The Availability of Potassium to Plants From Several Calcareous and Non-Calcareous Manitoba Soils

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ABSTRACT

The soils of Manitoba could be divided into two broad groups, calcareous and non-calcareous, based on their percent calcium carbonate equivalent. Previous field and greenhouse experiments had indicated that there existed differences in the relative ease of availability of soil potassium from these soils to plants. Also that the NH_4OAc extractable potassium determined on these soils did not adequately describe the amount of potassium in these soils available to plants.

An investigation, including greenhouse and laboratory experiments, was conducted to investigate these problems.

It was found that the differences with respect to the availability of potassium to plants from these two groups of soils were dependent on the texture of the soils compared. Thus for equivalent levels of NH_4OAc and NaCl extractable potassium, the coarser textured soils in both groups supplied approximately equal amounts of potassium to corn. However on the finer textured soils the non-calcareous soils supplied more potassium to the plants than did the calcareous soils. The finer textured calcareous soils were found to "fix" more added potassium than the non-calcareous soils of equivalent texture.

It was also observed that an equilibrium condition appeared to be operating in the soil potassium system of these soils.

NH_4OAc solution extracted more potassium than the NaCl solution, which in turn extracted more potassium than the H_2O solution from fine textured soils in both soil groups. However on the coarser textured soils the NaCl and NH_4OAc solutions

extracted similar amounts of potassium. The NaCl extraction method was the best method, of the three methods used, to extract soil potassium when the data was used to indicate the relative amount of potassium that might be available to plants.

Corn was found to take up more magnesium from both groups of soils than calcium. The uptake of calcium and potassium by the plants increased with addition of potassium, however the magnesium content of the plants remained relatively constant for any one soil. Optimum yield of plant material was obtained when the value of the ratio Ca/K in the plants was approximately 0.10 to 0.15.

In both greenhouse experiments it was found that banding the potassium in to the soils below the seeds, gave a better yield of plant material than mixing the potassium throughout the soil. The amount of potassium taken up by the plants from the banded source of potassium was larger than the amount they took up from the diffused source.

INTRODUCTION

In Manitoba workers in the field of soil science recognize two distinct soil groups,--(1) calcareous and (2) non-calcareous soils, based on the percent calcium carbonate equivalent measured.

Several problems associated with plant mineral nutrition have been identified with one or the other of these two soil groups; although work has been carried out in solving these problems with regard to the more limiting elements nitrogen and phosphorous, it has always been the opinion of most workers that potassium, calcium and magnesium were adequate for plant growth in these soils.

In recent years the idea that potassium was adequate in these soils has been severely challenged by several workers. Soper (26) in a series of field plot trials with barley obtained good response to potassium fertilizer applications. In greenhouse experiments conducted by Bailey (5) and Copeland (10) the non-calcareous soils were found to be the more productive of the two soil types; it was also observed that there might be differences in the potassium supplying power of these soils to plants grown on them.

Worsham and Sturgis (29) discussing the availability of potassium to plants state that "the amount of available potassium in a soil is largely limited by the rate at which it is liberated from the primary minerals, by the amount of potassium that the soil could hold in soluble and exchangeable forms, and by the tendency of the potassium to be changed from the soluble and exchangeable forms to the more fixed states from which it is not released by the exchange reactions", this statement adequately describes the soil-potassium system. The authors have proposed the theory of a soil-potassium equilibrium reaction, a theory which is accepted by several workers, as the important reaction in potassium availability to plants; they have also proposed that the forms in which the potassium is present in the soil is of importance to the equilibrium reaction, since it would direct the shift in the equilibrium reaction.

The present study was thus initiated with the object of:

(1) Examining the potassium status of several calcareous and non-calcareous Manitoba soils, with respect to the availability of potassium to plants grown on these soils.

(2) Comparing two methods of applying potassium fertilizer to corn,

  (i) Banding the potassium below the seeds prior to seeding.
  (ii) Mixing the potassium throughout the soil prior to seeding.

(3) Comparing the merits of H_2O, NaCl and NH_4OAc as solutions for extracting potassium from calcareous and non-calcareous soils in Manitoba, when the data are to be used as a measure of plant available potassium.

LITERATURE REVIEW

The relationship of the various cations in the soil with respect to their availability to plants has been the subject of much controversy. Potassium, one of the most important cations and perhaps the most investigated has had its share of controversy with respect to soil-plant relationship.

Plant potassium requirement is usually associated with carbohydrate metabolism, in which the element is reported to act as an enzyme activator. Hendricks (13) states, however, that a much more likely reason for the potassium requirement for growth, than for enzyme activation, is that the potassium imparts particular configurations to some proteins necessary for their specific functioning.

Peaslee and Moss (20) working with maize found that photosynthesis was strongly affected by potassium and magnesium concentrations in the leaves of these plants. In the case of low potassium content all the leaves of these plants appeared normal and did not differ significantly in chlorophyll content; however on some potassium-deficient plants, the older leaves showed typical potassium deficiency symptoms, while the younger leaves were normal, and since these young leaves were the ones examined in the experiment, it suggested that potassium effects on photosynthesis occurred before visible symptoms appeared on the leaf. They suggested that potassium deficiency of the leaf decreased the stomatal openings, however the condition could be corrected with application of potassium.

Jenny _et_ _al_. (16a) in studying the lime-potassium problem of soils concluded that lime added to the soil liberated potassium.

York and Rogers (30) stated that although the addition of calcium was instrumental in releasing non-exchangeable potassium, fixation of applied potassium was encouraged by liming.

Worsham and Sturgis (29) working on the factors affecting the availability of potassium in soils of the lower Mississippi delta concluded that--(a) the high available potassium content of some soils was associated with a high base exchange capacity, exceptions occurring in soils that were completely base saturated; (b) calcium salts added to one hundred percent base saturated soils liberated potassium. $CaSO_4$ liberated potassium from both acid and basic soils; (c) an increase in the base saturation was associated with an increase in potassium fixation until complete base saturation occurred, after which there was a decrease in fixation of potassium; (d) organic matter markedly increased the available potassium in the soil; this was also accompanied by a high leaching of potassium from the soil.

Salmon (23) worked with clay and peat soils saturated with calcium, magnesium and potassium ions in different proportions. He measured the activity ratio of these ions in dilute equilibrium solutions and found from his results that, (a) a decrease in the Ca:Mg ratio increased the strength with which potassium is absorbed by peat, but had no effect on potassium absorption by clays; (b) peat absorbed potassium much less strongly than magnesium and calcium. Thus since calcium is more strongly absorbed by peat than magnesium, adding calcium to these soils would release more potassium than would be released by adding an equivalent amount of magnesium.

Peech and Bradfield (21) studied the effect of lime and neutral calcium salts on the solubility of potassium and concluded that calcium does not facilitate the conversion of the exchangeable potassium of collodial clay into less exchangeable forms. They further showed that an increase in absorbed calcium favours the absorption of potassium from neutral salts, while increases in the calcium ion concentration results in the liberation of absorbed potassium.

Other factors bearing on the release of potassium have been studied. Bartholomew (6) and others have shown that crops remove considerably more potassium, in addition to that added in manure, from plots fertilized with manure than they did from unfertilized plots, thus indicating that the decomposition of organic matter converts some of the insoluble minerals of the soils into forms which could be used by plants. Jenny (16b) however found that micro-organisms reduced the leaching of potassium from soils as compared with sterile systems. He demonstrated that this reduction was more pronounced in the presence of $CaCo_3$.

De Turk et al. (10) defined potassium fixation as the change of water soluble or replaceable potassium into forms which are neither water soluble nor instantly replaceable. They found that during growth there was a drop in the replaceable potassium but that after growth the potassium status of the soil was again built up. They observed that when soils were taken from the field and kept under moist storage conditions without previous removal of the replaceable potassium, little change occurred in the potassium status, even with long storage. They distinguished an equilibrium condition operating in the soil potassium system and illustrated it as K (fixed) $\rightleftharpoons$ K (released). When potassium was added to the soil in the phosphate form they observed a greater amount of fixation than when the potassium was added as potassium chloride. They assumed that the $PO_4^{=}$ group acted as a link to join the potassium to the soil colloid as an Al - O - P - K complex. Hoagland and Martin (14) however working with barley and tomatoes found no difference with respect to the relative amounts of potassium fixed when the source was KCl or K_2SO_4.

Anderson _et_ _al_. (3) stated that plants appeared to use a definite total quantity of the three cations K^+, Ca^{++} and Mg^{++} and that any excess or deficiency of one of these ions resulted in an increase or decrease, respectively, in the absorption of the other ions. Based on this and similar observations several workers have attempted to relate these cations by a series of cationic ratios involving activity or concentration of the ions.

Beckett (7b) calculated ratios of $A_k\sqrt{Aca}$ and $A_k\sqrt{Aca + Amg}$ to relate the availability of labile potassium in the soil. In another paper (7a) he used the equation $\frac{[Ca] \times (Mg)}{[Mg] \times (Ca)} = K$, proposed by Jenny and other workers. The square brackets represent the total amount of calcium and magnesium; parentheses represent the concentration or activities of calcium and magnesium in the soil solution; K is the "ion - exchange constant", when $K > 1$ it suggests that exchangeable magnesium is less tightly held than exchangeable calcium. From a series of computations on various soil types he concluded that except at specific sites calcium and magnesium are held with approximately equal attraction by exchange surfaces; also that in a natural soil there are a number of exchange sites apparently capable of showing a specific affinity for calcium, and a smaller number of similar sites showing an affinity for magnesium; once these sites are occupied there is apparently little difference between the affinity of the soil exchange surface for calcium or magnesium.

Gillingham (12) used the Neubauer rye seedling method to study factors affecting the net absorption of exchangeable potassium; he found that the recovery of exchangeable potassium was related to available nitrogen and phosphorous supplies. He obtained increases of 72 - 100 percent in potassium uptake from additions of phosphorous and nitrogen as P_2O_5 and NH_4NO_3 respectively. At high rates of nitrogen and phosphorous the plants were capable of extracting some non-exchangeable potassium. On some soils however (i.e. Vancouver Island soils) he got incomplete extraction of exchangeable potassium, the plants were only capable of extracting 30 - 40 percent of the measured exchangeable potassium.

Pierre and Bower (22) from a review of previous literature and their own experimental investigations suggested that the ability of a plant to obtain a sufficient amount of potassium or other nutrient element for optimum growth depends not only on the concentration of the element in the nutrient medium (the soil) but also on certain environmental factors affecting absorption.

Considering the effect of liming on the absorption of potassium by plants they concluded, from a review of previous literature, that the apparent contradictory results reported by several investigators as to the possible effect of calcium and/or magnesium on the uptake of potassium was due to some extent on the kind of plants investigated (3,8). They were also of the opinion that the potassium content of crops was undoubtedly influenced also by the fact that liming may either decrease or increase the water - soluble potassium content of the soil. Thus it was obvious, they stated, that unless the effect of lime on the potassium water - soluble content of the soil was known, it would be impossible to determine from such experiments whether the decreased absorption of potassium by plants was due to a lower amount of potassium in the solution or to an antagonistic effect of the increased calcium concentration in accordance with Ehrenberg's law.

The depressing effect of calcium and magnesium on potassium absorption by corn has been advanced as a possible explanation for the marked deficiency symptoms and the low potassium content of this crop when grown on the high - lime soils of North-Central Iowa. Alloway and Pierre (2) and Sanford _et al_. (24) have found that although many of these Iowa soils contain 150 - 200 pounds of exchangeable potassium per acre, corn showed marked potassium deficiency symptoms and that yield may be more than doubled by application of potassium fertilizers. They found that the calcium and magnesium content of these plants was higher than normal while potassium content was low. Sanford _et al_. (24) used the ratio Ca + Mg : K as the determining factor in potassium absorption by corn. Thus for $Ca + Mg : K \geqslant 5$, in the plant, they got a low potassium uptake by the plants and potassium deficiency symptoms were observed, this phenomena they explained as being due to a lack of a favourable potassium, calcium, magnesium balance in the plants. On the other hand for a $Ca + Mg : K < 3.5$ they obtained good plant growth, and attributed this to the presence of a favourable potassium, calcium, magnesium balance in the plants. They proposed that for the area suggested by the ratio $3.5 < Ca + Mg : K < 5$ was an indication of a state of transition between favourable and unfavourable potassium, calcium, magnesium balance in the plants. Comparing the "High-lime soils" and the "Normal Soils" (these differentations of soils were based essentially on percent calcium carbonate equivalents) they observed that there was no sensible relationship between yield of corn and exchangeable potassium on the High-lime soils as were observed on the Normal soils.

In an evaluation of the mechanisms governing the supply of calcium, potassium, magnesium and sodium to soybean roots, Oliver and Barber (19) concluded that three mechanisms govern the rate of supply of nutrients from the soil mass to plant roots; these they listed as (a) root interception, (b) mass-flow, (c) diffusion. They concluded from a review of past literature that the principal mechanism which supplies the root with nutrient varies with the nutrient, plant species, and the properties of the soil used. Thus for calcium, root interception accounted for 14 - 19% of the uptake of this cation, while mass-flow accounted for the remaining 86 - 81%; for magnesium root interception accounted for 12 - 14%, mass flow accounted for 88 - 86%, in the case of this element some uptake due to diffusion occurs at low transpiration rates; in the case of potassium diffusion accounted for 87 - 96%, thus mass flow and root interception are of very little importance.

Fox and Kacar (11) studying the mobilization of non-exchangeable potassium and sodium in a calcareous soil during plant growth, reported that if the "contact mechanism" is apparent then the extensivity of the root system is important in potassium and sodium release from primary and secondary soil minerals. They found that plants grown in pots in the greenhouse were capable of mobilizing non-exchangeable potassium, in this capacity they found that legumes were more effective than grasses--the reasons suggested were that legume roots had a higher exchange capacity, greater retention of cations, and possibly the fact that they have a more acid surface, thus may be more effective in decomposing easily weathered primary minerals with the subsequent release of potassium. They found that the grasses took up more potassium than the legumes, however the legumes took up correspondingly more calcium. They also proposed the following equilibrium equation for soil potassium--

K "fixed" in layer silicates $\rightleftharpoons$ (Exchangeable + Solution)K $\rightleftharpoons$ Plant K.

Albrecht (1) showed from data presented, that the increasing stages of soil development, which gives increasingly more calcium in relation to potassium on the soil colloid clay, gives correspondingly increasing potassium over calcium in the plant. In general he stated that the potassium and calcium of the soil decreased as the soil becomes more highly developed. The portion of the soil potassium utilized or available to plants he termed "Active" potassium. This "Active" potassium, he stated, is provided essentially by the absorbed potassium or that supplied by the breakdown of silt and sand fractions, thus chemical breakdown of the clay fraction to provide this active potassium is of no significance. He stated also that although calcium - potassium ratio has been emphasized as a reflection, via the plant, of these nutrients on the colloid complex and in the soil mineral reserve, one must not deduce physiological functions to the extent of exclusion of one by the other. Thus before any plant can grow, it must have both calcium and potassium. At starvation levels and even at more nearly balanced concentrations, calcium and potassium are directly associated, and either one may be instrumental in moving the other into the crop.

McEwen and Matthews (18) working with several Ontario soils stated that the supplying power of potassium in these soils was related primarily to their clay content. Thus since fertilizer treatments and cropping history have no effect on the potassium supplying power, it should not be necessary to measure potassium power of all soils in the routine soil testing program. Thus with a significant number of samples a mean potassium - supplying power of all soils of each textured class could be established. On the other hand, differences in potassium - supplying power of soils undoubtedly explain the fact that exchangeable potassium levels of soils do not correlate well with crop response to applied fertilizer, especially at low levels of exchangeable potassium. Therefore for the interpretation of exchangeable potassium levels in terms of potassium fertilizer requirements it would be necessary to set up different requirement tables for soils of different texture.

