THE CATION EXCHANGE CAPACITY AND PERCENT CALCIUM SATURATION IN RELATION TO THE RELEASE AND UPTAKE OF EXCHANGEABLE CALCIUM AND POTASSIUM

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THE CATION EXCHANGE CAPACITY AND PERCENT CALCIUM SATURATION IN RELATION TO THE RELEASE AND UPTAKE OF EXCHANGEABLE CALCIUM AND POTASSIUM

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Introduction

Early studies in Soil Chemistry led soil scientists to suspect that certain cations in the soil were available to the plant in the exchangeable form (12). This consideration resulted in a change of concepts in the realm of soil fertility and plant nutrition investigations.

It was discovered that as soils were depleted of bases such as Ca, Mg, K, and Na they became acid as a result of H-saturation (17). This condition resulted in a considerable decrease in plant growth. In experiments carried out to correct this condition (12) it was soon found that the addition of the depleted cations, mainly calcium and potassium, resulted in a significant increase in plant growth.

While studying the factors governing the uptake of cations from the soil it was discovered that calcium occurred in larger amounts than other soil cations and that it acts as a regulator of the physiological equilibrium of salt intake by plants (37).

The percent base saturation is an important factor in the soil fertility status of a soil for it has been established, that the release and uptake of the exchangeable cations is a dependent function of the aforementioned factor (2).

Ionic exchange is one of the most dynamic properties of the soil as far as determining the magnitude of adsorption and supply of exchangeable cations in the soil for plant growth is concerned.

Many soils have a low total cation exchange capacity and therefore the amount of cations held in exchangeable form is low. Under these conditions the productive capacity of the soil may be decreased considerably.

A great many studies (12, 13, 51) have been made towards the general understanding of the role of exchangeable cations in soils and the mechanism of ionic exchange. In searching the literature no contribution could be found pertaining to a systematic investigation of the factors which govern the release and uptake of exchangeable calcium and potassium, as influenced by the percent calcium saturation in a soil, in which different levels of total cation exchange capacities were established with the use of peat. It is the object of this investigation to elucidate:

(a) the relationships existing between the inorganic (H-soil) and the organic (H-peat) fractions as they affect cation exchange capacity;

(b) the effect of percent calcium saturation upon the adsorption of potassium added to the soil at different symmetry concentrations;

(c) the effect of percent calcium saturation on the release and uptake of calcium and potassium in a soil in which different levels of total cation exchange were maintained with a peat depleted of bases.

Review of the Literature

The application of physico-chemical methods to the study of the forms in which the cations occur in the soil system has resulted in a series of scientific findings which clarify the mechanism of certain colloidal phenomena in the soil.

Way (17) found in 1850 that the soil exchanged ions supplied in solution of neutral salts with those found in the soil. Later, it was postulated that the plants take up only the cations which are found in the soil in the exchangeable form (20). These findings led soil scientists to consider the importance of cation exchange capacity in soils as one of its most dynamic properties (26). Although the mechanism of ionic exchange was at first not well understood, methods to determine the "total base exchange capacity" were proposed and adopted (25).

The cation exchange capacity has been found to be a constant property of a soil (12) although the magnitude of the estimated value depends upon a number of factors such as the nature of the exchange complex (37), the hydrogen ion concentration (49) and the nature, kind and concentration of the saturation cation (19, 38).

It has been found (20) that plants take up the cations from the soil when they are in the exchangeable form. Several factors (26) govern the equilibrium relations of these cations in the exchange complex and consequently the ease of their availability. Among these factors, the percent base saturation has been found to be very important (2). Base unsaturated soils are infertile and acid due to a process of depletion of bases and replacement of those cations by H ions.

Gedroiz (12, 37) conducted a number of experiments to determine the role of percent base saturation on the uptake of cations by plants. As a result he concluded that calcium is the major exchangeable cation in a normal soil and that the availability of other exchangeable cations such as potassium and magnesium depends to a large extent on the percent saturation of the calcium ion. He showed that plants can not grow when the adsorbed calcium is removed from the soil, and that plants could secure potassium and magnesium from the soil where the exchangeable forms were removed by leaching, provided the calcium ion was present. Similar results have been obtained by other workers in carefully controlled experiments (1, 2).

The increase in percent calcium saturation in acid soils results in an increase in the delivery of exchangeable calcium to the plant (1, 30). This is due to (a) a higher ionic activity, (b) the forces which hold the cations adsorbed by the colloid complex become smaller, and (c) the nature of the other saturating cations (19).

Allaway (2) has shown that the increase in calcium saturation results in an increase in the availability of calcium and other saturating cations up to an optimum which he found to be forty percent in the case of soils containing kaolinite and eighty percent in soils containing montmorillonite.

Jenny and Ayres (19) showed that ionic exchange between the soil solution and clay surfaces is not a prerequisite to the intake of adsorbed ions by plants. Jenny and Overstreet (20) theorized that the intake of cations is due to a process of direct contact exchange between soil colloids and root surfaces. As a result of this investigation, they concluded that the degree of base saturation of the soil is one of the governing factors of the availability of adsorbed ions.

The cations making up the total percent of base saturation of soils are mainly calcium, potassium, and magnesium (12). If the effect of the percent saturation of a particular cation is to be studied it has been found convenient to single it out by designating the other ions as "complimentary ions." This new concept has been very useful in studying certain soil phenomena of a physico-chemical nature.

Many workers have found that the ease of replacement of an exchangeable cation depends upon the kind and number of complimentary ions held on the exchange surfaces (19). If the complimentary ions are held loosely they will tend to depress the release of the other "adsorbed ion."

In reference to the relation of exchangeable calcium to the release and fixation of potassium in the exchange complex it may be stated that there is no general agreement (41). Under certain circumstances it has been found that the amount of exchangeable potassium varies inversely with the percent calcium saturation (21). Jenny et al. (20) found that in multiple ion systems the replacement of potassium is governed by complicated interactions of adsorbed and released ions.

Jenny et al. (18, 19) explained the quantitative relation of the saturating exchangeable cation to the complimentary ions in the process of exchange, by means of the kinetic theory of ionic exchange. They showed that a decrease in percent base saturation reduces the amount of exchangeable cations replaced by the added cation. Furthermore, if the complimentary ions are held more tightly than the saturating cations in question the added cations will displace more readily the saturating cations. In this case the degree of base saturation has little effect. When the ions included in exchange have equal oscillation volumes (equal adsorbability) the release of exchangeable cations is a direct function of percent base saturation. When the complimentary ions are held loosely as compared with the exchangeable cation, the complimentary ions will be more easily replaced than the exchangeable cation in question and therefore the percent base saturation assumes a significant role.

Jenny et al. (21) have found that in acid soils a higher degree of calcium saturation of the soil colloids results in a higher release of exchangeable potassium.

Bear and Toth (6) while studying the influence of calcium on the availability of other cations came to the conclusion that deficiencies in potassium in the soil occur due to a disequilibrium of the Ca:K ratio.

Jenny and Shade (21) state that in acid soils additions of calcium results in the liberation of potassium while in alkaline soils, where the hydroxyl ions are not excessive, additions of calcium induces fixation of potassium.

Peach and Bradfield (41) reconciled the controversies by evaluating the experimental conditions under which the various results were obtained. It should be indicated here that the factors determining the availability of potassium are numerous (8) although release occurs through the process of ionic exchange (20).

The exchange complex of the soil is considered to be the active fraction which is capable of ionic exchange consisting of the inorganic fractions (clay minerals) and the organic fraction made up by the end-products of the decomposition of organic matter (49).

