placement 2 (Table 33). This would suggest that the ammonium ion blocked fixation of the potassium ion as has been previously reported (1).

Considering potassium fixation as a percent of the potassium applied, the N.A. form gave a significantly higher fixation than the A.S. form in the case of placement 1 and a higher, though not significantly so, fixation for placement 2. There were no significant differences in fixation with placements within nitrogen forms (Table 33).

Results and Discussion (Part (b))

Data for the potassium fixed or released are presented in Table 34. The non-calcareous check treatment resulted in greater potassium release than did the check calcareous soil. Placement 1 for the 0-100-200-20 fertility level gave generally greater fixation for both soils than did placement 2. In general, for the 160-100-0-20 and 160-100-200-20 fertilizer rates the calcareous soil fixed more or released less potassium than did the non-calcareous soil for comparable placements and nitrogen forms. The larger potassium fixation capacity for the calcareous soil may be due to the larger base exchange capacity of this soil. Previous work (62) suggest a direct relation between base exchange capacity and amount of potassium fixed. The exceptions are placements 2 and 3 for the N.A. form at the 160-100-200-20 fertility level.

TABLE 34. POTASSIUM FIXED (-) OR RELEASED (+) UPON INCUBATION OF PELAN CALCAREOUS AND NON-CALCAREOUS SOILS WITH AND WITHOUT ADDED POTASSIUM (ppm or percent of potassium added)

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous		Pelan non-calcareous		Treatment average
		ppm	percent	ppm	percent	percent
0-0-0-20		- 2.0	-	+ 2.9	-	-
(1) 0-100-200-20		-44.9	44.9 c_1	-61.1	a61.1 a_2b_2	53.0 c
(3) 0-100-200-20		-37.7	33.7 d_1	-33.5	33.5 d_2	35.6 d
(1) 160-100-0-20	A.S.	- 3.5	-	- 2.6	-	-
(2) 160-100-0-20	A.S.	- 1.8	-	+ 0.4	-	-
(1) 160-100-0-20	N.A.	+ 0.2	-	+ 0.4	-	-
(2) 160-100-0-20	N.A.	- 0.6	-	+ 0.6	-	-
(1) 160-100-200-20	A.S.	-54.2	54.2 b_1	-40.1	40.1 c_2d_2	47.2 c
(2) 160-100-200-20	A.S.	-56.3	56.3 a_1b_1	-51.5	51.5 b_2c_2	54.0 c
(3) 160-100-200-20	A.S.	-58.7	58.7 a_1b_1	-47.0	47.0 $b_2c_2d_2$	52.8 c
(1) 160-100-200-20	N.A.	-58.4	58.4 a_1b_1	-56.1	56.1 b_2	57.3 bc
(2) 160-100-200-20	N.A.	-60.8	60.8 a_1b_1	-71.8	71.8 a_2	66.1 ab
(3) 160-100-200-20	N.A.	-66.8	66.8 a_1	-75.3	75.3 a_2	71.0 a

At the 160-100-0-20 fertility level irrespective of placement used, the A.S. form released less potassium than did the N.A. form for both soils. However, at the 160-100-200-20 fertilizer rate this trend is reversed; the N.A. form resulted in more fixation of the added potassium than did the A.S. form regardless of placement or soils used. This agrees closely with results reported for the Almasippi soil (Table 33).

For both soils placement 3 generally fixed more of the applied potassium than did any of the other placements regardless of nitrogen form used at the 160-100-200-20.

Presumably, for this placement in which potassium is surface applied a larger number of attraction sites which function in fixation are exposed to the applied potassium thus resulting in greater fixation (29). Placement 1 for the same soils and the same fertility level resulted in the least fixation.

Considering potassium fixation as a percent of the potassium applied, the fixation of the 0-100-200-20 fertilizer rate with placement 1 is significantly greater than that of the same rate with placement 3 for both soils. There are no significant differences in fixation of potassium amongst placements within the A.S. form at the 160-100-200-20 fertility level for either of the soils.

There are no significant differences in potassium fixation, regardless of placement, between the N.A. and A.S. forms with the calcareous soil although the N.A. form gave greater fixation than the A.S. form for comparable placements. For the non-calcareous soil the N.A. source gave significantly larger fixation values for comparable placements than did the A.S. form.