Smith and Matthews (25) working in the greenhouse with eighteen Ontario soils found that when these soils were cropped they had the characteristic of retaining a minimum level of potassium which is unavailable. They also found that fine textured soils released more non-exchangeable potassium and maintained a higher level of exchangeable potassium than the coarser textured soils.

Beckett (7a) studied the cation - exchange equilibria of calcium and magnesium and concluded that while individual analytical procedures may be expected to give consistent results, different procedures give different results; and that there was considerable uncertainty as to whether all the ions removed by strong leaching solutions, such as ammonium acetate, would in fact have been in exchange equilibrium with the soil solution.

Aslander and Armolik (4) working with peat soils concluded that organic soils do not fix potassium as do mineral soils. They found that by previously oxidizing the organic matter in the soil they could reduce the amount of potassium that would be fixed; they explained this phenomena by assuming that the acidity which developed in the soil prevented potassium fixation. They found also that when organic matter was added to the soil it competed with the mineral or inorganic fractions of the soil for exchangeable cations, potassium in this case. Thus because of its greater cation exchange capacity, the organic matter competed successfully with and diverted considerable quantities of potassium from the mineral fractions. Thus since organic matter cannot fix potassium, and since the quantity of potassium in the inorganic fractions had been considerably decreased the fixation of potassium was decreased in the soil. The organic matter also changed non-exchangeable potassium to exchangeable forms. They found however that farm yard manure did not lower the fixation power of the soil for potassium; and concluded that the beneficial effects of farm yard manure and mulching straw was caused mainly by improved structure. Using oats as a crop they found that this plant was a heavy extractor of potassium; also a comparison of three methods of applying potassium showed that broadcasting potassium was not as efficient as banding it, and that mixing the potassium throughout the soil was not as effective as banding it, relative to plant growth and response.

Walker (27) studied the effect of various environmental conditions on potassium fixation and concluded that successive wetting and drying of soils greatly increased potassium fixation; also that heating soils to 105° C resulted in fixation of 45% of the potassium which was formerly exchangeable. When he added potassium to the soil as KCl he found that on air drying, approximately 28% of the potassium added was fixed. Like Aslander and Armolik (4) he showed that adding organic matter to the soil not only reduced potassium fixation but also changed non-exchangeable potassium to exchangeable forms.

GENERAL METHODS AND MATERIALS

DETERMINATION OF K, Na, Ca and Mg ON THE SOILS

Three different extracting solutions were used to extract the cations K^+, Na^+, Ca^{++} and Mg^{++} from the soils used in the experiments:

Solution #1 - 1.0 N Ammonium Acetate pH 7 plus 250 ppm of Lithium Nitrate.

Solution #2 - 2.0 N Sodium Chloride plus 250 ppm of Lithium Nitrate.

Solution #3 - Copper free distilled water plus 250 ppm of Lithium Nitrate.

The general procedure employed in extracting the cations was similar in all three cases:

10 grams of air dried soil, previously ground to pass through a 2 mm sieve, was placed in a 500 ml. shaking bottle, to this was added 100 ml. of the extracting solution, and the mixture placed on a rotating shaker and allowed to shake for one hour.

In the case of the water extract the mixture was then transferred to 250 ml. centrifuge tubes and centrifuged at 1000 rpm for five minutes. The solution was then filtered through #42 filter paper. The ammonium acetate and sodium chloride extracts were removed from the shaker and filtered through #1 filter paper.

An extract was taken from the various solutions thus prepared and potassium and sodium were determined by Flame Photometry using the Baird Atomic KY2 Flame Photometer.

Calcium and magnesium were determined by EDTA (disodium salt) titrations, on separate extracts; the indicators employed were Erio Black T for calcium plus magnesium, and Cal-Red for calcium titration.

DETERMINATION OF THE SOILS PHYSICAL CHARACTERISTICS

The texture of the various soils used were determined by the Mechanical Fractionation Method as outlined by Jackson (15).

DETERMINATION OF CATIONS K, NA, Ca and Mg IN THE PLANT MATERIAL

All determinations were made on a dry weight basis. The plant material having been harvested was allowed to air dry for three days, it was then transferred to an oven where it was dried at 60°C for two days. The oven dried material was weighed and ground.

The extracting solution used for the determination of potassium and sodium was similar to solution #1 used for the soils (1.0 N NH_4OAc pH 7). The plant material-extracting solution ratio employed was 1:500 (0.2g of plant material in 100 ml of solution). The mixture was allowed to shake for one hour on a rotating shaker, the solution was then filtered off using a #1 filter paper. Aliquots were taken and both potassium and sodium determined by Flame Photometry on the Baird Atomic KY2 Flame Photometer.

Calcium and Magnesium were determined by the dry ash and EDTA (disodium salt) titration method as described by Word and Johnson (28).

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS

Tables1 & 2 give the location, soil type and general physical and chemical composition of the soils used in the greenhouse and laboratory experiments.

Fourteen soils were collected and used in the greenhouse and laboratory experiments. The soils were divided into two groups of seven, based on their percent calcium carbonate equivalent. Those soils having a percent calcium carbonate equivalent of two or greater were placed in the calcareous group, and those with less than two percent calcium carbonate equivalent were placed in the non-calcareous group.

The soils were collected in the spring of 1965, and were taken from the 0 - 6" depth. The sites chosen from which soil was collected were in areas which were being cropped in the summer of 1965.

Three criteria were used in collecting the soils:

(a) The percent calcium carbonate equivalent of the soils, such that two groups of seven soils were collected.

(b) A gradiation in texture of the two groups of soils.

(c) A range in the ammonium acetate extractable potassium in both groups of soils.

TABLE 1

Some Characteristics of the Soils Used

Soil Code	Area Soil collected from	Soil Association or Series*	pH	Conduct-ivity mmhos	% $CaCO_3$ equivalent	% Organic matter	0-6" NO_3-N ppm	P ppm
	Non-Calareous Soils							
1	Dauphin	Miniota	6.7	0.26	0.32	1.86	1.2	14.0
2	Giroux	Poppleton	7.0	0.34	0.91	3.13	1.0	1.1
3	Carman	Almassippi	6.9	0.38	0.11	2.55	7.1	5.3
4	Sidney	Stockton	5.7	0.22	0.05	2.64	1.7	16.8
5	Carberry	Wellwood	5.5	0.53	0.10	8.53	20.4	24.2
6	Morden	Altona	6.9	0.53	0.18	6.24	13.3	12.3
7	Carman	Almassippi	7.0	0.50	1.37	5.55	10.9	10.3
	Calcareous Soils							
8	Giroux	Pelan	7.3	0.43	5.62	1.64	6.5	13.4
9	Elm Creek	Almassippi	7.6	0.53	2.49	2.53	11.7	3.6
10	St. Rose	Plum Ridge*	7.8	0.46	37.53	5.55	14.9	2.7
11	Steinbach	Steinbach	7.4	0.61	3.00	7.17	3.5	37.8
12	Teulon	Lakeland*	7.7	0.45	16.92	7.39	4.1	13.1
13	Carman	Almassippi	7.8	0.40	2.54	2.13	7.1	16.3
14	Teulon	Balmoral*	7.7	0.42	15.02	2.04	8.6	4.5

Description of the soil associations and series listed are given in the "Report of Reconnaissance Soil Survey" numbers 4, 5, 7, 9 and 12, published by The Manitoba Department of Agriculture and Immigration and The Canada Department of Agriculture.

TABLE 2

Mechanical Analysis of Soils

Soil Code	% Sand	% Silt	% Clay	Texture -
Non-Calcareous Soils				
1	94.66	3.67	1.66	Sand
2	81.73	5.53	12.74	Loamy Sand
3	83.83	10.83	5.34	Loamy Sand
4	69.20	18.50	12.30	Fine Sandy Loam
5	14.20	55.93	29.84	Silty Clay Loam
6	60.78	25.89	13.32	Very Fine Sandy Loam
7	34.46	40.44	25.10	Loam
Calcareous Soils				
8	89.67	7.60	2.73	Sand
9	69.75	20.35	9.90	Fine Sandy Loam
10	16.60	70.65	12.74	Silt Loam
11	15.43	33.84	50.73	Clay
12	15.46	57.09	28.45	Silty Clay Loam
13	78.82	16.00	5.18	Loamy Fine Sand
14	37.23	50.64	12.13	Silt Loam

Discussion and General Conclusions based on the Analytical results obtained for the soils

Table 3 gives the data for the chemical analysis of the various soil extracts for the cations K^+, Na^+, Ca^{++} and Mg^{++}.

A consideration of the data presented in Table 3 was made to evaluate the merits of the extracting solutions to extract "plant-available" potassium from the soils. The results indicated that the NH_4OAc solution removed more cations than the NaCl solution which in turn removed more cations than the water solution. With respect to the removal of individual cations, the NaCl and NH_4OAc solutions removed similar amounts of potassium from the coarse textured soils, which had very low to low levels of soil potassium; however on the finer textured soils the NH_4OAc solution was the greater extractor of potassium. These soils also had high to very high levels of soil potassium. The amount of potassium extracted by the water solution was also largest for the finer textured soils.

With respect to the amounts of calcium and magnesium extracted by the various extracting solutions, there were no observed differences in the amounts extracted with gradiation in texture of the soils.

A consideration of the two groups of soils showed that the NH_4OAc solution extracted more calcium and magnesium from the calcareous soils than did the NaCl solution; on the non-calcareous soils the NH_4OAc solution extracted more calcium than the NaCl solution, however both solutions extracted similar amounts of magnesium within experimental error.

It is assumed that the cations extracted by the water solution were those present in the soils in soluble or very easily extractable forms, thus relatively more magnesium was extracted than calcium. The former ions being much more soluble and less tightly held on the soil exchange sites (7b).

The high cation extracting power of NH_4OAc on the soils used in the experiment and in particular the calcareous group of soils could be attributed to chemical decomposition of some soil minerals such as $CaCO_3$ and other trapped minerals in the clay lattice structure. Also since the NH_4^+ ion is of a similar size to the K^+ ion it is assumed that the NH_4^+ ion could enter in to the lattice structure of the clay minerals in a 1:1 substitution for K^+ ions, which had formed part of the mineral's lattice structure and were not on the exchange sites.

The sodium chloride solution, it is assumed, was not capable of causing similar mineralogical decomposition (7a), thus resulting in a small amount of cations being extracted.

There is evidence of some relationship between texture (Table 2) and soil potassium. Thus the coarser textured soils in both soil groups had the smaller amounts of extractable soil potassium.

TABLE 3

Cations extracted from the soils by the use of three different extracting solutions - NH_4OAc, Na Cl and water

	NH_4OAc Extractable				Water Extractable				NaCl Extractable		
Soil Code	K ppm	Ca Me/ 100g	Mg Me/ 100g	Na ppm	K ppm	Ca Me/ 100g	Mg Me/ 100g	Na ppm	K ppm	Ca Me/ 100g	Mg Me/ 100g
Non-Calcareous Soils											
1	48.5	8.2	1.6	7.5	1.48	.56	1.12	.45	50.0	3.6	1.8
2	80.0	23.2	5.0	10.0	1.71	.44	.76	.91	80.0	10.8	4.6
3	98.0	9.8	3.4	7.5	2.39	.84	.88	.68	90.5	8.4	3.4
4	163.0	4.6	2.0	7.5	4.21	.95	.76	.45	160.2	4.5	2.0
5	363.5	17.8	6.0	13.0	5.34	.76	.50	.91	280.5	17.2	5.8
6	641.0	17.0	5.4	10.0	10.92	.91	.52	.91	500.0	14.8	5.0
7	686.0	33.2	13.4	50.0	11.94	.52	.46	3.41	425.5	22.4	9.0
Calcareous Soils											
8	60.0	12.9	2.9	12.0	1.48	.52	.56	3.41	60.0	7.2	2.2
9	57.5	14.8	3.8	18.5	1.46	.40	.56	1.82	55.5	9.8	3.2
10	90.0	25.8	14.2	20.0	1.82	.36	.12	1.82	90.0	10.8	8.0
11	816.0	38.3	20.1	165.0	14.00	.38	.20	8.00	460.5	26.4	14.6
12	281.0	32.6	16.6	66.0	4.55	.76	.34	6.14	160.0	17.0	10.8
13	187.0	15.0	2.8	12.5	2.60	.68	.40	1.36	120.2	9.0	3.0
14	250.0	30.0	14.6	21.0	2.80	.36	.26	1.82	155.5	16.5	9.2

The percent cations, based on me/100 gms., extracted by both the NH_4OAc and water solutions are given in Table 4.

The percent of relatively water soluble forms of the cations varied considerably in both soil groups. In the non-calcareous soils the percent potassium was always larger than the percent sodium. Only in soil numbers 1, 2 and 3 was the percent magnesium greater than the percent calcium. On the calcareous soils the percent calcium was greater than the percent magnesium except in soil numbers 8 and 9; also in soil numbers 8, 9, 10 and 14 the percent sodium was greater than the percent potassium.

The preponderance of percent cations for the NH_4OAc extract are in the order $Ca^{++} > Mg^{++} > K^{+} > Na^{+}$, for both groups of soils. This solution also extracted a larger percent calcium than did the water solution. For equivalent levels of actual NH_4OAc extractable potassium in both soil groups (Table 3), the calculated percentages for the non-calcareous soils were larger than for the calcareous soils.

In general the only observable differences in the two groups of soils are - (a) The calcareous soils have a higher percent calcium carbonate equivalent than the non-calcareous soils. (b) The amount of NaCl and NH_4OAc extractable calcium and magnesium ions from the calcareous soils was in general larger than the amounts extracted from the non-calcareous soils. (c) The amount of water extractable magnesium from the non-calcareous soils was larger than the amount extracted from the calcareous soils.

In general one could classify the fertility of the fourteen soils as ranging from very low to high.

TABLE 4.

Percent cations (me/100g) in the soil:- NH_4OAc and H_2O extractable

Soil Code	NH_4OAc Extractable % K	 % Na	 % Ca	 % Mg	H_2O Extractable % K	 % Na	 % Ca	 % Mg
	Non-Calcareous Soils							
1	1.21	0.30	82.41	16.08	0.32	0.12	33.22	66.43
2	0.74	0.14	81.55	17.57	0.36	0.33	36.41	62.90
3	1.85	0.22	72.70	25.22	0.35	0.16	48.58	50.90
4	5.60	0.43	65.25	28.37	0.64	0.10	55.14	44.12
5	3.48	0.24	72.00	24.27	1.07	0.31	59.48	39.13
6	6.81	0.17	70.60	22.43	1.90	0.23	62.42	35.45
7	3.62	0.45	68.34	27.58	3.30	1.61	56.19	38.90
	Calcareous Soils							
8	0.94	0.31	80.75	18.00	0.35	1.35	47.34	50.96
9	1.22	0.42	78.60	20.18	0.39	0.81	41.16	57.63
10	0.57	0.20	64.00	35.23	0.93	1.61	73.10	24.37
11	3.41	1.18	62.49	32.92	5.51	5.35	58.40	30.78
12	1.43	0.54	64.93	33.06	2.00	1.34	66.78	29.88
13	2.25	0.64	81.83	14.87	0.62	0.39	62.32	36.66
14	1.41	0.20	66.18	32.21	1.35	1.48	67.28	29.90

GREENHOUSE EXPERIMENTS

Experiment 1

Methods and Materials

A greenhouse experiment, using corn (Morden 88) as the crop, was designed to study:

(a) The relative availability of potassium from both groups of soils.