It has been found that the "humus" fraction of soils exhibits high cation exchange per unit weight. According to Mitchell (33) the organic fraction is responsible for 41 to 65 percent of the cation exchange of a mineral soil. Olson and Bray (36) found that in a humus soil the organic fraction contributed 6.8 to 43.3 percent of the total cation exchange capacity. Therefore, it is obvious that additions of organic matter to a mineral soil would result in a significant increase in the total capacity of the treated soil to hold and exchange cations.

A critical review of the literature indicates that there is no comprehensive study in which peat has been used as a source of material to increase total cation exchange capacities of soils in making exchange studies.

Jones (24) in a study on the availability of humate potassium found that the potassium held by the humate fraction was more readily exstractable than that from clay.

For the proper growth of plants it is necessary to have not only an adequate supply of cations but also of certain anions such as NO_3^- and PO_4^{---} which are indispensable for the proper growth of plants (32).

Truog (48) asserts that calcium plays an important role in the economy of nitrogen.

Pierre and Allaway (42) found that calcium in the soil is essential for the nitrification process to take place. In acid clay soils calcium is the limiting factor for the development of micro-organisms, specially nitrifying bacteria.

Calcium depresses the solubility of phosphorus (48) at pH values higher than 7. McGeorge (28) states that the alkalinity caused by additions of lime to the soil is instrumental in reducing the availability of phosphorus. When the soil contains free calcium, the phosphate ions will combine with calcium ions and precipitate as an insoluble salt provided the pH is higher than 8.

Experimental Methods

The soil used in the investigation was a gray-brown podzolic soil low in fertility characterized by a low total cation exchange capacity, a relatively high saturation of hydrogen and an acid reaction.

A well decomposed peat which had pH 3.9 was used to increase the total cation exchange capacity of the soil. Sudan grass was used as the indicator of the uptake of potassium and calcium from the soil.

The percent calcium saturation was adjusted with calcium acetate and the potassium was supplied as potassium chloride. Both of these salts were chemically pure.

Laboratory Investigations

Preparation of the H-soil

In order to carry out certain studies of the effect of calcium saturation upon the release of exchangeable calcium and potassium it was necessary to prepare a hydrogen saturated soil.

Since the soil was low in total cation exchange capacity, in order to have a relatively high total exchange capacity per unit weight, it was found convenient to eliminate the sand fraction.

The sand fraction (0.052 mm) was separated by sieving retaining the very fine sand, silt, and clay fractions respectively. By this procedure it was possible to increase the total base exchange capacity by more than 100 percent.

In preparing a hydrogen saturated soil a very dilute solution of HCl was used to prevent changing the nature of the exchange complex. Gedroiz (12) and Yarusov (51), in preparing a hydrogen soil, used 0.05 N HCl as the leaching solution to remove the exchangeable bases of the soil and to saturate it with hydrogen ions.

Assuming that all the exchangeable cations are not leached out, it was decided to determine the effect of different concentrations of HCl-leaching upon the exchange capacity of the soil. It was expected that a maximum point would be found in the curve formed by plotting the concentrations of HCl solutions against the total cation exchange capacity. A maximum capacity was found in every case as is shown in Table 1. The maximum cation exchange capacity was found in most instances where the soil was leached with 0.1 N HCl solution as shown by the curve in Figure I. On this basis the H-saturated soil was prepared by leaching each 10 grams of soil with 500 ml of 0.1 N HCl. The saturated system was then washed with 150 ml of CO_2-free water until free from chlorides. Finally it was rinsed with 10 ml of 90% ethyl alcohol to eliminate occluded water. The soil was air-dried and stored. This procedure was assumed to give a soil one hundred percent saturated with hydrogen.

Table 1

THE EFFECT OF DIFFERENT CONCENTRATIONS OF HCL ON THE CATION EXCHANGE CAPACITY OF SOIL*

Treatment Number	500 ml N HCl	$BaSO_4$ grams	Ba grams	Barium m.e.	Cation Exchange m.e./100 grams
1	0.000	0.1126	0.0663	0.9650	9.650
2	0.025	0.1214	0.0715	1.0399	10.399
3	0.050	0.1232	0.0725	1.0559	10.559
4	0.075	0.1337	0.0787	1.1460	11.460
5	0.100	0.1421	0.0836	1.2321	12.321
6	0.125	0.1319	0.0776	1.1290	11.290
7	0.150	0.1087	0.0640	0.9320	9.320
8	0.175	0.0890	0.0524	0.7625	7.625
9	0.200	0.0860	0.0506	0.7370	7.370
10	0.225	0.0850	0.0500	0.7290	7.310
11	0.250	0.0848	0.0495	0.7210	7.210
12	0.275	0.0839	0.0494	0.7190	7.190
13	0.300	0.0836	0.0492	0.7165	7.165

*The values reported are averages of two determinations.

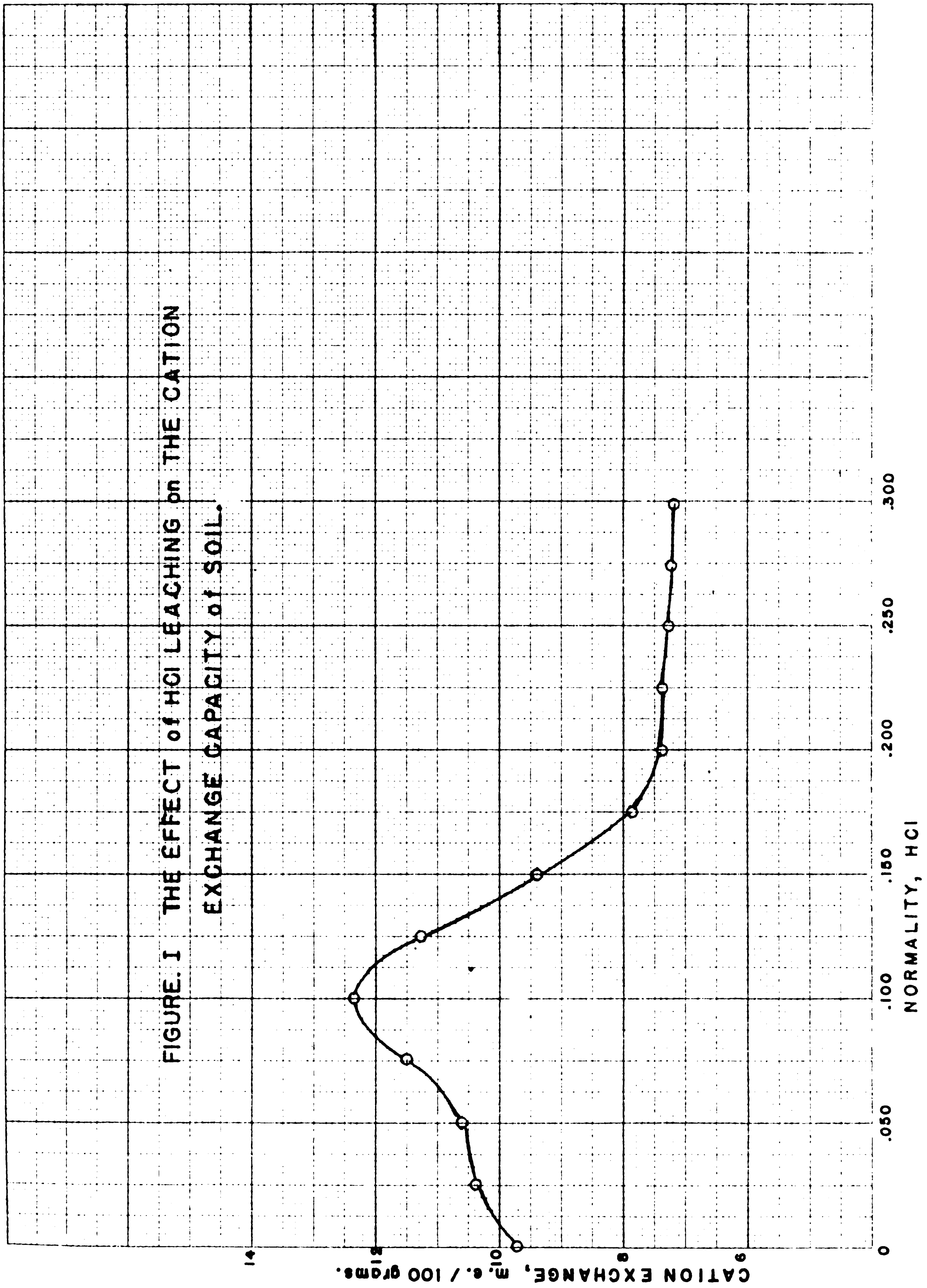


FIGURE. I THE EFFECT of HCl LEACHING on THE CATION EXCHANGE CAPACITY of SOIL.