SUMMARY AND CONCLUSIONS

The uptake of nitrogen and potassium by barley and oats and their effect on yield were studied. Three soils, namely Almasippi very fine sandy loam (calcareous), Pelan loamy very fine sand (calcareous) and Pelan fine sand (non-calcareous) with exchangeable potassium levels ranging from moderately high to low, respectively, were employed in greenhouse experiments. Fertilizer nutrients were placed one-half inch below the seed and on the soil surface. Potassium was applied as K_2HPO_4, K_2SO_4 and KCl. The nitrogen carriers were NH_4NO_3, $(NH_4)_2SO_4$, $NaNO_3$ and HNO_3.

Evaluation of crop yields and soil and plant material analyses justify the following conclusions:

1. Potassium application, regardless of placement, significantly enhanced crop yields of both soils low in exchangeable potassium but gave little or no response on an Almasippi soil with a moderately high exchangeable potassium status. Considering the soils low in exchangeable potassium, addition of potassium depressed the sodium, calcium, magnesium and phosphorus contents of barley grown on the calcareous soil to a much larger extent than it did for the non-calcareous soil. For the soil with a moderately high exchangeable potassium level the above depression with potassium application was minor and occurred only with nitrogen placed one half inch below the seed.

2. The N:K ratios were generally lower and the phosphorus,

calcium, magnesium contents larger for barley than for oats with similar treatment.

3. It was found that potassium uptake, nitrogen uptake and N:K ratio for both crops generally increased with increasing nitrogen rate. Greater fixation of potassium occurred at the lower nitrogen rates than at the higher rates.

4. For comparable treatments (Pelan soils) the calcareous soil generally gave larger potassium uptake and lower N:K ratios for barley than did the non-calcareous soil. Considering similar treatments, phosphorus and sodium contents were larger generally and calcium and magnesium contents smaller for crops grown on the calcareous soil. Regardless of placement, nitrogen form or potassium application, during cropping, the non-calcareous soil invariably fixed more added potassium and released less non-exchangeable potassium than did the calcareous soil. Conversely, during incubation, the calcareous soil fixed more added potassium and released less non-exchangeable potassium than did the non-calcareous soil.

5. With no potassium added, for all soils, placement of nitrogen at the surface resulted in larger plant material yields and potassium uptake by barley than did placement of nitrogen 1/2 inch below the seed. For the same placement and soils, regardless of potassium addition, nitrogen uptake by both crops exceeded that for either of the other placements.
Placement of nitrogen at the surface with and without added potassium resulted in the lowest phosphorus, sodium, calcium and magnesium contents of barley grown on soils low in exchangeable

potassium only.

6. Placement of potassium at the surface resulted in the lowest yields and potassium uptake and the highest N:K ratios of barley regardless of soil or nitrogen form. Phosphorus, sodium, calcium and magnesium contents of barley were largest with this placement for all soils. Regardless of nitrogen form, for both the cropped and incubated soils placement of potassium at the surface invariably gave the largest potassium fixation. For the incubated soils, placement of nitrogen below the surface, i.e., in association with the other added nutrients, resulted in the least fixation of added potassium.

7. In general, for the calcareous soils, the A.S. form gave the highest plant material yields and potassium uptake for both crops regardless of placement or potassium application. For both calcareous soils, without added potassium, the A.S. form provided the largest release of non-exchangeable potassium regardless of crop grown.

8. Generally for the non-calcareous soil, the A.N. form gave plant material yields and potassium uptake superior to the other nitrogen forms with similar treatment.

9. For all soils with no potassium added, regardless of placement or crop, the N.A. form led to the lowest plant yields of all nitrogen forms. For the soils low in exchangeable potassium the N.A. carrier gave the highest nitrogen uptake, calcium and sodium contents of barley of all nitrogen forms for comparable treatments. Regardless of placement, fixation of

added potassium for all soils was generally largest for the N.A. form.

10. The S.N. form, regardless of placement, crop or potassium addition resulted in the lowest potassium uptake. Consequently S.N. gave N:K ratios for either crop larger than any other nitrogen form with potassium added. Regardless of placement or fertilizer rate, the S.N. form generally depressed the calcium and magnesium contents and enhanced the Na^+ content of both crops. The N.A. form gave potassium uptake values lower and N:K ratios larger than A.S. or A.N. with potassium applied to both the calcareous and non-calcareous soils.