(b) The effect of adding fertilizer potassium to these soils on the uptake of potassium, calcium and magnesium.

(c) The best method of applying fertilizer potassium, either banding it below the seed or mixing it throughout the soil prior to seeding.

(d) The relative merits of the three cation-extracting solutions, NH_4OAc, NaCl and water, for predicting soil potassium availibility to corn.

The soils used in the experiment were those previously discussed. 1800 grams of air dried soil was mixed thoroughly and added to each of the one-half gallon glazed porcelain pots in which the crop was to be grown. A total of 126 pots were prepared. The experiment consisted of three treatments replicated three times. The three treatments in the experiment were: Treatment 1, a check treatment (no potassium fertilizer added); Treatment 2, a potassium fertilized treatment in which 100 ppm of potassium as KCl was mixed thoroughly throughout the soil prior to seeding; Treatment 3, a potassium fertilized treatment in which 100 ppm potassium as KCl was banded one-half inch below the seed depth prior to seeding.

At the time of seeding, July 6, 1965, 20 ppm of phosphorous as $NH_4H_2PO_4$ was banded in all the pots at a depth of one-half inch below the seed depth. Four corn seeds were placed in each pot at a depth of one-half inch below the surface of the soil. The pots were placed in the greenhouse and the soils brought up to field capacity with distilled water. The pots were kept at optimum moisture condition for plant growth throughout the experiment. Micronutrients were added in a solution form to all the pots, at periodic intervals throughout the experiment, to off-set the lack of these elements in the distilled water with which the plants were watered. The micronutrient solution was made up according to the method suggested by Machlis and Torney (17). Appendix A gives the concentration of the various elements used in making up the solution. 20 ppm sulphur as NH_4SO_4 was added to all the pots as a surface application immediately preceding the seeding of the corn.

The plants emerged on July 10th. Two days after emergence nitrogen as NH_4NO_3 was added to all the pots in a concentration sufficient to bring all the pots up to an equivalent amount of nitrogen, i.e. 25 ppm nitrogen. Three more additions of nitrogen as NH_4NO_3 were made during the course of the experiment, at each time, which was about eight days apart, 50 ppm of nitrogen was added.

On July 20th, the pots were thinned to leave only two corn plants per pot; wire props were also inserted to keep the plants upright.

About August 8th, the plants grown in soil numbers 1 and 11 were observed to be developing a chlorosis at the base of the leaf, which kept extending up the leaf blade towards the apex. The chlorotic condition persisted after an application of 25 ppm of nitrogen as NH_4SO_4. It was thus assumed that the condition might be due to lack of some other mineral element, thus on August 13th, 5 ppm of copper as $CuSO_4.5\ H_2O$ was added to all the pots. The chlorotic condition of the plants in soil numbers 1 and 11 disappeared after only three days.

The plants were harvested on August 26th, 50 days after seeding. The plants were cut off at the soil surface and were chopped in approximately one-quarter inch lengths and placed in paper bags to air dry. When air dried, the plant material was oven dried at $60^{\circ}C$ for several hours, then cooled and weighed. The oven dried plant material was finely ground and composites of the various treatments were made for individual soils. A representative sample was taken from the ground plant material and analyzed for potassium, sodium, calcium and magnesium.

Results and Discussion

The average yields of plant material in grams of oven dry weight, and the percent yield for the fertilized treatments are given in Table 5.

Yield of plant material

Statistical analysis of the data in Table 5 was completed for both groups of soils as individual units, and for each soil within a group. The results are listed in Table 5.

It was found that while within any soil group there existed

TABLE 5.

Experiment 1.

Average yield of plant material (oven dried) in grams and percent yield of fertilized treatments.

Soil Code	T - 1 Check	T - 2 K-mixed	T - 3 K-Banded	+ % Yield T-2	+ % Yield T-3
	Non-Calcareous Soils				
1	9.34 e_1	9.47 e_1	10.38 e_2	98.63	89.98
2	10.35 e_1	10.94 d_1	11.53 e_2	98.66	89.77
3	13.67 d_1	15.62 c_2	15.71 d_2	87.52	87.01
4	16.03 c_1	17.64 b_2	18.12 c_2	90.87	88.47
5	17.33 bc_1	18.54 b_2	20.46 b_3	93.47	84.70
6	19.82 a_1	20.25 a_2	24.83 a_3	97.88	79.82
7	17.99 b_1	18.57 b_1	21.13 b_2	96.88	85.14
Treat Average	14.93* $_1$	15.86* $_2$	17.45* $_3$		
	Calcareous Soils				
8	12.12 d_1	13.20 d_2	14.83 d_3	91.82	81.73
9	9.80 e_1	12.21 d_2	13.53 d_3	80.26	72.43
10	6.97 f_1	8.60 e_2	8.81 e_2	81.05	79.11
11	26.40 a_1	24.43 a_2	25.11 a_2	108.06	105.14
12	14.82 c_1	16.96 b_2	18.40 b_3	87.38	80.54
13	15.51 b_1	16.44 b_{12}	16.93 c_2	94.34	91.61
14	12.73 d_1	15.31 c_2	17.03 c_3	83.15	74.75
Treat Average	14.05* $_1$	15.31* $_2$	16.38* $_3$		

Note: Yield accompanied by the same letter a, b, c, d or e in any one treatment and for any one group of soils are not significant at P = .05 (Duncan's Test.) Yield accompanied by the same number 1, 2 and 3 for any one soil within a group are not significant at P = .05 (Duncan's Test.)

* No significant differences at P = .05 (Duncan's Test.) when treatment averages were compared between groups.

$$+\ \frac{\text{Check - T}}{\text{Fertilized - T}} \times 100 = \%\ \text{Yield}$$

differences among soils with respect to the amount of plant material produced; the greatest and most consistent differences were recorded between individual treatments within a particular soil group, thus treatment three was better than treatment two which in turn was better than treatment one. There is no significant difference between the amount of plant material produced by both groups of soils when they are treated as individual units.

The percent yield data was determined by calculating the yield of the check treatment as a percentage of the yield of the fertilized treatments. The data indicates that except for the plants grown on soil number 11 in which there was a negative response, all other plants grown on soils in both groups showed a greater response to potassium when it was applied as a band below the seed to when the potassium was mixed throughout the soil before seeding. A comparison of soils from both groups which had comparatively low but similar amounts of soil potassium as determined by both the NH_4OAc and NaCl extraction procedures, revealed that adding potassium to these soils resulted in a lower percent yield for corn on the calcareous soils, whether the potassium was banded or mixed throughout the soil as compared to the non-calcareous soils.

Figures 1, (A), (B), and (C) show the relationship between yield of plant material and extractable soil potassium, as was determined on the three extractions; water extract, NaCl extract and NH_4OAc extract respectively.

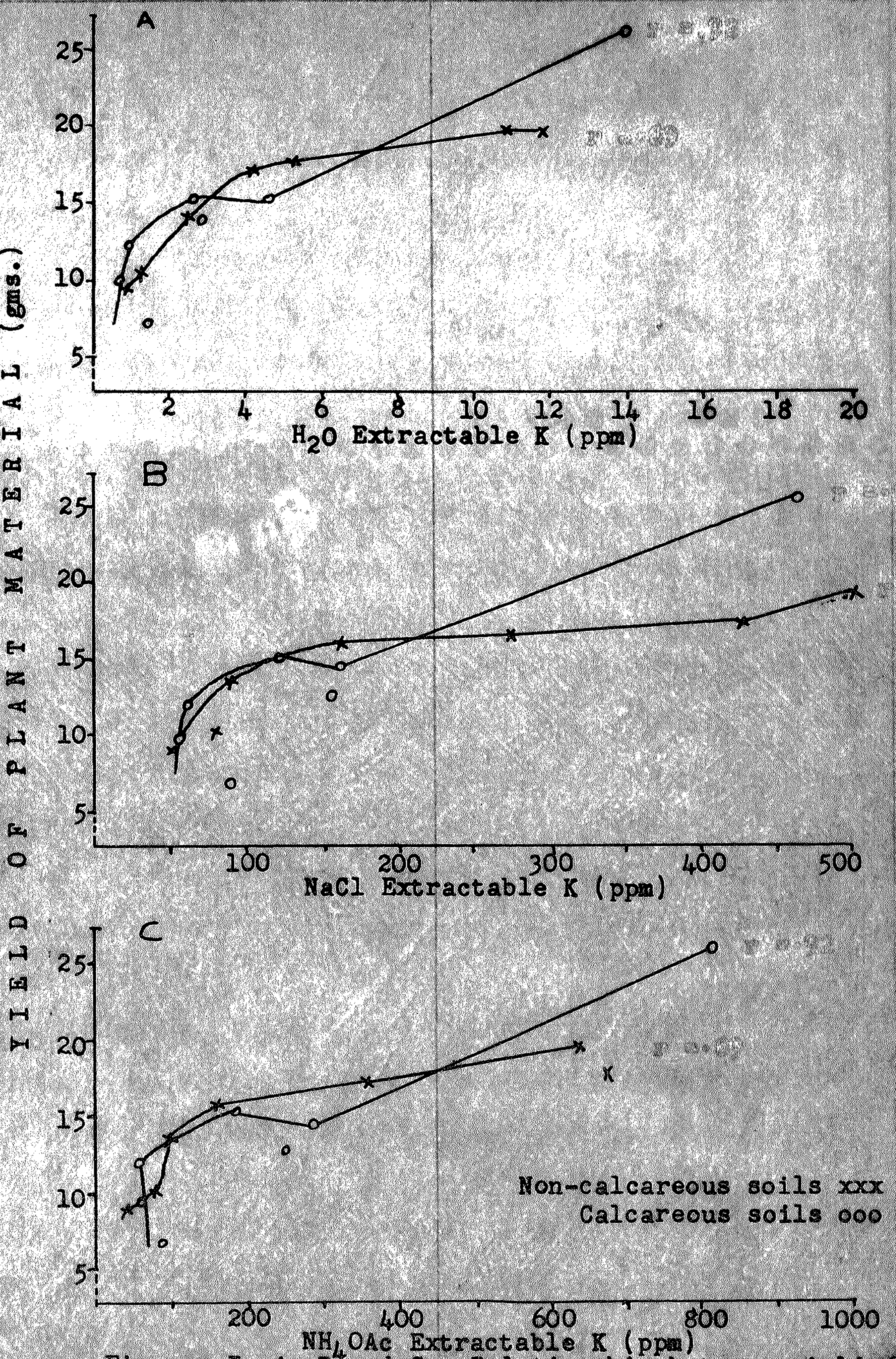
The three sets of figures (A, B and C) show that for both groups of soils there exists a good relationship between the yield of plant material and extractable soil potassium.

The figures constructed for the non-calcareous soils show a levelling off in yield with increase in soil potassium, as determined from the three extraction procedures used. The levelling off in yield occurs at approximately 16 grams of plant material in all three curves, this corresponds to approximately 4 ppm of water extractable potassium, 150 ppm of NaCl extractable potassium and 200 ppm of NH_4OAc extractable potassium. Except for soil number 11, the tendency for a levelling off in yield with increase in extractable soil potassium was also observed from the figures for the calcareous group of soils. However the levelling off points on these figures are not as obvious as the points on the figures for the non-calcareous soils.

The very high yield recorded in the case of soil number 11 is attributed to the exceptionally high fertility of this soil as is recorded in Tables 1, 2 and 3.

Analysis of Plant Material

Table 6 gives the data for the analysis of the plant material. The percent potassium in all the plants increased when 100 ppm of potassium was added to the soils. This increase was greatest when the potassium was banded into the soils as opposed to the treatment in which it was mixed throughout the soils. Thus one could assume that corn fed best from a concentrated source of potassium rather than from a diffused source. The plants grown on the check treatment had a very low level of soil potassium, while those grown on the two fertilized treatments bordered on the low to medium range level.



Figures I, A, B and C - Relationship between yield of plant material and H_2O, NaCl and NH_4OAc extractable K in soil respectively.

TABLE 6

Experiment 1.

Analysis of Plant Material

Soil Code	T-1 "Check" % K	%Na	%Ca	%Mg	T-2 "K-mixed" % K	%Na	%Ca	%Mg	T-3 "Banded" % K	%Na	%Ca	%Mg
	Non-Calcareous Soils											
1	0.53	0.50	0.52	0.72	1.24	0.45	0.55	0.61	1.26	0.45	0.51	0.65
2	0.73	0.45	0.45	0.65	1.15	0.45	0.46	0.55	1.20	0.40	0.47	0.65
3	0.70	0.65	0.32	0.62	0.89	0.53	0.27	0.44	1.00	0.50	0.27	0.60
4	1.00	0.55	0.16	0.40	1.50	0.40	0.18	0.43	1.50	0.38	0.17	0.40
5	1.39	0.60	0.17	0.42	1.56	0.48	0.15	0.39	1.60	0.35	0.14	0.40
6	1.79	0.40	0.16	0.40	1.93	0.32	0.19	0.43	1.99	0.27	0.15	0.41
7	2.05	0.40	0.20	0.41	2.11	0.28	0.19	0.43	2.24	0.30	0.16	0.46
	Calcareous Soils											
8	0.48	0.55	0.44	0.64	1.04	0.49	0.44	0.45	1.06	0.45	0.38	0.54
9	0.43	0.65	0.38	0.60	0.84	0.62	0.45	0.50	0.90	0.52	0.40	0.67
10	0.69	0.65	0.18	0.97	1.35	0.56	0.27	0.86	1.39	0.50	0.26	0.82
11	1.53	0.54	0.10	0.48	1.73	0.45	0.12	0.51	1.75	0.40	0.11	0.55
12	1.00	0.60	0.10	0.49	1.08	0.54	0.17	0.55	1.10	0.47	0.14	0.57
13	0.65	0.55	0.20	0.53	1.09	0.45	0.22	0.47	1.16	0.42	0.19	0.55
14	0.83	0.60	0.17	0.56	1.25	0.50	0.22	0.64	1.30	0.55	0.13	0.65

The percent magnesium content of all the plants was higher than the percent calcium. This phenomena, one can assume, is due to the specificity of the particular variety of corn (Morden 88) for magnesium.