The air-dried fine soil was leached with 0.1 N HCl in the ratio of 50 ml of solution for each gram of soil. The soil was then leached with distilled water until free of the chlorine ion. It was finally leached with 90 percent alcohol in the proportion of 5 ml per gram of soil.

Preparation of H-peat

A well decomposed and strongly acid (pH 3.9) peat was used. Although no bases were detected by titrating the residue remaining after all the leachate was evaporated, with 0.05 N HCl, using methyl red as indicator, it was decided to leach the air-dry peat with 0.1 N HCl in the proportion of 25 ml per gram of air-dried peat. It was then washed with distilled water until free of chlorine. Alcohol was not used in the final leaching because it has been found that it produces dispersion of some organic materials (33).

The effect of percent calcium saturation on the adsorption of potassium added to the soil at different symmetry concentrations was determined by saturating the hydrogen soil with calcium from 0 to 25, 50, 75, 100 and 125 percent with respect to the total exchange capacity.

At each calcium saturation level, potassium was added to make up 0, 0.5, 1.0, 1.5, and 2.0 symmetry concentration levels.

The calcium was added to the soil in Erlenmeyer flasks in a solution of calcium acetate containing 0.1 m.e. Ca per ml. The excess water was evaporated followed by the addition of potassium as KCl in a solution containing 0.1 m.e. K per ml. The liquid phase was made up to 250 ml in every case. All the Erlenmeyer flasks were shaken and left standing at room temperature for a period of 72 hours, although the reaction is instantaneous (26, 34). Aliquots of the supernatant liquid were removed with a bent-tipped pipette, filtered through Whatman filter paper No. 42 and analyzed for potassium using the flame photometer.

Adsorbed potassium is reported as the difference between the initial and final concentrations. pH determinations with the glass electrode were made as soon as the initial volumes were made up and at the time of removing the aliquots for analysis.

Greenhouse Experiment

In order to determine the effect of percent calcium saturation on the uptake of calcium and potassium by sudan grass and find the interaction effects of treatments upon total yields, a factorial experiment was set up in which three factors were involved: cation exchange, percent calcium saturation and potassium levels respectively.

The cation exchange level served as an independent group in which three levels of percent calcium saturation and three levels of potassium were combined in all possible ways in order to have three groups with nine treatments each. Four replications were used.

The air-dried soil was passed through a 3 mm mechanical sieve for the purpose of removing stones and other coarse materials. Seven thousand grams of soil were placed in each of the one hundred and eight glazed earthenware two-gallon jars which were then distributed at random in three groups of thirty-six units each. The first group received no peat and was designated as M_1. Peat was added to the soil in the second group in the proportion of five grams per one hundred grams of soil in order to give the desired exchange capacity which was determined previously in samples of different soil: peat ratios. This group was called M_2. Similarly the third group was treated with 15 grams of peat per 100 grams of soil to give the highest cation exchange capacity which was designated as M_3. See Table 2. The peat was sieved and mixed by hand in the proper proportions with the soil. The total weight of soil and peat in each case was adjusted to 7,000 grams per jar.

Each one of these cation exchange capacity levels was distributed at random in four replicates of nine jars each.

With each of the cation exchange capacity treatments three levels of percent calcium saturation were established by adding 1 N calcium acetate in amounts, to give levels of Ca_1, Ca_2, Ca_3, representing forty, seventy, and one hundred percent calcium saturation respectively. The summary of treatments is shown in Table 3.

Finally, three levels of potassium, using 1 N potassium chloride, were distributed factorially in order to have each percent calcium saturation level combined with each potassium treatment in all possible combinations as listed in Table 4.

$$Ca_1 \left[\begin{array}{l} K_1 \\ K_2 \\ K_3 \end{array} \right. \qquad Ca_2 \left[\begin{array}{l} K_1 \\ K_2 \\ K_3 \end{array} \right. \qquad Ca_3 \left[\begin{array}{l} K_1 \\ K_2 \\ K_3 \end{array} \right.$$

The contents of each jar were mixed thoroughly by hand to give a homogeneous distribution of peat, calcium, and potassium throughout the soil.

Soon after the saturating solutions were added, a strong fermentation process started in all jars accompanied by the evolution of carbon dioxide which was most conspicuous in the M_3 group. This action should aid in keeping the calcium ion in a free state. Hypothetically, the reaction can be represented as follows:

$$Ca(CH_3COO)_2 + H_2CO_3 + O_3 \Longleftrightarrow CH_4 + 4CO_2 + 2H_2O + Ca^{++}$$

The jars were left for eight days with adequate aeration for the purpose of allowing time for the attainment

Table 2

THE TOTAL CATION EXCHANGE CAPACITY OF TREATMENTS: M_1, M_2, AND M_3

Treatments	Peat Added grams/100 grams soil	Organic Matter Percent	Cation Exchange Capacity m.e./100 grams
M_1	0	2.71	5.83
M_2	5	7.05	10.85
M_3	15	9.82	19.13

Table 3

SUMMARY OF PERCENT CALCIUM SATURATION ON TREATMENTS M_1, M_2, AND M_3

Saturation Treatments	Calcium Saturation Percent	Exchangeable Calcium m.e./100 Grams	Exchangeable Bases in Soil m.e./100 Grams	Exchangeable Calcium Required m.e./100 Grams	Exchangeable Calcium Added m.e./100 Grams
Treatment M_1					
Ca_1	54.88	3.20	3.20	0.00	0.00
Ca_2	70.00	4.08	3.20	0.88	1.40
Ca_3	100.00	5.83	3.20	2.63	3.08
Treatment M_2					
Ca_1	40.00	4.34	3.15	1.19	1.75
Ca_2	70.00	7.60	3.15	4.45	4.55
Ca_3	100.00	10.85	3.15	7.70	7.89
Treatment M_3					
Ca_1	40.00	7.65	3.10	4.55	4.63
Ca_2	70.00	13.39	3.10	10.29	10.49
Ca_3	100.00	19.13	3.10	16.03	16.31

Exchangeable calcium found by previous analysis was as follows:

Treatment M_1 = 2.17 m.e./100 grams
Treatment M_2 = 1.46 m.e./100 grams
Treatment M_3 = 1.35 m.e./100 grams

Table 4

THE POTASSIUM TREATMENTS ON CALCIUM SATURATION LEVELS IN TREATMENTS M_1, M_2, AND M_3 RESPECTIVELY

Potassium* m.e./100 grams	Ca_1	Ca_2	Ca_3
K_1	0.00	0.00	0.00
K_2	0.32	0.32	0.32
K_3	0.64	0.64	0.64

* 0.32 m.e./100 grams = 250 pounds K/2 x 10^6 pounds soil

0.64 m.e./100 grams = 500 pounds K/2 x 10^6 pounds soil

The native exchangeable potassium found in the soil by analysis was equal to 0.19 m.e./100 grams.

of equilibrium. The jars were watered and seeded with sudan grass. After eight days the seedlings were thinned to twelve plants per jar giving an even distribution of plants. The plants were harvested after 45 days, at which time some had started to bloom. In general the growth was scant. In level M_1, at forty percent calcium saturation, no yields were recorded. It was believed the poor growth was due to deficiencies in other plant nutrients or to an unbalance of the nutrient elements in the soil.