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APPENDIX I

NITROGEN RECOVERY (percent)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre	Barley	Oats	Treatment average
40-80-200	95.5	102	99.0
(1) 80-80-200	77.4	94.3	85.9
(2) 80-80-200	88.4	90.0	89.2
(1) 160-80-200	55.4	72.6	64.0
(2) 160-80-200	61.1	69.8	65.5
Crop average	75.6	85.8	

1. Percent nitrogen recovery = $\frac{\text{yield of nitrogen}}{\text{nitrogen applied}} \times 100$

APPENDIX II

INCREASE (+) OR DECREASE (-) IN YIELD DUE TO POTASSIUM (percent)[1]

Fertilizer carrier	Barley	Oats	Treatment average
(1) A.S.	+ 4.2	+14.2	+ 9.2
(1) N.A.	+11.6	- 4.3	+ 3.7
(1) S.N.	+ 5.9	-13.3	- 3.7
(2) A.S.	- 8.1	- 6.8	- 7.5
(2) N.A.	- 7.4	- 4.4	- 5.9
(2) S.N.	-15.1	-13.0	-14.1
Crop average c	- 1.5	- 4.6	

1. Percent increase or decrease in yield due to potassium =

$$\frac{\text{NPKS treatment yield - NPS treatment yield}}{\text{NPS treatment yield}}$$

APPENDIX III

NITROGEN RECOVERY (percent)[1]

Fertilizer treatment $N-P_2O_5-K_2O$ lbs/acre		Barley	Oats	Treatment average
(1) 160-100-0	A.S.	65.9	61.0	63.5
(1) 160-100-0	N.A.	56.0	45.7	50.9
(1) 160-100-0	S.N.	52.8	47.7	50.1
(2) 160-100-0	A.S.	54.1	59.0	56.6
(2) 160-100-0	N.A.	55.9	43.8	49.9
(2) 160-100-0	S.N.	56.7	48.9	52.8
(1) 160-100-140	A.S.	61.1	59.5	60.3
(1) 160-100-140	N.A.	60.3	43.7	52.0
(1) 160-100-140	S.N.	56.4	44.8	50.6
(2) 160-100-140	A.S.	52.4	53.5	53.0
(2) 160-100-140	N.A.	52.2	44.6	48.4
(2) 160-100-140	S.N.	54.0	45.1	49.6
Crop average		56.5	49.8	

1. Percent nitrogen recovery = $\frac{\text{yield of nitrogen}}{\text{nitrogen applied}} \times 100$

APPENDIX IV

INCREASE IN YIELD DUE TO POTASSIUM (percent) [1]

Fertilizer carrier		Pelan calcareous	Pelan non-calcareous	Carrier average
(1)	A.S.	60.1	84.0	72.1
(2)	A.S.	52.2	51.9	52.1
(3)	A.S.	36.2	43.4	39.8
(1)	N.A.	59.3	77.1	68.2
(2)	N.A.	45.6	68.4	57.0
(3)	N.A.	49.9	46.9	48.4
(1)	A.N.	53.7	80.8	67.3
(2)	A.N.	37.3	61.8	49.6
(3)	A.N.	38.6	52.8	45.7
	Soil average	48.1	63.0	

1. Percent increase in yield due to potassium =

$$\frac{\text{NPKS treatment yield} - \text{NPS treatment yield}}{\text{NPS treatment yield}} \times 100$$

APPENDIX V

NITROGEN RECOVERY (percent)[1]

Fertilizer treatment $N-P_2O_5-K_2O-S$ lbs/acre		Pelan calcareous	Pelan non-calcareous	Treatment average
(1) 160-400-0-20	A.S.	64.2	57.9	61.1
(2) 160-400-0-20	A.S.	36.6	34.1	35.4
(1) 160-400-0-20	N.A.	66.3	57.7	62.0
(2) 160-400-0-20	N.A.	65.6	60.3	63.0
(1) 160-400-0-20	A.N.	59.1	60.8	60.0
(2) 160-400-0-20	A.N.	54.4	50.7	52.6
(1) 160-400-200-20	A.S.	72.2	62.8	67.5
(2) 160-400-200-20	A.S.	60.1	35.6	47.9
(3) 160-400-200-20	A.S.	64.3	54.7	59.5
(1) 160-400-200-20	N.A.	71.4	66.0	68.7
(2) 160-400-200-20	N.A.	71.4	70.7	71.1
(3) 160-400-200-20	N.A.	74.5	69.4	72.0
(1) 160-400-200-20	A.N.	68.1	66.6	67.4
(2) 160-400-200-20	A.N.	59.5	53.0	56.3
(3) 160-400-200-20	A.N.	68.0	69.0	68.5
Soil average		63.7	58.0	

1. Percent nitrogen recovery = $\frac{\text{yield of nitrogen}}{\text{nitrogen applied}} \times 100$