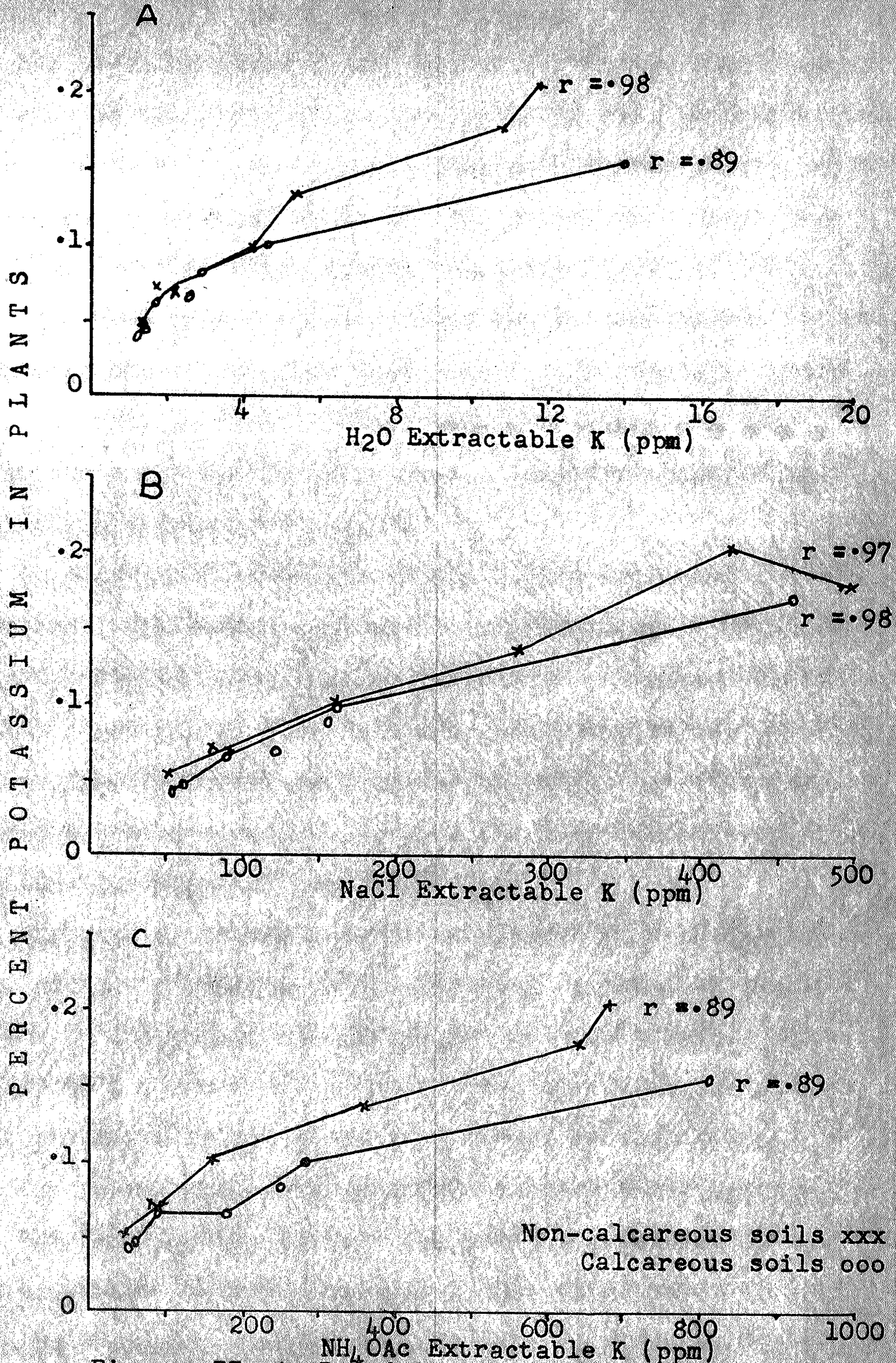
The percent magnesium content of the plants grown on the calcareous soils was higher than for those plants grown on the non-calcareous soils. Contrary to this, the percent calcium content of the plants grown on the non-calcareous soils was higher than for those grown on the calcareous soils.

In both groups of soils the percent magnesium content of the plants grown on any one soil was relatively constant for all three treatments. Thus adding potassium in a band or mixing it throughout the soils had no effect on the relative availability of magnesium to the plants. The percent calcium content of any one soil, however, was relatively constant only in treatments one and three; in treatment two the percent calcium content of the plants showed a slight increase. Thus mixing potassium throughout the soils apparently released calcium in an available form.

Figures 2, (A), (B), and (C) show the relationship between percent potassium in the plants grown on treatment one and the soil extractable potassium as determined from the three extraction procedures, water, NaCl and NH_4OAc respectively.

In general for any one group of soils the percent potassium in the plants increases with increase in soil extractable potassium.

Figure 2 B, constructed for the NaCl extractable potassium,



Figures II, A, B and C - Relationship between %K in plants and H_2O, NaCl and NH_4OAc exchangeable K in soils respectively.

gave the best relationship between soil potassium and percent potassium in the plants. At low levels of soil potassium the points for both groups of soils fall on the same curve, however they separate at high levels of soil potassium. Thus there exist some similarities between the availability of soil potassium from both groups of soils when the amount present is low (generally the coarser textured soils). At relatively high levels of soil potassium (finer textured soils) the non-calcareous soils appear to possess a larger percentage of available potassium for plants.

In Figure 2 C, constructed for NH_4OAc extractable soil potassium, both curves are completely separated. Therefore using the NH_4OAc extractable potassium as a measure of plant-available potassium, one would conclude that the availability of potassium from both soil groups to plants was different. The non-calcareous soils possessed the larger amount of plant-available potassium of the two groups.

Figure 2 A, constructed for the water extractable potassium, shows a similar trend to Figure 2 B, thus the conclusion arrived at for the latter figure is applicable here. The relationship between water extractable potassium and percent plant potassium is not as good, for both groups of soils, as was the relationship involving NaCl extractable potassium.

The relationship between the percent potassium in the plants and the percent potassium in the soil (Table 4) determined by the water extraction procedure is given by Figure 3. In general as the percent soil potassium increases in both

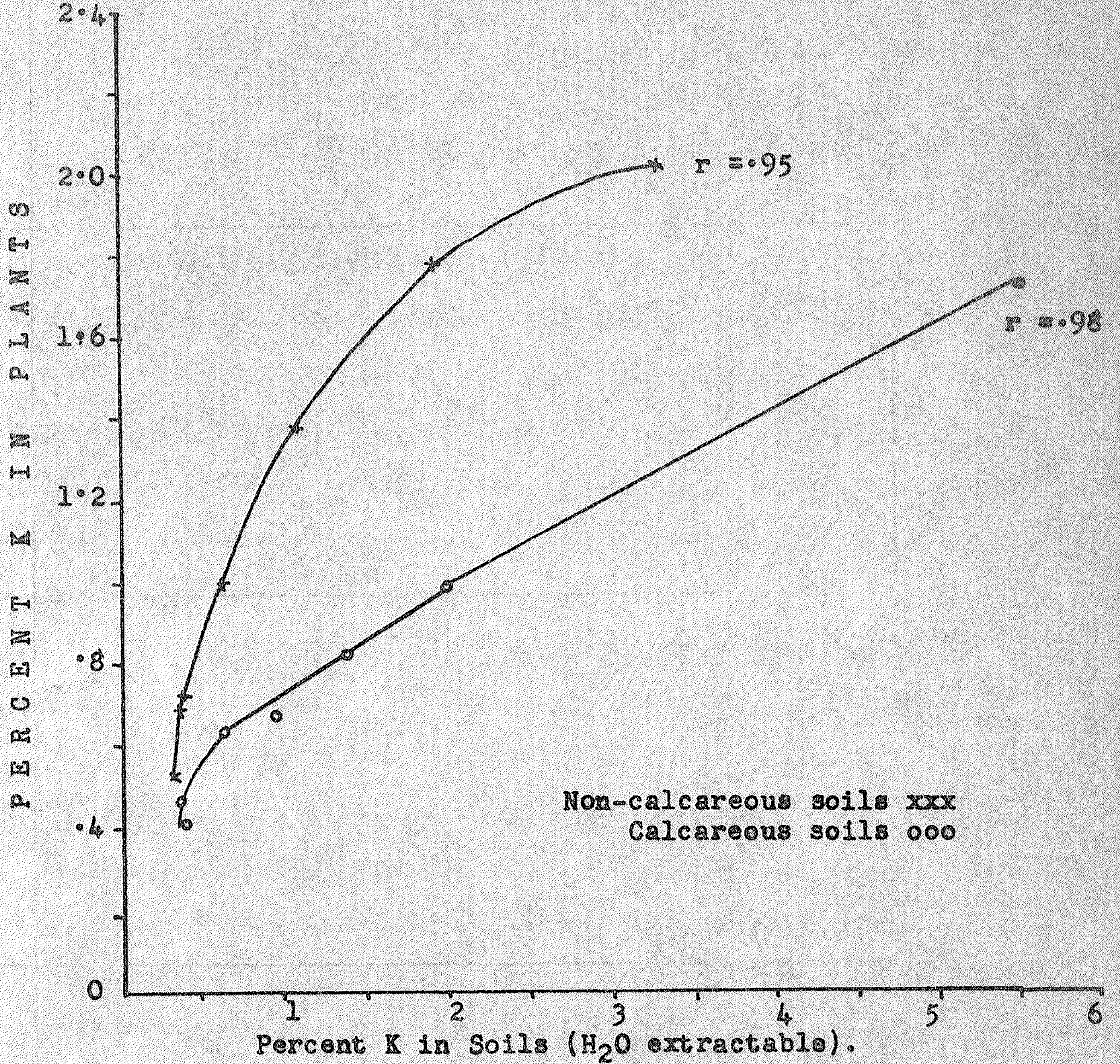


Figure III - Relationship between percent K in plants and percent H_2O extractable K in soils (Table IV).

groups of soils the percent potassium in the plants also increases. Thus the plants utilized sources of soil potassium which are water extractable.

There was no observed relationship between the percent NH_4OAc extractable soil potassium and percent plant potassium. This is further evidence that the NH_4OAc solution is capable of extracting cations from some soils which are unavailable to plants.

A comparison of the two groups of soils shows that for equivalent levels of percent H_2O extractable potassium, plants grown on the finer textured non-calcareous soils had a higher percent potassium content than those grown on the finer textured calcareous soils. Thus apparently a larger portion of the potassium extracted from the non-calcareous soils was available to the plants.

The percent sodium content of all the plants generally decreased with addition of fertilizer potassium (Table 6). The relatively high sodium content of the plants grown on soils Numbers 1, 2, 3, 8, 9, 10 and 13, in comparison to the relatively low potassium content of these plants, for the check treatment, could have resulted from a substitution of sodium for potassium in the plants' nutrition. This condition would result in physiological damage to the plants and could account in part for the reduced yields obtained.

Table 7 gives the data for the total uptake of potassium, calcium, magnesium and sodium by the plants.

A comparison of both soil groups shows that the plants

TABLE 7.

Experiment 1.

Total cations in plant material (mgm.)

Soil Code	Total Potassium T-1	T-2	T-3	Total Sodium T-1	T-2	T-3	Total Calcium T-1	T-2	T-3	Total Magnesium T-1	T-2	T-3
Non-Calcareous Soils												
1	50	117	131	47	43	47	49	52	53	67	58	67
2	76	126	138	47	49	46	47	50	54	67	60	75
3	96	139	157	89	83	79	44	42	42	85	69	94
4	160	265	272	88	71	69	26	29	31	64	71	96
5	241	289	327	44	89	72	28	29	29	73	74	108
6	355	391	494	79	65	67	32	38	37	79	87	122
7	369	392	473	72	52	63	36	35	34	74	80	97
Calcareous Soils												
8	58	133	157	67	65	67	53	58	56	78	59	80
9	42	103	122	64	76	70	37	55	54	59	61	91
10	48	116	122	45	48	44	13	23	23	68	74	72
11	404	423	439	143	110	100	26	23	20	127	128	136
12	148	183	202	89	92	86	15	28	26	73	127	136
13	101	179	196	85	74	71	47	36	34	82	77	93
14	117	191	221	76	77	94	22	34	32	64	98	111

grown on the non-calcareous soils generally had a larger potassium content than those grown on the calcareous soils. This tendency was also observed for treatments two and three. The total amount of magnesium and calcium in the plants remained relatively constant with addition of potassium to any one soil in a particular group.

Using the data collected in Tables 3 and 7, the percent of soil potassium and applied potassium used by the plants was calculated and the data given in Table 8. The table was constructed using the data for NH_4OAc and NaCl extractable soil potassium.

The plants used more NaCl extractable potassium in comparison to NH_4OAc extractable potassium. This fact is particularly obvious for those plants grown on the finer textured soils. This is further evidence of the fact that the NH_4OAc solution was extracting potassium from these soils which is unavailable to plants. This is particularly true in the case of the calcareous soils, since on these soils the plants used a smaller percentage of the NH_4OAc extractable potassium than they did on the non-calcareous soils; also a review of Table 3 shows that the percent NH_4OAc extractable potassium used by the plants decreases with increase in the amount of NH_4OAc extractable potassium determined on the soils. In general the plants grown on the non-calcareous soils also made greater use of the NH_4OAc extractable soil potassium.

The percent of NaCl extractable soil potassium used by the plants grown on the non-calcareous soils was relatively

TABLE 8.

Percent of soil K and Applied K used by Plants.

Soil Code	% soil K used by plants *		% applied K used by plants +	
	NH_4OAc Extractable K	NaCl Extractable K	T - 2 K-"mixed"	T - 3 K-"Banded"
	Non-Calcareous Soils			
1	29.94	28.90	19.42	23.49
2	27.54	27.54	14.49	17.97
3	28.40	30.77	12.46	17.68
4	28.46	28.93	30.43	32.46
5	19.25	24.89	13.91	24.92
6	16.06	20.58	10.43	40.28
7	15.59	25.14	6.67	30.14
	Calcareous Soils			
8	28.02	28.02	22.89	23.69
9	21.21	21.99	17.68	23.18
10	15.43	15.43	19.71	21.45
11	14.35	25.45	5.51	10.14
12	15.27	26.81	10.14	15.65
13	15.65	24.33	22.60	27.53
14	13.55	21.82	21.44	29.64

$$* \quad \%\text{ Soil K used by plants} \doteq \frac{\begin{pmatrix}\text{Check-T}\\ \text{Plant K mgm}\end{pmatrix}}{(\text{Soil K mgm})} \times 100$$

$$+ \quad \%\text{ Applied K used by plants} = \frac{\begin{pmatrix}\text{Fertilized-T}\\ \text{Plant K mgm}\end{pmatrix} - \begin{pmatrix}\text{Check-T}\\ \text{Plant K mgm}\end{pmatrix}}{(\text{Applied K mgm})} \times 100$$

constant, within experimental error. This is also observed for the calcareous soils. However a comparison of both soil groups shows that the plants grown on the finer textured non-calcareous soils made better use of NaCl extractable soil potassium than those grown on the finer textured calcareous soils. This could be due to the fact that these non-calcareous soils possessed a greater quantity of plant-available potassium, or that the calcareous soils "fix" potassium due to the presence of large amounts of absorbed calcium (21).