A second experiment was set up because of the poor plant growth in the first experiment. Nitrogen and phosphorus were added to all jars. Substances which would affect the "saturation status" the least were used, i.e., nitric and orthophosphoric acids in very dilute solutions. The high degree of dilution coupled with the high buffering capacity of the soil-peat systems resulted in no significant change in soil environment as indicated by the pH values shown in Tables 8 and 9. The nitrate ion was added at the rate of 500 ppm, requiring 3.53 ml of HNO_3 CP grade (1.005 gms HNO_3/ml) per 7,000 grams of soil. Phosphorus was added at the rate of 20 ppm. It required 3.05 ml of H_3PO_4 CP grade (1.453 gms H_3PO_4/ml) per 7,000 grams soil. The acids were made up to 600 ml with distilled water and the two solutions were mixed thoroughly to give a homogeneous system before being applied to the jars.

The water holding capacity was determined previously at $_pF$ 1.6 and was found to be as follows: Level M_1 = 8.09%, level M_2 = 23.20% and level M_3 = 55.40% respectively. Therefore, the water saturation in the cation exchange capacity groups was brought up to the respective water holding capacities with additional water. The jars were left for five days to allow for aeration and attainment of equilibrium.

The jars were then seeded with sudan. After 8 days the seedlings were thinned to 12 plants per jar distributed evenly over the entire area. The plants were harvested after 50 days when they had started to bloom.

Exchangeable calcium and potassium were analized in the soil after cropping. The total contents of these cations were also determined in the aerial tissues of sudan grass after the yields (oven dry tops) were recorded.

Analytical Methods

All quantitative determination were made using standard procedures.

The percent organic matter in the soil and in the soil-peat mixtures was determined by the method of Peech (40). The soil sample was subjected to wet oxidation using a normal solution of potassium dichromate, activated by the heat of dilution of concentrated sulfuric acid, and titrated with a normal solution of fresh ferrous sulfate to reduce the dichromate ions.

The cation exchange capacity of the soil and the soil-peat mixtures was determined by saturating 20 grams of soil with 250 ml of 1 N barium acetate solution (25). The systems were left overnight and filtered with suction. The saturated system was rinsed first with 100 ml CO_2-free water and finally 50 ml of 95% ethyl alcohol until free from acetate. The adsorbed barium ions were displaced with 300 ml of 1 N ammonium chloride which was sufficient to give complete displacement, as evidenced by tests for barium carried out with ammonium carbonate and sulfuric acid.

The barium was precipitated as $BaSO_4$ with 0.01 N H_2SO_4 from a hot solution which was digested for two hours. The precipitate was then washed with plenty of boiling distilled water and filtered through Whatman paper No. 40. The precipitate was ignited at constant weight with the proper precautions to prevent reduction of the sulfate ion and weighed. The number of milliequivalents of barium recovered as the sulfate is equal to the total cation exchange capacity expressed in m.e./100 grams of soil.

The cation exchange capacities of the H-soil, the H-peat, and the hydrogen saturated soil-peat mixtures which were prepared in the same way as the H-soil, were determined potentiometrically (27, 39). In making these determination, 10 grams of soil were saturated with 30 ml of 1 N barium chloride. These were stirred and left overnight. The exchanged hydrogen was titrated potentiometrically with 0.05 N barium hydroxide which was added in small aliquots at intervals of two minutes. The equivalence point was determined by extrapolation in the titration curves to pH 7.00.

In exploratory experiments it was found that the time rate of addition of the standard barium hydroxide is important in the neutralization of the hydrogen ions. At the interval of two minutes per addition, the equivalence point found by extrapolation in the curve, gave a value which compared favorably with values obtained by the gravimetric determination of barium in the sulfate precipitate. Otherwise, smaller values were recorded invariably.

The total bases were determined by leaching the soil with 400 ml 1 N ammonium acetate solution (27). The system was left overnight and filtered with suction. The leachate was evaporated and the residue treated with 10 ml of concentrated nitric acid and 4 ml of hydrochloric acid to oxidize residual organic matter. The bases were then dissolved in a known volume of standard hydrochloric acid and back titrated with standard sodium hydroxide. Methyl orange was used as indicator.

The excess of base needed to neutralize the system, after the acid had been neutralized, was considered as equal to the total bases present expressed in m.e. per 100 grams of soil.

The exchangeable calcium in soils was determined by Peech's Method (40). Calcium was precipitated as the oxalate in the ammonium acetate extract which had been evaporated and taken up with diluted nitric acid.

An aliquot of the extract, heated almost to boiling, was saturated with 5% oxalic acid and adjusted to pH 4.6 with 1 N ammonium hydroxide using bromecresol green as the indicator. The calcium oxalate precipitate was titrated with 0.05 N potassium permanganate in the presence of 100 ml of hot 1 N sulfuric acid. The exchangeable calcium is reported in m.e. per 100 grams.

The exchangeable potassium in soils was determined by the method proposed by Attoe and Truog (4) whereby a soil sample is treated with a 2 N solution with respect to ammonium acetate and 0.2 N with respect to magnesium acetate. The systems were stirred and left overnight. They were then filtered with suction through Whatman paper No. 42 and made up to volume with the extracting solution. The determination of potassium was made spectrophotometrically using a flame photometer calibrated with standard solutions made up with the extracting solution. A standard curve was prepared covering an adequate range of concentrations.

In plant analyses, the ground material was treated with perchloric and sulfuric acids mixed in the proportions of 2:1 (43). The mixture was added to the plant material in a 450 ml beaker followed by 20 ml of nitric acid. The plant material was oxidized first at low temperature but as soon as the nitric fumes disappeared the oxidation was completed at a higher temperature. The residual sulfates were taken up in H_2O, filtered through Whatman paper No. 42 and made up to volume.

Calcium was determined by the procedure of Piper (43) whereby an aliquot of the extract is acidified with 5 ml of hydrochloric acid and neutralized with ammonia using methyl red until a full yellow color was developed. Hydrochloric acid is added until the solution turns red followed by the addition of 10 ml of 2.5% oxalic acid. At this point, the solution is brought up to the boiling point and 10 ml of ammonium oxalate is added drop by drop with constant stirring. The solution is cooled and adjusted with a saturated solution of sodium acetate to pH 5 (the indicator has an orange pink color with tendency to red). If an excess of sodium acetate is added the solution is adjusted to the proper pH with acetic acid. After the solutions are allowed to stand overnight they are filtered through Whatman paper No. 42 and washed with cold water until free from chlorine. Corrections were made for the error introduced by oxidation of filter paper in the titration with the standard permanganate solution in the presence of hot sulfuric acid (40). The calcium is reported as m.e. per 100 grams of plant material.

Total potassium in plant materials was determined by the spectrophotometric method proposed by Attoe (3) whereby a finely ground sample is digested overnight with a solution of 2 N ammonium acetate and 0.2 N magnesium acetate, filtered through Whatman paper No. 42 and made up to volume with the extracting solution. The apparatus was calibrated and a standard curve prepared using solutions of known concentrations covering a range from 0 to 100 ppm.

The final results are reported as m.e. of potassium per 100 grams of plant material.

The pH of the soils was measured with the glass electrode using a soil water ratio of 1:2 by volume.

All results are expressed on an oven-dry weight basis.

Experimental Results

The Relationship Between the Inorganic (H-Soil) and the Organic Fraction (H-Peat) with Respect to Cation Exchange Capacity

It has been reported (27) that the cation exchange capacity of the sum of the individual cation exchange capacities of the organic and inorganic fractions is not equal to the cation exchange capacity of the mixture. In other words the cation exchange capacity is not an "additive property."

In the present study it was found that the cation exchange capacity of the mixture was less than the sum of the cation exchange capacities of the components. This is illustrated by the experimental data shown in Table 5.

The decrease in cation exchange capacity by mixing the two components may be due to sorption of the organic fraction by the hydrogen saturated soil resulting in a decrease of the available surface.

The parallelism of the curves, shown in Figure II, suggest that the rate of sorption is constant over a wide range of variation in the ratio of the cation exchange of soil:peat, although cation exchange decreases exponentially the larger the ratio of cation exchange capacity of soil to peat. The curves would converge in both directions if extended, and continue parallel

Table 5

THE RELATION BETWEEN THE CATION EXCHANGE CAPACITY OF SOIL-PEAT MIXTURES AND THE CALCULATED SUMS OF THE EXCHANGE CAPACITIES OF THE INDIVIDUAL COMPONENTS

Treatments Soil (grams)	Treatments Peat (grams)	Cation Exchange Mixture m.e./100 grams	Cation Exchange Soil m.e./100 grams	Cation Exchange Peat m.e./100 grams	Sum Cation Exchange m.e./100 grams	Cation Exchange Soil+Peat m.e.
95	5	11.95	11.33	3.58	14.91	3.16
90	10	14.50	10.73	7.17	17.90	1.49
85	15	16.65	10.13	10.76	20.89	0.94
80	20	19.14	9.54	14.34	23.88	0.67
75	25	22.20	8.94	17.94	26.88	0.50
70	30	24.44	8.34	21.52	29.86	0.39

Cation exchange capacity H-peat = 71.70 m.e./100 grams.

Cation exchange capacity H-soil = 11.92 m.e./100 grams.

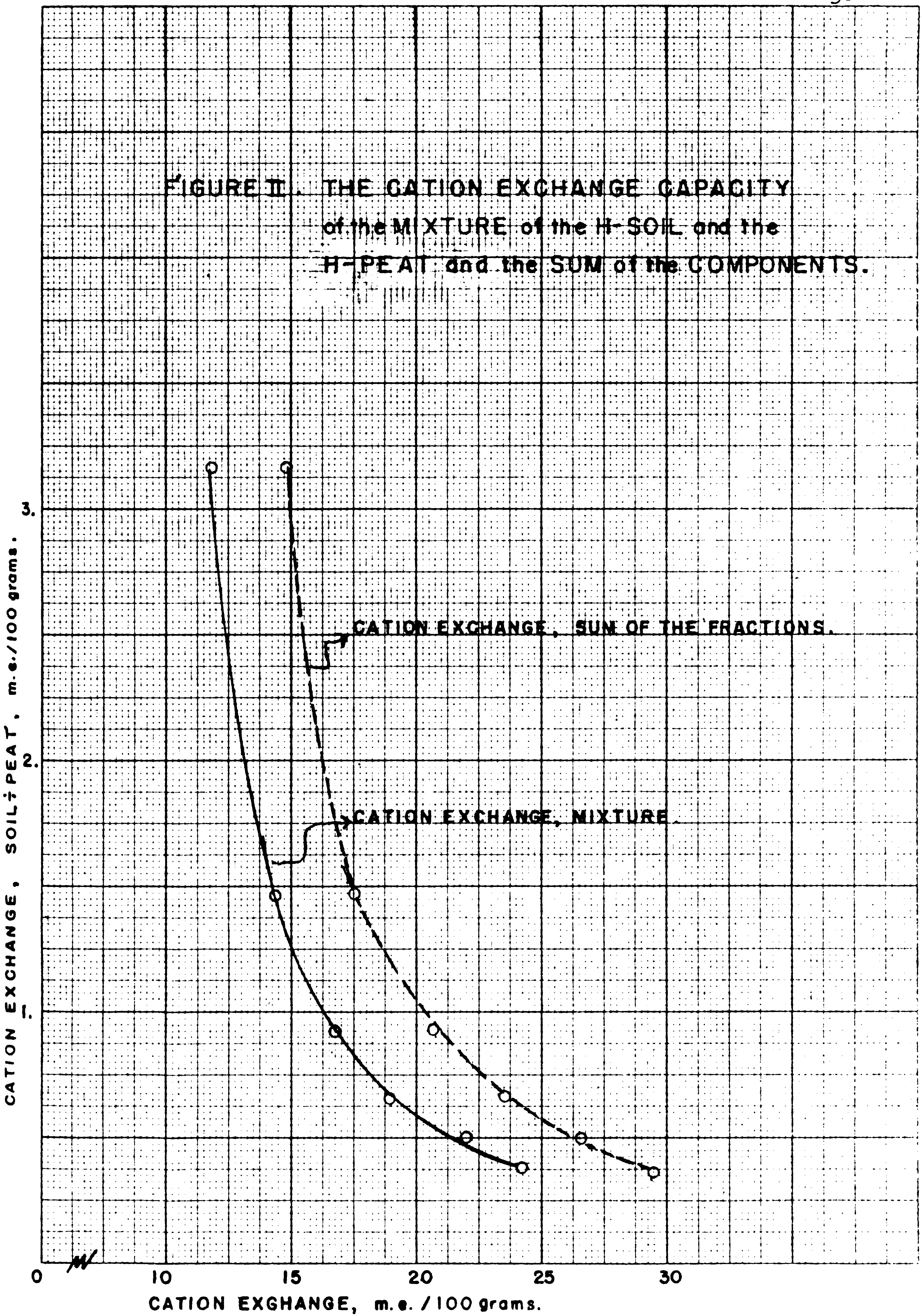


FIGURE II. THE CATION EXCHANGE CAPACITY of the MIXTURE of the H-SOIL and the H-PEAT and the SUM of the COMPONENTS.

to the coordinates. The slope of the curves will become 0 and ∞ respectively indicating that a constancy has been reached.

The Effect of Percent Calcium Saturation upon the Adsorption of Potassium Added at Different Symmetry Concentrations to the Soil System

Many workers (6, 21, 22, 29) have investigated this relationship and reported considerably different results.

In this investigation it was found that a higher adsorption of potassium occurred with a higher percent of calcium saturation in the soil.

A critical analysis of the experimental results shown in Table 6 indicates that a maximum level of adsorption of potassium is attained at 75% calcium saturation and that this maximum level of adsorption is practically the same up to 125% calcium saturation.

The effect of symmetry concentration of potassium at each level of percent calcium saturation is noticeable; the greater the amount of potassium added, the higher was the adsorption.