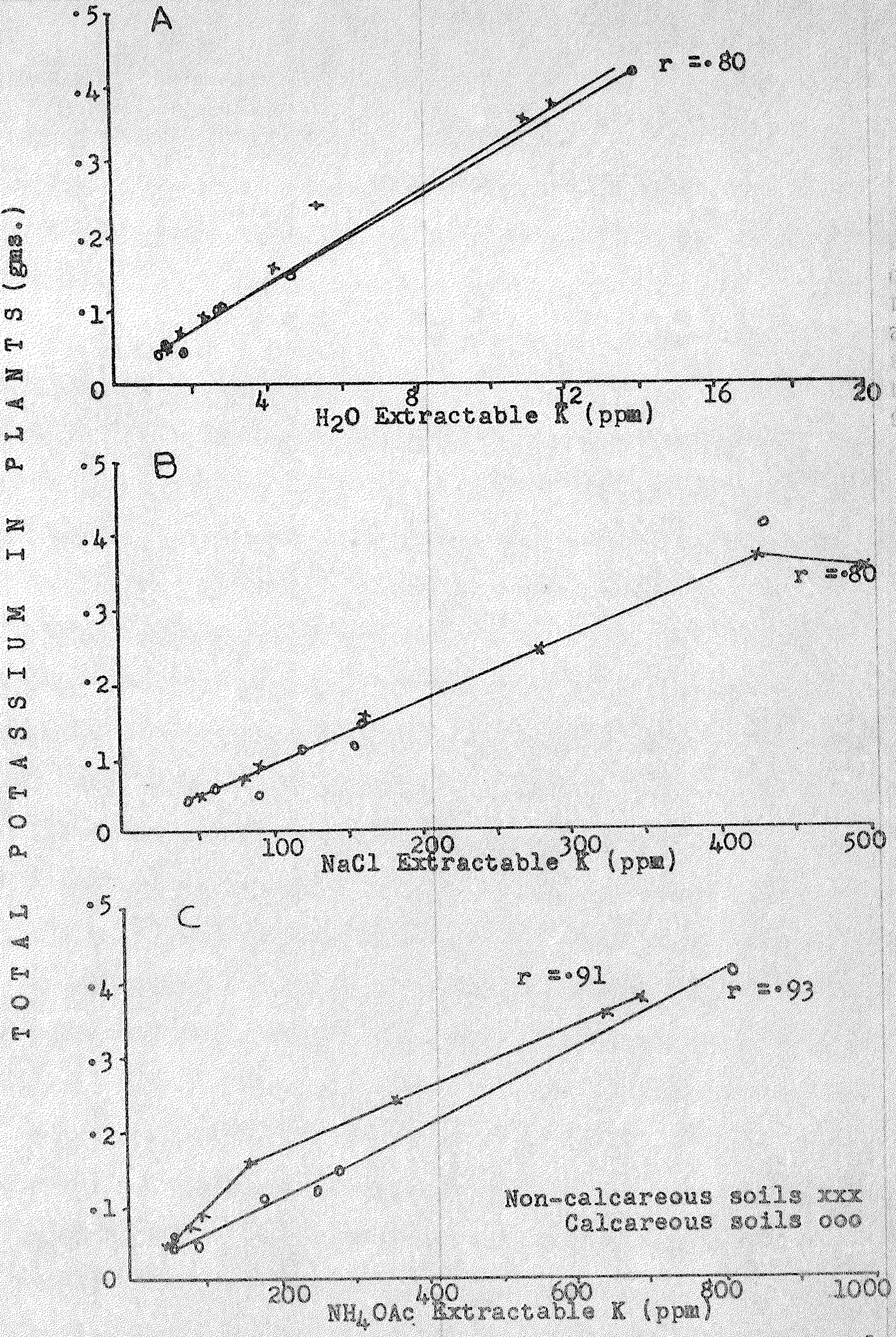
The plants grown on both groups of soils used more of the soil potassium (NH_4OAc and NaCl extractable potassium), than they did of applied potassium when the potassium was mixed throughout the soil. When the potassium was applied in a band below the seeds prior to seeding, the percent of applied potassium used by the plants increased markedly.

In general, the plants grown on the finer textured soils made greater use of applied potassium from a band than did the plants on the coarser textured soils. In this respect plants grown on soil numbers 8, 9 and 10 in the calcareous group used more of the applied potassium than those plants grown on soil numbers 1, 2 and 3 of the non-calcareous group. Similarly plants grown on soil numbers 4, 5, 6 and 7 of the non-calcareous group used more of the applied potassium than did the plants grown on soil numbers 11, 12, 13 and 14 of the calcareous group. Therefore one could assume that the finer textured calcareous soils are capable of "fixing" more potassium than the finer textured non-calcareous soils.

The relatively small amount of applied potassium used by the plants grown on the coarser textured non-calcareous soils, resulted from the fact that adding water to the pots prior to germination of the seeds, resulted in a diffusion of the potassium placed in a band into the soils, thus the plants, by the time they were able to utilize soil nutrients, were feeding from a diffused source of potassium, in effect similar to the source in treatment two. A similar explanation could be applied to the coarser textured calcareous soils. Therefore the essential differences between these two groups of soils with respect to availability of potassium to plants is apparently related in some degree to their texture. Thus coarse textured soils in both groups could be expected to behave essentially alike, while one could expect to observe differences in the finer textured soils of both groups.

Figures 4, A, B and C, were constructed to evaluate which of the three methods used to extract soil potassium from both groups of soils gave the best relationship when extractable soil potassium was compared with the total amount of potassium the plants removed from the soils.

The water and NaCl extraction methods, Figures 4, A and B, were comparable in relating total plant potassium with extractable soil potassium. However in the case of the water extractable potassium the plants removed a larger amount of potassium from the soils (Table 7) than was extracted by this solution. Thus it is assumed that the plants fed from sources other than water soluble potassium, namely exchangeable potassium sources.

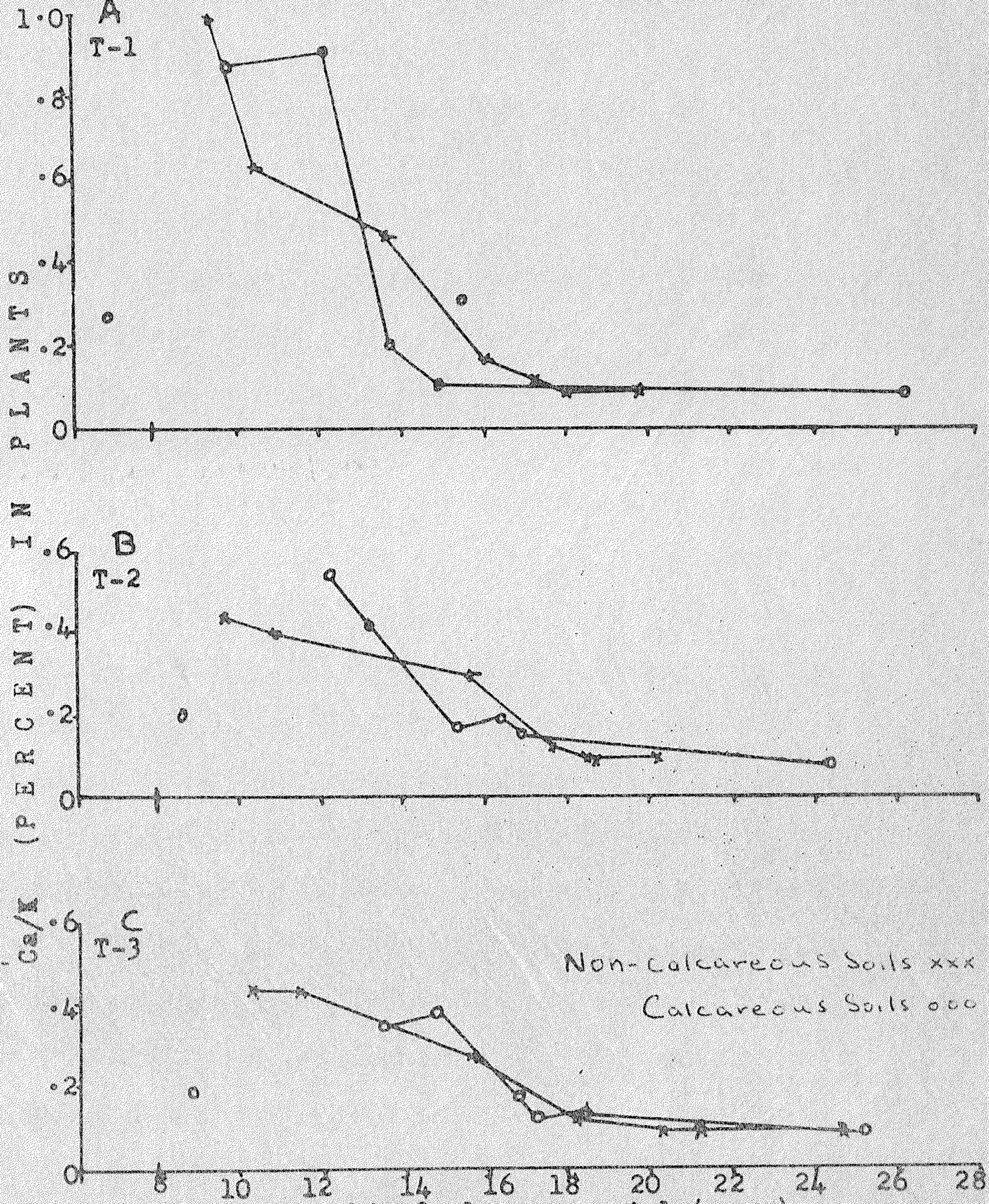


Figures IV, A, B and C - Relationship between total K in plants and H_2O, NaCl and NH_4OAc extractable K in soils respectively.

Because of this fact, one would consider the NaCl extraction method, which extracted both soluble and exchangeable sources of potassium, the better of the two extraction methods. The NaCl solution could therefore be used effectively in determining plant-available potassium from soils, within any of the two soil groups considered, without reference to whether they are calcareous or non-calcareous.

Figure 4 C, constructed for the NH_4OAc extraction method, shows two distinct lines representing both groups of soils. Although at low levels of soil potassium (coarser textured soils) both lines converge, in the intermediate range, the area in which most soils in Manitoba would fall, they are separated. Thus this method of extracting soil potassium, from calcareous and non-calcareous soils, as a measure of soil potassium availability to plants, is effective only on the coarser textured soils. On these soils both the NaCl and NH_4OAc solutions extracted identical amounts of potassium (Table 3), thus both methods could be used interchangeably. On the finer textured soils the NH_4OAc extraction method for soil potassium must be used cautiously. On these soils it is necessary to first determine whether the soil is calcareous or non-calcareous (the 2% $CaCO_3$ equivalent level is used to separate the two groups of soils) before the results obtained could be correctly interpreted as to the availability of the extracted potassium to plants. There exists a good relationship between NH_4OAc extractable potassium and total potassium in the plants for soils within a particular group. However when the soil from both groups was compared, as is the case for the H_2O and NaCl extractable potassium, the relationship was not as good. It is thus presumed that both the H_2O and NaCl method of extracting soil potassium is better than the NH_4OAc method.

Based on several of the literature reviewed (7, 24) a series of cationic ratios was calculated for the plant materials, in an effort to relate these to the effect of different soil types on the uptake of the various cations. None of the calculated ratios gave any sensible relationship when they were compared to soil type. However it was found that the ratio Ca/K for the plant material was related to the yield of plant material (Figure 5). From the figure it is observed that as the yield increases for both treatments 1, 2 and 3 the Ca/K ratio decreases. At a value of approximately 0.10, for the Ca/K ratio, there is no further decrease in the ratio with increase in yield for plants on both groups of soils. Thus this value of 0.10 for the ratio Ca/K is perhaps a characteristic of corn (Morden 88), and is required for optimum yield. Thus the plants would take up potassium or calcium in excess of the other until this ratio is satisfied. At this point any increase in the uptake of one of these elements is reflected in a similar uptake of the other. Therefore limiting one of these elements to the plant would result in a decrease in yield of plant material.



Yield of plant material (gms.)

Figures V, A, B and C - Relationship between Ca/K (percent) in plants and yield of plant material for treatments 1, 2 and 3 respectively.

GREENHOUSE EXPERIMENTS

Experiment 2

Methods and Materials

An observation of the data collected from greenhouse experiment 1 revealed that potassium was perhaps limiting growth on some of the lower yielding soils. It was also observed that the yield of plant material from soil number 10 was exceptionally low. Thus, with the idea of investigating these facts and also to further the observations with respect to the differences and similarities between calcareous and non-calcareous soils observed in greenhouse experiment 1, an experiment was initiated in the greenhouse using corn (Morden 88) as the test crop on eight soils.

The eight soils used in the experiment were taken from the two groups of soils previously discussed. The soils used were soil numbers 1, 2, 6 and 7 of the non-calcareous group, and soil numbers 10, 11, 12 and 14 of the calcareous group. The soils were prepared in the same manner as that described for experiment 1, and 1800 gram portions of air dried soil were weighed into fifty-one one-half gallon glazed porcelain pots. The experiment consisted of two treatments replicated three times; in the case of soil number 10 there was a third treatment. The treatments in the experiment were: Treatment 1, a check treatment (no potassium fertilizer added); Treatment 2, a potassium fertilized treatment in which 250 ppm of potassium as KCl was banded one-half inch below the seed depth prior to seeding. The special treatment which was applied to soil number 10, and which would be referred to as T_{10}, consisted of 250 ppm of potassium as KCl mixed throughout the soil, plus 250 ppm of potassium as KCl banded one-half inch below the seed depth.

At the time of seeding, December 11, 1965, 40 ppm of phosphorous as $NH_4H_2PO_4$ was mixed throughout the soil in each pot. Four corn seeds were placed in each pot at a depth of one-half inch below the surface of the soil. The pots were placed in the greenhouse and pre-emergence care was administered to them as was described in greenhouse experiment 1.

The post-emergence care of the plants was similar to that described for greenhouse experiment 1, except for the following deviations--(a) Four applications of nitrogen as NH_4NO_3 were made ten days apart, beginning on the day the plants first emerged which was December 14. (b) Three applications of copper as $CuSO_4.5H_2O$, each consisting of 5 ppm copper, were made to each pot. The first application was made two days after the plants emerged, and the other two applications were spaced at two week intervals.

No signs of chlorosis were observed in these plants throughout the period of growth. In general, the plants appeared to be much healthier than those grown in experiment 1. Although the corn grown in experiment 2 was not as tall as those grown in experiment 1, their stems were much larger in diameter and the leaves much wider.

The plants were harvested on January 31, 1966, 51 days after seeding. The harvesting procedure and sample preparation for chemical analyses were similar to that described in experiment 1.

Results and Discussion

The average yield of plant material in grams of oven dry weight, and the percent yield of the fertilized treatments, are given in Table 9.

Yield of Plant Material

As was recorded in greenhouse experiment 1, there were significant differences between soils with respect to yield of plant material; however the largest differences were observed when the potassium fertilized treatments were compared with the check treatments for any soil within a group. In general, for equivalent levels of soil potassium (Table 3) the non-calcareous soils out-yielded the calcareous soils (check treatments).

Soil number 10 which was of special interest in this experiment gave a good response to the high rate of potassium banded in the soil. This response was further observed in the special treatment T_{10}.

The percent yield data were determined as for greenhouse experiment 1. All the soils used in the experiment gave a positive percent yield. However the percent yield for those plants grown on the calcareous soils were in general better than the percent yield for the plants grown on the non-calcareous soils. Thus one might conclude that the response to fertilizer potassium was greatest on these soils. In particular, soil number 10 gave a percent yield of 57.53 when 250 ppm of potassium as KCl was banded. This further decreased to 53.65%

TABLE 9.

Experiment 2.

Average yield of plant material (oven dried) in grams and percent yield of fertilized treatments

Soil Code	T-1 Check	T-2 K-Banded	T_{10} K (Mixed & (Banded	% Yield T-2	% Yield T_{10}
	Non-Calcareous Soils				
1	12.50 b_1	17.35 b_2		72.05	
2	12.90 b_1	19.40 ab_2		66.49	
6	18.60 a_1	20.00 a_2		93.00	
7	18.50 a_1	21.15 a_2		87.47	
Treat. Averages	15.63*$_1$	19.50*$_2$			
	Calcareous Soils				
10	9.55 d_1	16.60 d_2	17.80$_3$	57.53	53.65
11	19.80 a_1	20.50 a_1		96.59	
12	15.10 b_1	19.05 b_2		79.27	
14	13.52 c_1	17.85 c_2		75.74	
Treat. Averages	14.49**$_1$	18.50*$_2$			

Note: Yield accompanied by the same letter a, b, c or d for any one Treatment within a group are not significant. $P = .05$ (Duncan's Test).

Yield accompanied by the same number 1, 2 and 3 for any one soil within a group are not significant. $P = .05$ (Duncan's Test).

The same number of * denotes no significant differences ($P = .05$) when treatment averages are compared between groups. (Duncan's Test).

when 250 ppm of potassium was mixed throughout the soil before banding a further 250 ppm of potassium as KCl. In general, for all soils used in experiment 2 the percent yield was better than that obtained for the similar soils in experiment 1. Thus banding 250 ppm of potassium to these soils was better than either banding or mixing throughout the soils 100 ppm of potassium.

A discussion of the check treatment in this experiment would involve a repetition of all that has been said for the similar treatment in greenhouse experiment 1. Therefore in the following discussion, Treatment 2 would be discussed in detail, and Treatment 1 would be used only for comparison.

Analysis of Plant Material

Table 10 gives the data for the analyses of the plant material.

The percent potassium content of the plants increased in all cases with addition of 250 ppm of potassium. The increase ranged from approximately two-fold in those plants grown on soils with a relatively high potassium content, to approximately four-fold in those plants grown on soils with a relatively low potassium content. Another factor of interest is that whereas in experiment 1 adding 100 ppm of potassium to the soil in a band did not appreciably change the percent calcium and magnesium content of the plants, in experiment 2 adding 250 ppm of potassium to the soils resulted in a general increase in the percent calcium and magnesium content of the plants. The increase in percent calcium content was especially

TABLE 10

Experiment 2.

Analysis of Plant Material

Soil Code	T-1 Check				T-2 K-Banded				T_{10} K (Mixed & Banded)			
	% K	% Na	% Ca	% Mg	% K	% Na	% Ca	% Mg	% K	% Na	% Ca	% Mg
Non-calcareous Soils												
1	0.71	0.53	0.46	0.65	3.00	0.42	0.40	0.60				
2	0.85	0.40	0.40	0.63	3.93	0.38	0.46	0.68				
6	1.80	0.48	0.18	0.51	3.52	0.45	0.32	0.54				
7	2.10	0.42	0.20	0.42	3.30	0.40	0.34	0.55				
Calcareous Soils												
10	0.85	0.67	0.18	0.90	3.00	0.58	0.46	0.80	3.35	0.52	0.42	0.82
11	1.50	0.62	0.13	0.50	3.10	0.49	0.40	0.80				
12	1.50	0.58	0.12	0.50	3.13	0.50	0.44	0.83				
14	0.90	0.60	0.15	0.73	3.30	0.55	0.40	0.79				

large on the calcareous soils. On the non-calcareous soils there was actually a decrease in the percent calcium content of the plants grown on soil number 1. The increase in percent magnesium was not as great as the observed increase in percent calcium, and in the case of soil numbers 1 and 10 there was a slight decrease.

The increase in percent calcium and magnesium in the plant material was also observed in the case of the special treatment T_{10}.

In general, the percent calcium and magnesium content of the plants grown on the calcareous soils was higher than those of the plants grown on the non-calcareous soils (Treatment 2). The plants grown on soil numbers 1 and 2 had similar percent calcium content to those grown on the calcareous soils.

The percent sodium content of the plants was equivalent to the amount noted in Table 6 for experiment 1.

The relatively high cation content of these plants is of particular interest when one considers the small amount (percent) noted in experiment 1. To explain this the total amount of cations taken up by the plants was calculated and is listed in Table 11.

A comparison of Table 7 and Table 11 shows that there were significant increases in both the total potassium and calcium content of the plants in experiment 2 over experiment 1. The increase in total calcium content was most obvious on the calcareous soils where it was approximately four-fold. In the case of total magnesium content of the plants, although there

TABLE 11.

Experiment 2.

Total Cations in Plant Material (mgm).

Soil Code	Total Potassium T-1	Total Potassium T-2	Total Sodium T-1	Total Sodium T-2	Total Calcium T-1	Total Calcium T-2	Total Magnesium T-1	Total Magnesium T-2
Non-calcareous Soils								
1	89	521	66	73	58	69	81	104
2	110	762	52	74	52	89	81	132
6	335	704	89	90	33	64	95	108
7	389	698	78	85	37	72	78	116
Calcareous Soils								
10	81	498	64	96	17	76	86	133
11	297	636	123	100	26	82	99	164
12	227	596	88	95	18	84	76	158
14	121	589	81	98	20	71	99	141
Special T_{10}		596		93		75		146

was some increase recorded in experiment 2 over experiment 1, this increase was considerably less than the increase in calcium. Thus only in soil numbers 1, 2, 10 and 14 was the increase in total magnesium of any consequence.

To explain this increase in total cation content of the plants the following suggestion is proposed: The addition of the large quantity of potassium to the soil constituted a source of readily available potassium to the plants which they readily utilized. Also when this exceptionally large amount of potassium was banded in the soil, it established a zone (banded area) of very high potassium concentration in the soil. This high potassium concentration in the soil would thus tend to shift the soil potassium equilibrium, with the effect that a large amount of potassium ions would move on to the exchange sites of the soil colloid thus releasing a considerable amount of calcium and magnesium ions. These ions thus put into the soil solution would be readily available for plant utilization. This phenomenon would be especially apparent on the calcareous soils in which the main cations on the exchange sites would be calcium and magnesium.

The percent of soil potassium and fertilizer potassium used by the plants was calculated, as in greenhouse experiment 1, and the data given in Table 12.

As was observed in greenhouse experiment 1 the plants in both groups of soils made greater use of NaCl extractable potassium in comparison to NH_4OAc extractable potassium. Also the plants grown on the non-calcareous soils used a larger

TABLE 12.

Percent of Soil Potassium and Fertilizer Potassium used by Plants.

	% soil K used by Plants *		% fertilizer K used by Plants *	
Soil Code	NH_4OAc Extractable	Na Cl Extractable	T-2	T_{10}
	Non-Calcareous Soils			
1	53.89	49.83	52.02	
2	39.86	75.32	39.86	
6	14.93	42.87	19.13	
7	16.48	35.92	26.57	
	Calcareous Soils			
10	25.72	48.67	25.72	25.55
11	10.66	53.97	18.90	
12	23.74	33.49	41.67	
14	13.90	55.62	22.39	

* For calculations see Table 8.

percent of the NH_4OAc extractable potassium than those grown on the calcareous soils. Thus as previously stated, this is further evidence that the NH_4OAc solution might be extracting potassium from some soils, in particular the finer textured soils, which are not available to plants.

In view of the fact that a relatively large quantity of the applied potassium was used by the plants it is conceivable that some luxury consumption of potassium might have taken place.

As was observed in experiment 1, the ratio Ca/K in the plant material (Table 13) is approximately 0.10 to 0.15 for optimum yield of plant material. This particular ratio appears to be a characteristic of corn plants (Morden 88).

Summary and Conclusions of Greenhouse Experiments

Two greenhouse experiments were conducted to study the availability of potassium from calcareous and non-calcareous Manitoba soils to plants. Corn (Morden 88) was the test crop. The better of two methods of applying fertilizer potassium to this crop (banding or mixing the potassium throughout the soil), and various interactions of potassium with the other common cations in the plants were also studied, to determine if these factors would have any effect on the uptake of potassium by the plants. A comparative study of H_2O, NaCl and NH_4OAc extractable soil potassium was made to determine the best of the three methods which might be employed in extracting soil potassium from calcareous and non-calcareous soils, when the information is to be related to availability of potassium from these soils

TABLE 13.

Experiment 2.

Ca/K in Plant Material

Soil Code	Ca/K T-2	Ca/K T_{10}
	Non-Calcareous Soils	
1	0.13	
2	0.12	
6	0.09	
7	0.10	
	Calcareous Soils	
10	0.15	0.13
11	0.13	
13	0.14	
14	0.12	

to plants.

The source of potassium added to the soils in both greenhouse experiments was KCl.

A consideration of the data collected in the two greenhouse experiments showed that there were certain differences and similarities associated with both groups of soils. In the majority of cases the differences were observed for the finer textured soils in both soil groups, while the similarities were observed for the coarser textured soils.

It was found that for equivalent levels of H_2O, NaCl or NH_4OAc extractable soil potassium the non-calcareous soils outyielded the calcareous soils. It was also observed that the plants grown on the finer textured non-calcareous soils had a larger amount of potassium than those plants grown on the finer textured calcareous soils. Thus it would appear that soil potassium was more available to the plants grown on the non-calcareous soils as compared to those grown on the calcareous soils. This fact was further emphasized when the percent soil potassium (NH_4OAc and NaCl extractable K) used by the plants was calculated. The plants grown on the coarser textured soils in both soil groups used similar amounts of soil potassium. However the plants grown on the finer textured soils of the non-calcareous group used a larger percent of the soil potassium than did those plants grown on the finer textured soils of the calcareous group.

It was apparent from the experiment that corn (Morden 88) requires a larger amount of magnesium relative to calcium, also that for the ratio Ca/K in the plant, at a value of 0.10 to 0.15 the best yields of plant material were recorded regardless of the soil type.

Corn fed best from a concentrated source of potassium, thus banding the potassium into the soils was better than mixing it throughout the soils prior to seeding. In this respect the plants made greater use of the banded potassium than the potassium mixed throughout the soils. It was found that as the percent potassium increased in the plants for any one soil within a group, the yield of plant material increased. The yield realized from banding 250 ppm of potassium into the soils prior to seeding was better than that realised from banding 100 ppm of potassium.

The magnesium and calcium content of the plants grown on any one soil remained relatively constant with addition of 100 ppm of potassium in a band or mixed throughout the soil. However when 250 ppm of potassium was banded into the soil, there was an increase in the percent calcium and magnesium in the plants.

A comparison of the three methods of extracting potassium from calcareous and non-calcareous soils shows that NH_4OAc solution extracted a larger amount of potassium than the NaCl solution, which in turn extracted more potassium than the H_2O solution. However when the amount of potassium extracted by the three solutions were examined with respect to the availability of this potassium to plants, the NaCl extractable potassium gave the best relationship in all cases.

The relationship obtained for the H_2O extractable potassium was generally good for both groups of soils; however this method is critized, due to the fact that the plants use a larger amount of potassium than the H_2O solution extracted. The NH_4OAc solution was found to be apparently extracting large amounts of potassium from some soils which were perhaps not readily available to the plants. This was particularly obvious in the case of the calcareous soils. In these soils it is assumed that not only were the NH_4^+ ions substituting for K^+ ions in the clay lattice structure, but mineralogical decomposition of certain soil minerals was taking place in the finer textured soils, thus resulting in the large amount of potassium extracted.

LABORATORY EXPERIMENTS

Following the greenhouse experiments, a series of laboratory experiments were conducted to further investigate the differences and similarities observed in the greenhouse work, with respect to the availability of potassium from calcareous and non-calcareous soils. The experiments were also intended to investigate the differences ~~in~~ between H_2O, NaCl and NH_4OAc solutions in extracting soil potassium from calcareous and non-calcareous soils, and to determine whether there is an equilibrium condition operating in the soil potassium system as was distinguished by De Turk *et al*. (10) and Fox and Kacar (11).

Experiment 1.

Methods and Materials

The experiment was conducted to evaluate the amount of potassium remaining in the soils after cropping with corn, and to determine whether there was any change in the potassium remaining in the soils upon incubation.

The experiment in effect is a continuation of greenhouse experiment 1, since the soils used were taken from the check treatment of the latter experiment after the corn was harvested.

The soils were emptied from the pots as soon as the plants were harvested. The plant roots were removed from each soil which was then thoroughly mixed. A representative sample was taken from each of the 14 soils and divided into two portions. One portion was air dried and analyzed for NH_4OAc and H_2O extractable potassium. The other portion was placed in a 400 ml. plastic dish and distilled water was added to bring the soil up to field capacity. The dish was then placed in the incubator where it remained for 30 days at 25°C. At the end of this time the samples were removed and analyzed for NH_4OAc and H_2O extractable potassium.

Results and Discussion

Table 14 gives the data for the NH_4OAc and H_2O extractable potassium determined on the soils before cropping, after cropping, and after incubation of the cropped soils.

It was found that on both groups of soils the plants reduced the NH_4OAc and H_2O extractable potassium levels of the soil significantly. In all cases the plants removed greater than 50% of the total soil potassium. There was no difference between the two groups of soils with respect to the amount of soil potassium removed by the plants.

When the cropped soils were incubated for 30 days at 25°C, both the NH_4OAc and H_2O extractable potassium levels of the soils returned in most cases to their original levels, and in some soils greater than the original values. Only in those soils in which the original levels of soil potassium was relatively high did it not return to the original level.

It appears that a build-up of H_2O extractable potassium occurred in the soils upon incubation. It has been suggested that the source of this potassium might be from the exchange sites or from fixed sources of soil potassium (10, 11, 29).

In considering the NH_4OAc extractable potassium, it is observed that on incubation of the cropped non-calcareous

TABLE 14.

Relationship between the original H_2O and NH_4OAc extractable K in the soils collected, the amount of K remaining in these soils after cropping to corn (Greenhouse Expt. 1, T-1), and the amount present in these cropped soils after incubation for 30 days at 25°C.

Soil Code	Original K in Soils NH_4OAc Extractable K ppm	H_2O Extractable K ppm	K in Soils after Cropping NH_4OAc Extractable K ppm	H_2O Extractable K ppm	K in Soils after Incubation NH_4OAc Extractable K ppm	H_2O Extractable K ppm
Non-calcareous Soils						
1	48.5	1.48	25	0.40	50	1.60
2	80.0	1.71	40	0.48	80	1.64
3	98.0	2.39	44	0.50	98	2.50
4	163.0	4.21	44	0.52	164	5.70
5.	363.5	5.34	60	0.60	364	5.82
6.	641.0	10.92	160	2.00	540	10.60
7.	686.0	11.94	175	2.40	575	12.30
Calcareous Soils						
8	60.0	1.48	30	0.35	60	2.10
9	57.5	1.46	38	0.30	66	1.50
10	90.0	1.82	43	0.40	100	2.80
11	816.0	14.00	210	3.06	728	10.02
12	281.0	4.55	112	1.20	254	4.60
13	187.0	2.60	50	1.00	150	4.40
14	250.0	2.80	75	0.80	278	3.90

soils, only soil numbers 6 and 7, which initially had a very high potassium content (600 ppm), did not return to their original potassium levels. On the calcareous group of soils, soil numbers 9, 10 and 14 showed a considerable increase over their original potassium levels, while soil numbers 11 and 13 had lower extractable potassium contents than were originally determined.

A consideration of the data and the foregoing discussion would lead one to assume that there is an equilibrium condition operating in the soil potassium system which could be illustrated thus:

$$\text{Soil K (fixed)} \overset{A}{\rightleftharpoons} \text{K soil} \left\{\begin{matrix}\text{exchangeable}\\ +\\ \text{available}\end{matrix}\right\} \overset{B}{\rightleftharpoons} \text{plant K}$$

This is as proposed by Fox and Kacar (11).

The shifts in equilibrium at A and B are strongest toward the right. However at A, the shift could and does move to the right regardless of the fact that there is no shift at B. This is brought about by two processes--(a) The presence of excess anions in the soil solution. This is a natural chemical equilibrium process. (b) ~~Due to~~ the natural breakdown of potassium bearing minerals in the soils (1).

There are no observable differences between calcareous and non-calcareous soils with respect to the operation of the equilibrium noted. However the shift in the equilibrium process appears to be faster for the coarser textured soils in both groups of soils.

Experiment 2.

Methods and Materials

In the previous laboratory experiment it was observed that in both calcareous and non-calcareous soils the potassium system is governed by an equilibrium condition. It was also observed that apparently the reactions within the equilibrium operated similarly in both groups of soils, with respect to the removal of potassium by plants and by various extracting solutions.