It has been shown (19) that potassium may be adsorbed or released from the soil through exchange or by the process of hydrolysis. The measurements of pH at the start and at the end showed no appreciable change of H^+ concentration, indicating little possibility of hydrolytic reactions. Therefore, it is believed that

Table 6

THE EFFECT OF PERCENT CALCIUM SATURATION ON THE ADSORPTION OF POTASSIUM BY A HYDROGEN SATURATED SOIL*

Percent Ca Saturation	Treat. K, m.e. per 10 grams	K Added m.e. per 250 ml	K, m.e. per ml	K Found m.e. per 250 ml	K Sorption m.e. per 250 ml	pH	
						Start	Final
	0.00	0.00	0.0000	0.000	0.000	3.40	3.40
	0.60	0.60	0.0020	0.500	0.100	3.40	3.40
0	1.20	1.20	0.0043	1.075	0.125	3.20	3.20
	1.80	1.80	0.0067	1.675	0.125	3.20	3.20
	2.40	2.40	0.0090	2.250	0.150	3.30	3.30
	0.00	0.00	0.0000	0.000	0.000	4.30	4.20
	0.60	0.60	0.0020	0.500	0.100	4.20	4.20
25	1.20	1.20	0.0041	1.050	0.150	4.30	4.30
	1.80	1.80	0.0068	1.700	0.100	4.20	4.30
	2.40	2.40	0.0089	2.223	0.177	4.40	4.40
	0.00	0.00	0.0000	0.000	0.000	5.00	5.00
	0.60	0.60	0.0020	0.500	0.100	5.10	5.00
50	1.20	1.20	0.0043	1.075	0.125	5.20	5.10
	1.80	1.80	0.0067	1.675	0.125	5.30	5.30
	2.40	2.40	0.0087	2.175	0.225	5.30	5.20
	0.00	0.00	0.0000	0.000	0.000	6.00	6.00
	0.60	0.60	0.0016	0.400	0.200	6.20	6.10
75	1.20	1.20	0.0042	1.050	0.150	6.20	6.10
	1.80	1.80	0.0064	1.600	0.150	6.20	6.10
	2.40	2.40	0.0087	2.175	0.225	6.10	6.10
	0.00	0.00	0.0000	0.000	0.000	6.50	6.40
	0.60	0.60	0.0019	0.475	0.125	6.60	6.50
100	1.20	1.20	0.0043	1.075	0.125	6.60	6.60
	1.80	1.80	0.0065	1.625	0.175	6.50	6.50
	2.40	2.40	0.0088	2.200	0.200	6.60	6.60
	0.00	0.00	0.0000	0.000	0.000	6.80	6.80
	0.60	0.60	0.0018	0.450	0.150	6.80	6.70
125	1.20	1.20	0.0042	1.050	0.150	6.90	6.80
	1.80	1.80	0.0064	1.600	0.200	6.70	6.70
	2.40	2.40	0.0087	2.175	0.225	6.80	6.80

* Used 10 grams of dry soil per 250 ml.

the adsorption of potassium by the (H-Ca) soil systems is a result of cation exchange.

The Effect of Percent Calcium Saturation and Potassium Treatments on Plant Growth

The First Crop

The percent calcium saturation appeared to effect the growth and nutrition of sudan grass to a great extent although, as shown in Figure IIIa, the effect of percent calcium saturation on plant growth varied with the level of cation exchange capacity.

In the treatment M_1 at 40% calcium saturation no growth was observed while at the 70% and 100% calcium saturation levels the growth was apparently the same.

In the treatment M_2 growth was appreciable at 40% and 70% calcium saturation levels but growth was reduced at 100% calcium saturation.

Results of the M_3 treatments shows a relation which is the inverse of M_1. This may indicate the cation exchange capacity may have an effect on the uptake of nutrients by this plant species.

The delay in germination of treatment M_3 Ca_3 appeared to be due to an accumulation of salts and consequently to an unbalance of the nutrient status of the soil. Salt content was determined by conductivity measurements of soil suspensions from composite samples drawn from the jars (see Table 7). Conductivity values higher than 100 x 10^{-5} $Ohms^{-1}$ appeared to delay germination.

Potassium did not appear to have a significant effect on growth in relation to percent calcium saturation as shown in figure IIIb. This may be due to the fact that potassium salts in plant tissues do not change the H^+ concentration significantly thus preventing a change in the starch $\rightleftarrows$ sugar equilibrium which in turn inhibits translocations and metabolic processes (32).

The Second Crop

The addition of nitrogen and phosphorus gave a significant increase in growth.

The increase in growth of treatment M_3 over M_1 may be attributed to an improvement in physical conditions, an increase in the supply of calcium, to an adequate supply of nitrogen and phosphorus, (See Figure IVa), or to a combination of these factors.

With no potassium addition, in level M_1 at 40% calcium saturation, no growth was observed while at 100% calcium saturation a significant increase in growth resulted.

In treatment M_2 maximum growth was obtained at 70% calcium saturation.

Table 7

THE SPECIFIC CONDUCTIVITY OF SOIL-WATER SUSPENSIONS OF THE SOIL AFTER THE FIRST HARVEST*

Treat-ments	Specific Conduc-tance $Ohms^{-1}$	Treat-ments	Specific Conduc-tance $Ohms^{-1}$	Treat-ments	Specific Conduc-tance $Ohms^{-1}$
$M_1Ca_1K_1$	26×10^{-5}	$M_2Ca_1K_1$	60×10^{-5}	$M_3Ca_1K_1$	34×10^{-5}
$M_1Ca_1K_2$	36	$M_2Ca_1K_2$	66	$M_3Ca_1K_2$	52
$M_1Ca_1K_3$	48	$M_2Ca_1K_3$	62	$M_3Ca_1K_3$	62
$M_1Ca_2K_1$	21	$M_2Ca_2K_1$	48	$M_3Ca_2K_1$	36
$M_1Ca_2K_2$	36	$M_2Ca_2K_2$	54	$M_3Ca_2K_2$	60
$M_1Ca_2K_3$	42	$M_2Ca_2K_3$	72	$M_3Ca_2K_3$	70
$M_1Ca_3K_1$	26	$M_2Ca_3K_1$	46	$M_3Ca_3K_1$	102
$M_1Ca_3K_2$	35	$M_2Ca_3K_2$	58	$M_3Ca_3K_2$	108
$M_1Ca_3K_3$	38	$M_2Ca_3K_3$	76	$M_3Ca_3K_3$	118

The conductance of water = 5×10^{-5} ohms at 25 C.

* Determinations made at 25° C.

Figures IIIa and IIIb

THE EFFECT OF CATION EXCHANGE CAPACITY, PERCENT CALCIUM SATURATION, AND POTASSIUM TREATMENTS ON GROWTH OF SUDAN GRASS. FIRST CROP.