Laboratory experiment 2 was thus designed to investigate (1) the amount of potassium that could be removed, by a process of continuous leaching with 1N NH_4OAc solution, from calcareous and non-calcareous soils and (2) to study the effect of adding potassium as KCl to the leached soils.

The soils used in the experiment were those used in the greenhouse experiments. A 50 gm. portion of air dried soil was taken from each soil used and placed in a 9 cm. diameter buchner funnel which was attached to an evacuating apparatus. Each soil sample was leached with a total of 500 ml. of 1N NH_4OAc solution (pH=7).

The leaching process took three days. The daily procedure was as follows: 100 ml. of NH_4OAc solution was passed through the soils and the amount of potassium in the leachate was measured; this was followed by a further leaching with 50 ml. of solution and once again measuring the amount of potassium in the leachate. On the second day a third leaching using 50 ml. of solution was carried out. At the end of each day and at the end of the three day period of leaching, the total potassium in the leachate was calculated. Sodium, calcium and magnesium were determined on the last leachate of the third day.

At the end of the leaching period, the soils were removed from the buchner funnels and air dried. NH_4OAc and NaCl extractable potassium were determined on the air dried soils.

In the second part of the experiment only soil numbers 1, 4, 5 and 7 of the non-calcareous group and 8, 11, 12 and 13 of the calcareous group were used. A sample of each of these air dried soils (previously leached with NH_4OAc) were placed in plastic dishes, and to each potassium, as KCl, was added in an amount equivalent to the nearest 100 ppm of the original NH_4OAc extractable potassium determined on these soils before leaching. The method of adding the potassium to the soils was as follows: A small hole was made in the centre of the soil in each dish and the potassium (KCl salt) was placed in this hole and then covered with soil. The soils were then brought up to field capacity with distilled water and incubated for one week at 25°C. At the end of this time the soil in each dish was thoroughly mixed and once again brought up to field capacity with distilled water and incubated at 25°C. One week after the last step the soils were removed from the dishes and air dried. The air dried soils were crushed to pass a 2 mm. sieve and samples taken and analyzed for NH_4OAc and NaCl extractable potassium.

Results and Discussion

Table 15 gives the data for the amount of potassium

TABLE 15

Potassium (ppm) Removed from Soils by Successive Leaching with 1N NH_4OAc pH7.

Vol. Used Soil Code	1st Day		Total 1st Day	2nd Day			Total 2nd Day	3rd Day		Total 3rd Day	Total for 3 days	Original K in Soils	K Removed in excess of original
	100 mls	50 mls		100 mls	50 mls	50 mls		100 mls	50 mls				
	Non-Calcareous Soils												
1.	48.0	15.0	63.0	19.0	5.0	0	24.0	1.0	0	1.0	88.0	48.5	39.5
2.	76.0	12.0	88.0	20.0	2.0	0	22.0	3.0	0	3.0	113.0	80.0	53.0
3.	92.0	23.0	115.0	35.0	7.0	1.0	44.0	5.0	0	5.0	164.0	98.0	66.0
4.	150.0	35.0	185.0	80. 0	10.0	2.0	92.0	12.0	3.0	15.0	292.0	163.0	129.0
5.	400.0	135.0	535.0	170. 0	65.0	24.0	259.0	48.0	2.0	50.0	844.0	363.0	481.0
6.	590.0	185.0	775.0	205.0	80.0	35.0	320.0	41.0	12.0	53.0	1148.0	641.0	507.0
7.	628.0	210.0	838.0	238.0	76.0	24.0	338.0	67.0	21.0	88.0	1264.0	686.0	578.0
	Calcareous Soils												
8.	60.0	9.0	69.0	17.0	4.0	0.0	21.0	4.0	0	4.0	94.0	60.0	34.0
9.	53.0	16.0	79.0	29.0	10.0	3.0	42.0	6.0	2.0	8.0	119.0	57.5	61.5
10.	85.0	38.0	123.0	56.0	20.0	3.0	79.0	3.0	1.0	4.0	206.0	90.0	116.0
11.	670.0	305.0	975.0	390.0	85.0	32.0	507.0	80.0	30.0	110.0	1592.0	816.0	776.0
12.	240.0	85.0	325.0	160.0	46.0	9.0	215.0	24.0	4.0	28.0	568.0	281.0	287.0
13.	155.0	33.0	188.0	67.0	22.0	4.0	93.0	12.0	3.0	15.0	296.0	187.0	109.0
14.	235.0	58.0	293.0	92.0	41.0	15.0	148.0	34.0	5.0	39.0	480.0	250.0	230.0

removed from the soils by the leaching process; also the NH_4OAc extractable potassium determined on the soils prior to leaching.

It was found that successive leaching with NH_4OAc solution removed a larger amount of potassium from soils in both soil groups than was originally determined on the NH_4OAc extract. The "excess" potassium removed by the leaching process could contribute to the equilibrium reaction described in the soil potassium system in laboratory experiment 1. The probable sources of this "reserved" potassium are--(1) non-exchangeable or "fixed" sources as described by Fox and Kacar (11), (2) originated as a result of mineralogical decomposition of the soil mineral fraction by the NH_4OAc solution (7). In general, the finer textured soils had a larger "reserve" of potassium than the coarser textured soils of both soil groups.

Table 16 gives the data for the NH_4OAc and NaCl extractable potassium determined on the soils which had been previously leached with 1N NH_4OAc solution, then air dried.

On air drying the soils their potassium content increased appreciably over that determined on the last leachate (Table 15).

A comparison of the NH_4OAc and NaCl extraction procedure shows that both solutions extracted similar amounts of soil potassium. Thus on leaching the soils with NH_4OAc the potassium which had apparently returned on the colloidal exchange in the reaction:

TABLE 16

NH_4OAc and Na Cl extractable potassium determined on soils which had been previously leached with 1 N NH_4OAc pH 7, then air dried.

Soil Code	NH_4OAc Extractable K ppm	Na Cl Extractable K ppm
	Non-Calcareous Soils	
1	10.0	10.0
2	10.0	10.0
3	12.5	10.5
4	15.0	15.5
5	20.0	22.0
6	25.5	25.5
7	32.0	30.5
	Calcareous Soils	
8	10.0	10.0
9	10.0	10.5
10	10.5	10.5
11	50.0	50.5
12	20.0	20.0
13	15.5	15.5
14	25.5	25.0

$$\text{K (fixed)} \rightleftharpoons \text{K (exchangeable)}$$

was capable of being extracted by either NaCl or NH_4OAc solutions. It was also noted that the finer textured soils in both soil groups had larger amounts of potassium involved in the shift described above than did the coarser textured soils.

In an attempt to measure the capacity of soils to "fix" potassium from a KCl source, potassium was added to the soils which had been leached with NH_4OAc and air dried. Table 17 gives the data for the NH_4OAc and NaCl extractable potassium determined on the soils after incubation. The soils used in the experiment were soil numbers 1, 4, 5 and 7 of the non-calcareous group, and soil numbers 8, 11, 12 and 13 of the calcareous group.

The amount of potassium determined on a soil upon air drying plus the amount of potassium added as KCl would be the amount of potassium one would theoretically expect to extract from this soil after incubation. This was not observed in the experiment.

The amount of NH_4OAc extractable potassium determined on soil numbers 7 and 11 was less than the amounts theoretically expected. Thus it is assumed that these soils were capable of "fixing" potassium. On examination of the mechanical analysis data (Table 2) of the soils it is shown that these two soils had a relatively high clay content. Therefore since a high clay content is usually associated with a high exchange capacity and the ability to "fix" cations, this result would

TABLE 17

Analysis of soils which had been previously leached with 1 N NH_4OAc pH7, then air dried, and to which K as K Cl was added to the nearest 100 ppm of their original NH_4OAc extractable K, then incubated for two weeks at 25°C.

	K(ppm) in air dried leached soils		(C) K (ppm) added to soils	K(ppm) after two week incubation at 25°C		K(ppm) Airdried leached soil + K (ppm) added − K(ppm) after incubation	
Soil Code	(A) NH_4OAc Ext'able	(B) Na Cl Ext'able		(D) NH_4OAc Ext'able	(E) Na Cl Ext'able	A + C − D NH_4oAc Ext'able	B + C − E NaCl Ext'abl
	Non-Calcareous Soils						
1	10.0	10.0	100	150	125	− 40.0	− 15.0
4	15.0	15.5	200	225	210	− 10.0	+ 5.5
5	20.0	22.0	400	490	375	− 70.0	+ 47.0
7	32.0	30.5	700	615	590	+ 117.0	+ 140.5
	Calcareous Soils						
8	10.0	10.0	100	130	100	− 20.0	− 10.0
11	50.0	50.5	900	875	645	+ 75.0	+ 305.5
12	20.0	20.0	300	335	255	− 15.0	+ 65.0
13	15.5	15.0	200	245	200	− 29.5	+ 10.0

be expected (25). It was observed that the amount of potassium (NH_4OAc extractable) determined on the other six soils was more than that theoretically expected. Thus it is assumed that these soils liberated potassium upon incubation.

The data for the NaCl extractable potassium show that only in soil numbers 1 and 8 was the amount of potassium extracted after incubation greater than the theoretical amounts expected. Thus upon incubation these soils released potassium. The other six soils apparently were capable of "fixing" potassium in a form which was not capable of being extracted by NaCl but was capable to some extent of being extracted by NH_4OAc solution.

From the table it is observed that in general the calcareous soils "fixed" a greater amount of the potassium added to the soils.

Experiment 3.

Methods and Materials

In laboratory experiment 2 it was observed that calcareous soils are apparently capable of "fixing" more added potassium than non-calcareous soils. Therefore this experiment was conducted to investigate the relative abilities of calcareous and non-calcareous soils to "fix" potassium when it was added in the form of KCl, and also to observe the effect of air drying on the soil potassium status.

Two hundred and fifty gram portions of each of the 14 air dried soils were placed in plastic dishes. A depression was made in the soil, in the centre of each dish, and 100 ppm of potassium as KCl was added into the depression. The depression was covered with soil and distilled water was added to bring each soil up to approximately field capacity. The soils were then incubated at 25°C for 7 days. At the end of this time the soil in each dish was thoroughly mixed, to completely disperse the KCl throughout it. Distilled water was added to bring the soils back to field capacity and they were once again incubated at 25°C. At the end of one week the soils were removed from the incubator and a sample taken from each dish and air dried. The air dried soil samples were crushed to pass a 2mm sieve, and then analyzed for NH_4OAc and NaCl extractable potassium.

RESULTS AND DISCUSSION

Table 18 gives the data for the NH_4OAc and NaCl extractable potassium in the soils before addition of KCl and after incubation of the soils.

Theoretically the amount of potassium one would expect to extract from the soils after incubation, would be the amount of potassium recorded in Table 3 (NH_4OAc and NaCl extractable potassium) plus the amount added as KCl (100 ppm of potassium). This, however, is not evident from Table 18.

The amount of NH_4OAc and NaCl extractable potassium determined on the soils within both groups was in all cases less than the theoretically expected amount, thus "fixation" of added potassium must have taken place. It was found that the amount of potassium "fixed" by any soil was dependent on texture. Thus the finer textured soils "fixed" more potassium than the coarser textured soils. It is assumed that the

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TABLE 18

Changes in the NH_4OAc and Na Cl extractable potassium of calcareous and non-calcareous soils to which 100 ppm of K as K Cl was added prior to incubation

	Ⓐ Original soil K (Table 3) + 100 ppm K as K Cl		Ⓑ K in soil after incubation at 25°C for 14 days		Ⓐ-Ⓑ Changes in added K upon incubation	
Soil Code	NH_4OAc Extractable Kppm	Na Cl Extractable Kppm	NH_4OAc Extractable Kppm	Na Cl Extractable Kppm	NH_4OAc Extractable Kppm	Na Cl Extractable Kppm
	Non-Calcareous Soils					
1	148.5	150.0	145.4	145.0	3.1	5.0
2	180.0	180.0	155.8	150.2	24.2	29.8
3	198.0	190.5	180.2	170.0	17.8	20.5
4	263.0	260.2	205.2	205.5	55.0	54.7
5	463.5	380.5	393.1	305.0	70.4	75.5
6	741.0	600.0	640.0	499.1	101.0	100.9
7	786.0	525.5	685.3	426.8	100.7	98.7
	Calcareous Soils					
8	160.0	160.0	140.5	128.3	19.5	22.7
9	157.5	155.5	125.3	120.0	32.2	35.0
10	190.0	190.0	128.6	110.4	61.4	79.4
11	916.0	560.5	815.1	460.8	100.9	99.7
12	381.0	260.0	292.7	160.5	88.3	99.5
13	287.0	220.2	220.0	140.1	65.0	79.9
14	350.0	255.5	280.2	180.0	69.8	75.5

relatively high clay content of these soils was responsible for the "fixation" of the added potassium (10, 18, 25, 29)

A larger amount of added potassium was extracted by the NH_4OAc solution than by the NaCl solution. The ability of NH_4OAc to extract more potassium than NaCl is due primarily to the NH_4^+ ion. This ion is approximately the size of the K^+ ion, and can enter into a 1:1 substitution for K^+ ion in the lattice structure of clays. The Na^+ ion, due to size differences, cannot make such a substitution and is thus capable of exchanging for only those K^+ ions which are on the colloidal complex. These assumptions are substantiated by the fact that on the coarser textured soils, which had a relatively low clay content, both the NH_4OAc and NaCl solutions were capable of extracting approximately equal amounts of potassium.

A comparison of the two groups of soils showed that the calcareous soils were capable of "fixing" a larger amount of the added potassium than the non-calcareous soils for equivalent textural characteristics (Table 2).

A study of the NH_4OAc and NaCl extractable calcium and magnesium of the soils, with respect to the amounts present in the soils before and after the addition of potassium, was made. Table 19 gives the data. The study was intended to obtain information with regard to the amount of potassium "fixed" by calcareous and non-calcareous soils. It was found that the amount of NH_4OAc and NaCl extractable calcium and magnesium in the soils increased upon incubation, thus adding potassium to the soil must have caused a release of calcium and magnesium

TABLE 19

Changes in the NH_4OAc and NaCl extractable calcium and magnesium of soils to which 100 ppm K as K Cl was added prior to incubation.

	NH_4OAc Extractable Ca and Mg		NaCl Extractable Ca and Mg		(Ca and Mg) – (Ca and Mg) (Table 3) (after incubation)			
Soil Code	Ca me/100 gm	Mg me/100 g	Ca me/100 g	Mg me/100g	NH_4OAc Ca me/100g	NH_4OAc Mg me/100g	Na Cl Ca me/100g	Na Cl Mg me/100
	Non-Calcareous Soils							
1	8.6	1.4	4.0	2.0	-0.4	0.2	-0.4	-0.2
2	25.3	5.3	12.7	5.0	-3.1	-0.3	-1.9	-0.4
3	12.4	4.2	10.4	4.6	-2.6	-0.8	-2.0	-1.2
4	6.7	3.5	6.6	3.0	-2.1	-1.5	-1.1	-1.0
5	26.6	6.9	19.2	6.5	-8.8	-0.9	-2.0	-0.7
6	25.9	6.7	16.6	6.5	-8.9	-1.3	-1.8	-1.5
7	40.2	15.0	29.7	13.4	-7.0	-1.6	-3.3	-4.4
	Calcareous Soils							
8	13.4	3.2	8.1	2.7	-0.5	-0.2	-0.9	-0.5
9	17.3	4.6	12.8	4.0	-2.5	-0.8	-3.0	-0.8
10	30.2	16.8	14.3	9.6	-4.4	-2.6	-3.5	-1.6
11	49.5	26.5	32.5	17.8	-11.2	-6.4	-6.1	-3.2
12	40.9	19.6	23.5	12.4	-8.3	-3.0	-6.5	-2.4
13	21.2	3.9	17.0	4.9	-6.2	-1.1	-5.0	-1.9
14	36.0	17.6	19.2	11.8	-6.0	-3.0	-2.7	-2.6

ions in the soil solution. These ions it is assumed would come off the colloid exchange sites.