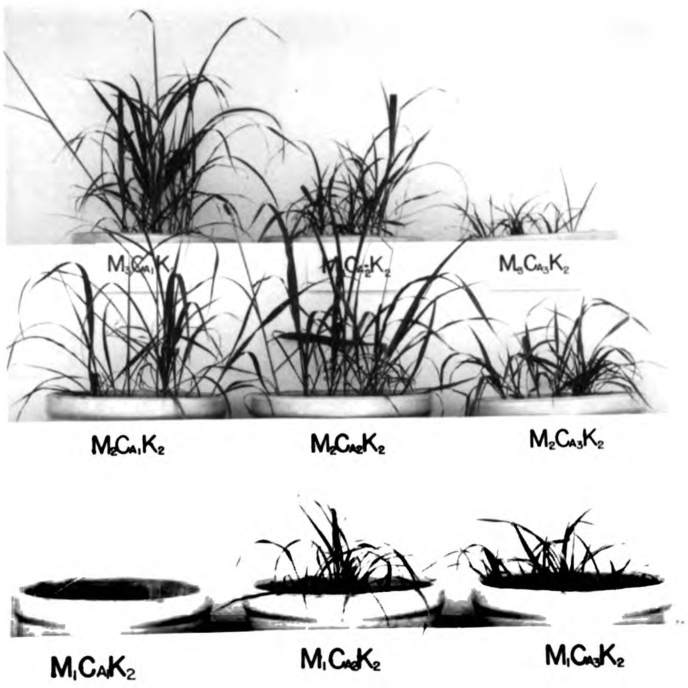


Figure IIIa

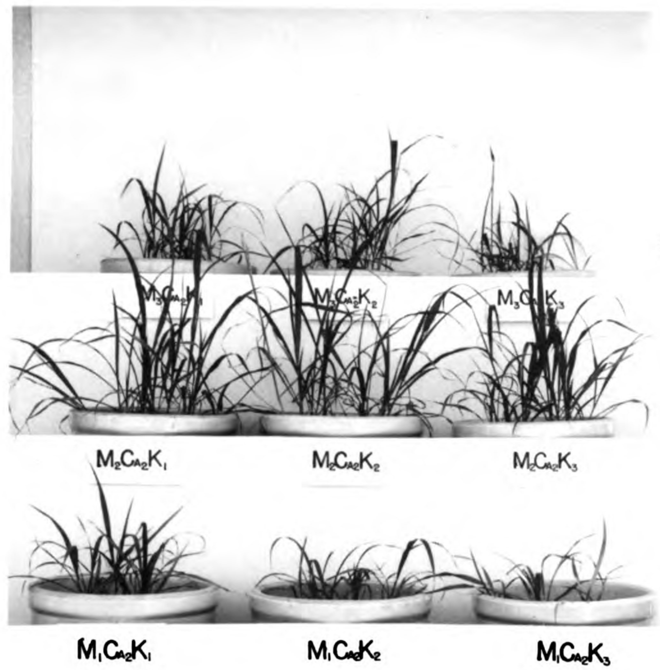


Figure IIIb

Figures IVa and IVb

THE EFFECT OF CATION EXCHANGE CAPACITY, PERCENT CALCIUM SATURATION, AND POTASSIUM TREATMENTS ON GROWTH OF SUDAN GRASS. <u>SECOND</u> <u>CROP</u>.

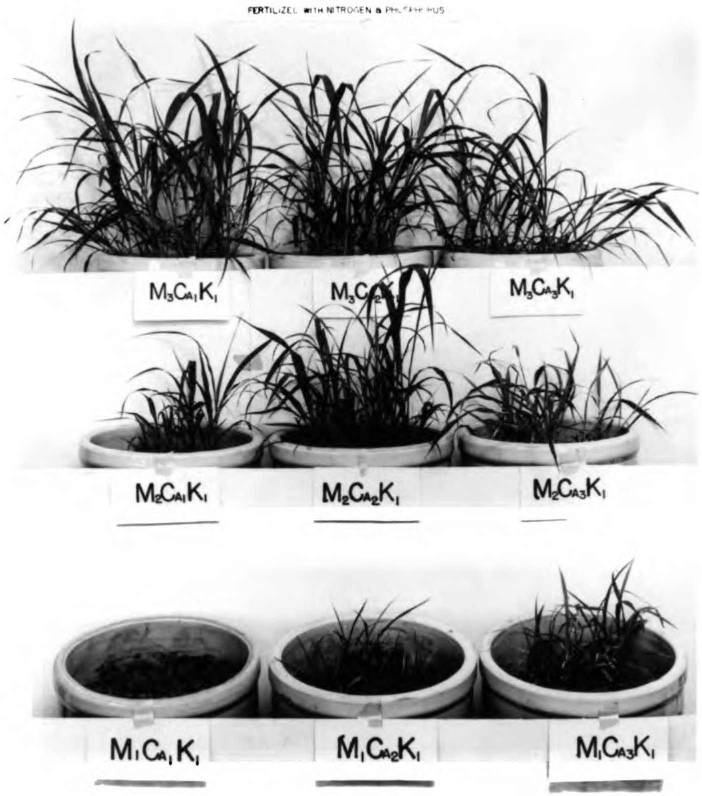


Figure IVa

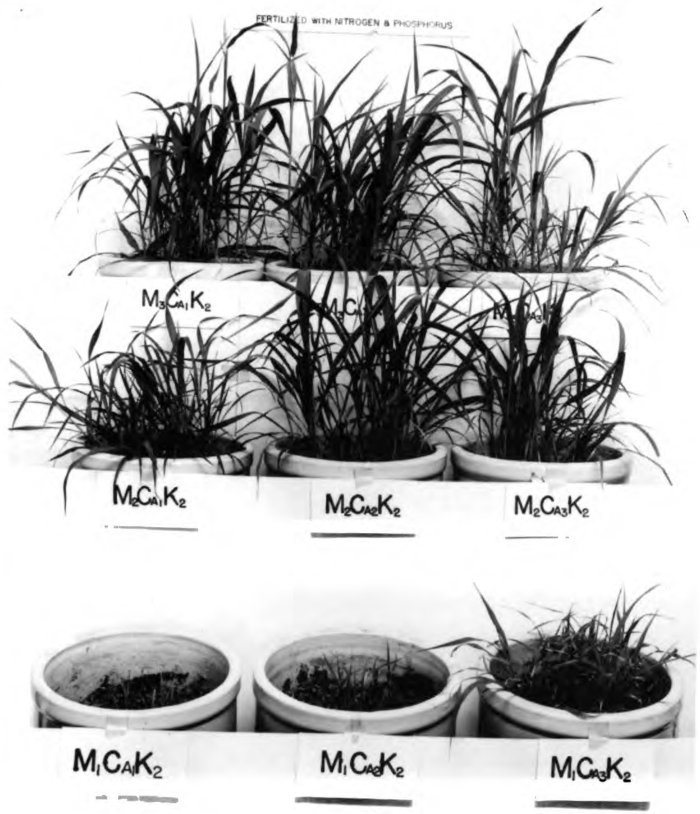


Figure IVb

Figures IVc and IVd

THE EFFECT OF CATION EXCHANGE CAPACITY, PERCENT CALCIUM SATURATION, AND POTASSIUM TREATMENTS ON GROWTH OF SUDAN GRASS. SECOND CROP.