The amount of divalent cations apparently released from the soil exchange sites by the addition of potassium, was greater for the calcareous soils than for the non-calcareous soils; this would in part account for the greater "fixation" of potassium by calcareous soils. In the previous literature review De Turk _et al_. (10) suggested that when potassium was added in the phosphate form to soils, the potassium became "fixed" to the soil colloid as an Al-O-P-K complex. Thus it is possible that in those soils which had a relatively large amount of phosphorous (Table 1) similar complexes could be formed resulting in a "fixation" of potassium.

Summary and Conclusions of Laboratory Experiments

A comparative study of the soil potassium status of several calcareous and non-calcareous soils was made in the laboratory. Three experiments were conducted. These were especially designed to detect differences or similarities in the soil potassium system of the two groups of soils, and also to determine the relative merits of NH_4OAc and NaCl solutions to extract potassium from these soils.

It was found that corn removed a considerable amount of H_2O and NH_4OAc extractable potassium from both the calcareous and non-calcareous soils. When samples of the cropped soils were incubated at field capacity and 25°C for thirty days, a general increase in both the H_2O and NH_4OAc extractable soil potassium was observed. This established the idea that an equilibrium condition, similar to that described by De Turk et al. (10) and Fox and Kacar (11) might be operating within the potassium system of these soils. This equilibrium condition appears to be operating in both the calcareous and non-calcareous soils with equal efficiency. However the "release" of "fixed" potassium was faster from the coarser textured soils, although a greater amount of "fixed" potassium was released by the finer textured soils.

A process of continuous leaching of calcareous and non-calcareous soils with a solution of 1N NH_4OAc, pH7, extracted a considerably larger amount of soil potassium from soils in both groups than was extracted by a process of shaking a 1:10 soil-solution mixture for one hour (solution used 1N NH_4OAc, pH7). It is assumed that a large amount of the potassium extracted by the leaching process was due to mineralogical decomposition as was suggested in the literature review by Beckett (7). There were no noticeable differences in the amount of potassium extracted by leaching from either groups of soils; however in general the finer textured soils in both soil groups released the larger amounts of potassium.

When the leached soils were air dried there was a noticeable build-up of NH_4OAc extractable potassium in these soils. It was also found that the NaCl and NH_4OAc solutions extracted similar amounts of potassium from the soils, whereas before leaching the amounts extracted by each solution were different (Table 3).

When potassium as KCl was added to soils in both groups, a larger amount of potassium apparently was "fixed" by the finer textured soils of each group. This is apparently due to the relatively higher clay content of these soils. For soils of equivalent textural characteristics the calcareous soils "fixed" a relatively larger amount of added potassium than did the non-calcareous soils.

Adding potassium as KCl to calcareous and non-calcareous soils resulted in a release of NH_4OAc and NaCl extractable calcium and magnesium in both groups of soils upon incubation. The largest release of the divalent cations was observed on the calcareous soils.

The NH_4OAc solution extracted a larger amount of soil and added potassium from both groups of soils than did the NaCl solution. Two possible reasons are suggested for the larger amounts of soil potassium extracted by the NH_4OAc solution:

(1) This solution causes some mineralogical decomposition in some soils (7).

(2) The NH_4^+ ion is similar in size to the K^+ ion, thus 1:1 substitution of NH_4^+ ions for K^+ ions occurs in the crystal lattice.

Final Summary and Conclusions

A comparative study of the potassium availability to plants was conducted on several calcareous and non-calcareous Manitoba soils. The study involved greenhouse and laboratory experiments. A consideration of the relative merits of NH_4OAc, NaCl and H_2O extractable potassium to predict availability of potassium to plants grown on these soils, and an examination of the soil potassium system in the two groups of soils were also investigated.

The soils collected were placed in two groups of seven based on their percent calcium carbonate equivalent.

It was found that the NH_4OAc solution extracted more cations from the soils collected than did the NaCl solution; this solution in turn extracted more cations than did the H_2O solution. A consideration of the data collected and previous literature reviewed (7) suggest that the larger amount of cations extracted by the NH_4OAc solution could be due to--(1) Destruction of soil minerals thus extracting cations which were not in readily available forms to plants. (2) Substitution of the NH_4^+ ion for K^+ ion in the clay lattice structure. Due to the large amount of potassium extracted by the NH_4OAc solution from the finer textured soils, and in particular the calcareous soils, relative to the amount extracted by the NaCl solution, it is assumed that the amount of mineralogical decomposition and/or NH_4^+ substitution for K^+ ions, was greater in these soils in comparison to the non-calcareous soils.

Based on the results obtained from the two greenhouse experiments, it was found that the NaCl extractable potassium gave the best relationship when soil potassium was related to yield or potassium uptake by plants. The H_2O extraction method was inadequate since it extracted much less potassium from the soils than was used by the plants. The NH_4OAc solution apparently extracted potassium from the soils which was perhaps not readily available to plants, thus the relationships involving NH_4OAc extractable potassium and yield of plant material and/or total potassium uptake by the plants were not as good as the relationships involving NaCl extractable potassium. It was also found that the plants used a larger percent of the NaCl extractable potassium than NH_4OAc extractable potassium.

There was some observed relationship between soil potassium extracted by either one of the three solutions, NaCl, NH_4OAc and H_2O, and texture; the finer textured soils in both groups having the larger amounts of potassium.

From a series of laboratory experiments involving leaching and incubation of soils from both the calcareous and non-calcareous groups, it was assumed that an equilibrium condition, similar to that described by Fox and Kacar (11), was governing the potassium status of these soils. The equilibrium is described as:

$$\mathrm{K}\ (\text{fixed}) \rightleftharpoons \mathrm{K}\left\{\begin{matrix}\text{exchangeable}\\ +\\ \text{available}\end{matrix}\right\} \rightleftharpoons \mathrm{K}\ (\text{plants})$$

When potassium as KCl was added to calcareous and non-calcareous soils, it was found that the amount of added potassium "fixed" by the finer textured soils in both groups of soils was greater than the amount "fixed" by the coarser textured soils. It was also found that the calcareous soils were capable of "fixing" more added potassium than the non-calcareous soils.

A consideration of the data collected from the two greenhouse experiments, with respect to the relative availability of potassium to corn grown on calcareous and non-calcareous soils, showed that there were certain differences and similarities associated with both groups of soils. The difference between the two groups of soils was observed when the finer textured soils were considered while the similarities were observed for the coarser textured soils.

Both NaCl and NH_4OAc solutions extracted similar amounts of soil potassium from the coarser textured soils in both groups, while on the finer textured soils the NH_4OAc solution extracted a larger amount of potassium.

For equivalent levels of NH_4OAc, NaCl and H_2O extractable potassium the non-calcareous soils out-yielded the calcareous soils. The plants grown on the non-calcareous soils also took up a larger amount of potassium than those plants grown on the calcareous soils, for equivalent levels of NH_4OAc or NaCl extractable soil potassium.

Plants grown on both groups of soils responded well to added potassium. The best response was observed when the potassium was banded below the seeds prior to seeding, as compared to mixing the potassium throughout the soils. The plants took up a greater amount of potassium from the banded source of potassium than from the diffused source (K-mixed throughout the soils).

The ratio Ca/K in the plant, at a value of 0.10 to 0.15 was required for optimum yield, regardless of the soil type.

In general the difference between calcareous and non-calcareous soils is a function of texture of the soils compared. Thus coarse textured soils in both groups are similar in most cases. Thus for equivalent levels of NaCl or NH_4OAc extractable potassium these soils appear to have similar levels of plant available potassium. They also "fix" only a relatively small amount of added potassium. Potassium must be banded into these soils in order to maximize yield; the amount of potassium to be added could be determined by either the NaCl or NH_4OAc extractable potassium determined on the soils.

Differences between the two soil groups were observed when the finer textured soils of both groups were compared. In this respect, for equivalent levels of NH_4OAc or NaCl extractable soil potassium, the non-calcareous soils appear to have a larger amount of plant available potassium. It was also found that the calcareous soils were capable of "fixing" a larger amount of added potassium than the non-calcareous soils. On these finer textured soils, especially the calcareous soils, the NH_4OAc solution apparently extracted potassium from these soils which is not readily available to plants, thus this method should be avoided when it is required to relate soil potassium to plant available potassium. A better relationship is obtained when NaCl extractable soil potassium is used as a measure of plant available soil potassium.

In order to further investigate some of the results obtained in the greenhouse, several experiments were conducted on a field basis in the summer of 1966 by Dr. G. J. Racz, in which corn was the test crop. Results from these experiments were not available at the time this thesis was being written.

Appendix A

1. Composition of solution of micronutrients added to the plants.

2.86 g	H_3BO_3
1.81 g	$MnCl_2 \cdot 4H_2O$
0.11 g	$ZnCl_2$
0.05 g	$CuCl_2 \cdot 2H_2O$
0.025 g	$NaMoO_4 \cdot 2H_2O$

The several compounds were dissolved in 1 liter of distilled water. 1 ml. of this solution was added to 10 ml. of distilled water and this was used to make one application of micronutrients to one pot containing 1800 - 2000 gms. of soils.

2. Composition of iron solution added to the plants. 13.05 gms of E D T A was dissolved in 134 ml. of 1.0 N NaOH. To this solution was added 12.45 gms of $FeSO_4 \cdot 7H_2O$. The solution was then placed on a shaker and shaken for about two hours to completely dissolve the $FeSO_4 \cdot 7H_2O$. The solution was removed from the shaker and diluted to approximately 400 ml. with distilled water. It was then connected to an air valve and air bubbled through it until the solution was clear of precipates (approximately 12 hrs.). The solution was then diluted to 500 ml. The final pH of the solution would be approximately 5.5.

1 ml of this solution is approximately 5 ppm Fe .10ppm iron was applied to each pot.

BIBLIOGRAPHY

1. Albrect, Wm. A. 1943. Potassium in the soil colloid complex and plant nutrition.......Soil Sci. Vol. 55, No. 1.

2. Allaway, H. and Pierre, W. H. 1939. Availability fixation, and liberation of potassium in high-lime soils. Jour. Amer. Soc. Agron. 31: 940-953.

3. Anderson, P. J.; Swanback, T. R., and Street, O. E. Potash requirements of the tobacco crop. Conn. Agr. Expt. Sta. Bul. 334.

4. Aslander, A. and Armolik, N. Aug. 1965. Peat soils - Leaching of K. Potash Review, Subj. 16, 32 suite.

5. Bailey, L. D. 1965. The influence of Ca and Mg content of calcareous and non-calcareous soils on the uptake of these elements by peas. Undergraduate Thesis (B.S.A.) University of Manitoba, Dept. of Soil Sci. Unpublished.

6. Bartholomew, R. P. 1938. The availability of potassium to plants as affected by barnyard manure. Journ. Amer. Soc. Agron. 20: 55-81.

7.(a)Beckett, P. H. T. 1965. The cation exchange equilibra of Ca and Mg. Soil Science, Vol. 100, No. 2.

7.(b)Beckett, P. H. T. Aug. 1965. Activities co-efficient for studies on soil K. Potash Review, Subj. 5. 23rd suite.

8. Bender, W. H. and Eisenmenger, W. S. 1941. Intake of certain elements by calciphilic and calciphobic plants grown on soils differing in pH. Soil Science, 52: 297-307.

9. Copeland, B. C. 1965. Effect of texture and calcium carbonate on the availability of potassium. Undergraduate Thesis (B.S.A.) University of Manitoba, Dept. of Soil Science. Unpublished.

10. De Turk, E. E.; Wood, L. K. and Bray, R. H. 1943. Potash fixation in corn belt soils. Soil Science, Vol. 55, No. 1.

11. Fox, R. L. and Kacar, B. 1965. Mobilization of non-exchangeable K and Na in a calcareous soil during plant growth. Plant and Soils, Vol. XXII, No. 1.

12. Gillingham, J. T. 1965. Some factors affecting the net absorption of exchangeable potassium by the Neubauer Rye Seedling Method. Soil Science, Vol. 100, No. 6.

13. Hendricks, S. B. 1966. Salt entry into plants. Soil Science Soc. Amer. Proc. Vol. 30, No. 1.

14. Hoagland, D. R. and Martin, J. C. 1933. Absorption of potassium by plants in relation to replaceable, non-replaceable and soil solution potassium. Soil Science, Vol. 36: 1-33.

15. Jackson, M. L. Text - "Soil Chemical Analysis" - Advanced Course.

16. (a) Jenny, H. and Shade, E. R. 1934. The K-Lime problem in soils. J. Amer. Soc. Agron. 26: 162-169.

16. (b) Jenny, H. 1961. Contact phenomena between absorbents and their significance in plant nutrition. Text book by Emil Truog - "Mineral Nutrition of Plants".

17. Machlis, L. and Torrey, J. G. "Plants in Action"--A Laboratory Manual of Plant Physiology.

18. McEwen, H. B. and Matthews, B. C. 1958. Rate of release of non-exchangeable potassium by Ontario soils in relation to natural soil characteristics and management practice. Can. J. Soil Sci. Vol. 38, No. 1.

19. Oliver, S. and Barber, S. A. 1966. An evaluation of the mechanism governing the supply of Ca, Mg, K and Na to soybean roots (Glycine Max). Soil Sci. Soc. Amer. Proc. Vol. 30, No. 1.

20. Peaslee, D. E. and Moss, D. N. 1966. Photosynthesis in K- and Mg-deficient Maiz leaves. Soil Sci. Soc. Amer. Proc. Vol. 30, No. 2.

21. Peech, M. and Bradfield, R. 1943. The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. Soil Sci. Vol. 55, No. 1

22. Pierre, W. H. and Bower, C. A. 1943. Potassium absorption by plants as affected by cationic relationship. Soil Sci. Vol. 55, No. 1.

23. Salmon, R. C. 1964. Cation exchange reactions. J. Soil Sci. Vol. 15, No. 2.

24. Stanford, G., Kelly, J. B. and Pierre, W. H. 1941. Cation balance in corn grown on high-lime soils in relation to potassium deficiency. Soil Sci. Soc. Amer. Proc. 6:335-341.

25. Smith, J. A., Matthews, B. C. 1957. Release of K by 18 Ontario soils during continuous cropping in the greenhouse. Can J. Soil Sci. Vol. 37, No. 1

26. Soper, R. J. The effect of fertilizers on the yield of barley grown on infertile soils. University of Manitoba, Dept. of Soil Sci. Unpublished.

27. Walker, R. K. The effect of fertilizer treatments, drying, heating and wetting on the solubility and availability of K in soils. Reported in publication by authors listed (29).

28. Word, G. M. and Johnson, F. B. "Chemical Methods of Plant Analysis" - C. D. A. Publication No. 1064. C.D.A. Publication Branch, Ottawa.

29. Worsham, W. E. and Sturgis, M. B. Factors affecting the availability of K in soils of the lower Mississippi deltas. Soil Sci. Soc. Amer. Proc. 6: 342-347.

30. York, E. T. and Rogers, H. T. 1947. Influence of lime on the solubility of potassium in soils and on its availability to plants. Soil Science 63: 467-477.