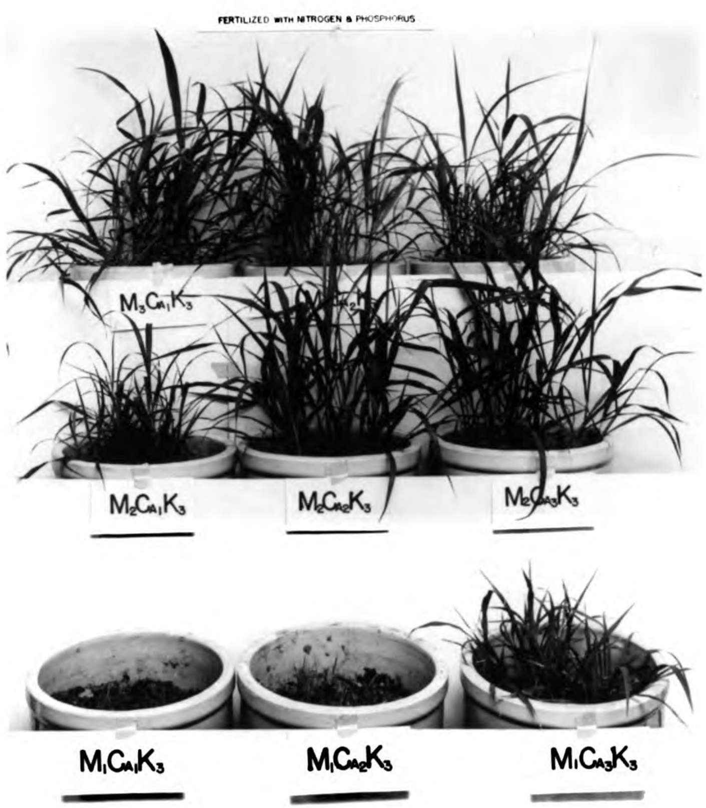


Figure IVc

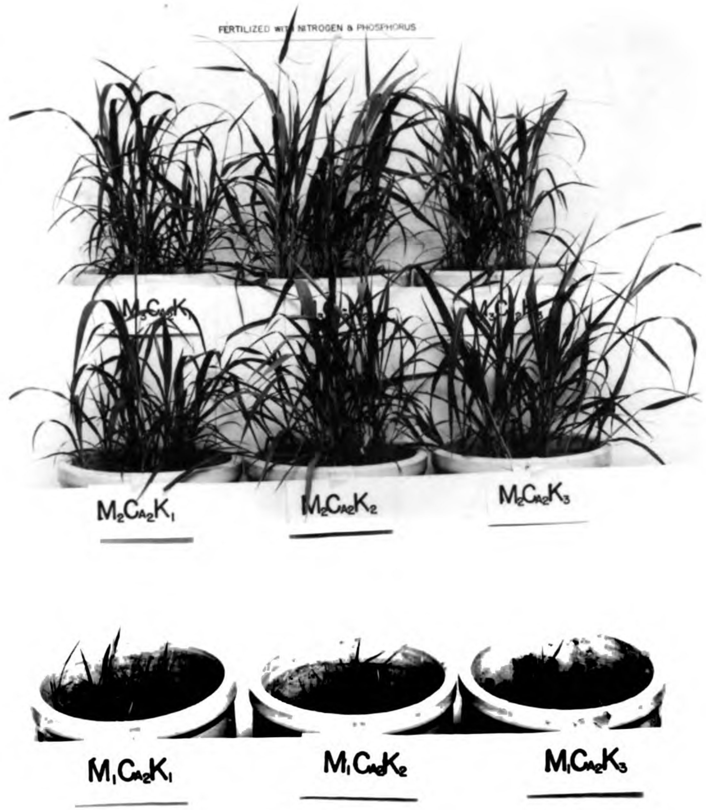


Figure IVd

Figures IVe and IVf

THE EFFECT OF CATION EXCHANGE CAPACITY, PERCENT CALCIUM SATURATION, AND POTASSIUM TREATMENTS ON GROWTH OF SUDAN GRASS. <u>SECOND</u> <u>CROP</u>.

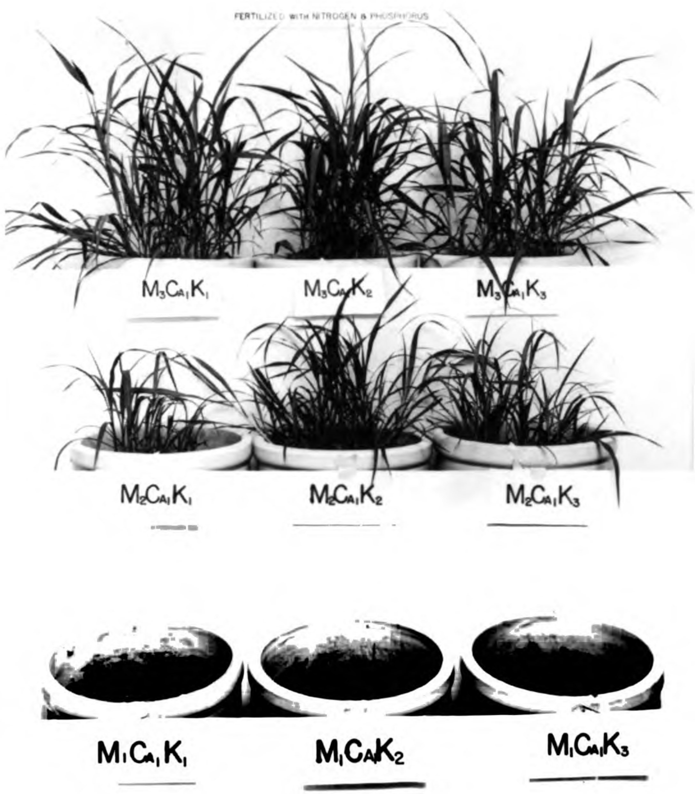


Figure IVe

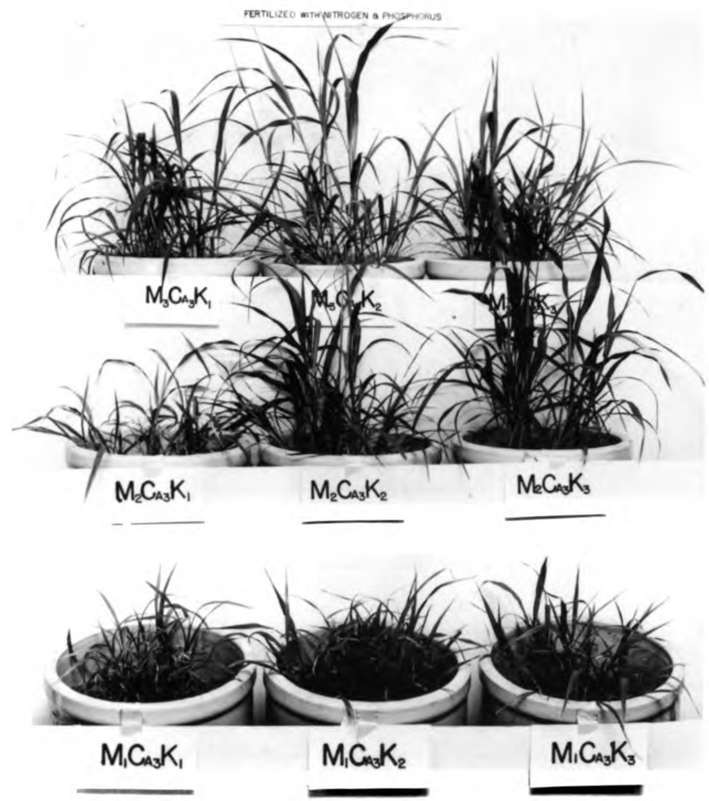


Figure IVf

At M_3, a tall scant growth occurred at 40% calcium saturation which may be attributed in part to a good supply of nitrogen. Again the maximum growth occurred at 70% calcium saturation.

As is illustrated in Figure IVb, the addition of potassium at the K_2 level influenced growth significantly over no potassium. With the M_1 group the maximum growth corresponded to 100% calcium saturation while in the M_2 and M_3 treatments the best growth occurred with 70% calcium saturation.

In the second crop, as was shown in the first crop, potassium did not affect growth as influenced by varying the percent calcium saturation. This is proved by the evidence given in Figures IVd, IVe, IVf, whereby the percent calcium treatments were held constant and the potassium levels were varied within each of the cation exchange capacity groups.

This, again indicates that the effect of potassium on the growth of sudan grass is less than the effect of percent calcium saturation.

The Effect of Percent Calcium Saturation and Potassium Treatments on Dry Matter Yield of Sudan Grass

The yields obtained in the first and second crops are reported in Tables 8 and 9 and in Figures Va and Vb.

The effect of percent calcium saturation upon dry matter yield of sudan grass has been determined quantitatively by finding the relation of average yields and the analysis of variance.

In general yields were higher for the second than for the first crop.

It is worthy to indicate here the relation of the cation exchange capacity level with percent base saturation as affecting yield. In the second crop, group M_1, an increase in yield was obtained by increasing the percent calcium saturation. In group M_2 the trend was somewhat similar to M_1 although maximum yield was obtained with 70% calcium saturation. In group M_3 yields decreased with an increase in percent calcium saturation (Figure Vb).

The effect of potassium on yield was somewhat variable but in general, higher yields were associated with the K_2 level (250 pounds of potassium per acre).

In order to determine the validity of these results an experiment, using a factorial design, was set up and the results analyzed statistically (9).

Table 8

THE OVEN-DRY WEIGHT OF SUDAN GRASS PRODUCED PER JAR EXPRESSED IN GRAMS

Replications	Ca_1 Treatment			Ca_2 Treatment			Ca_3 Treatment		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
				First Crop, M_1 level					
1	-	-	-	0.80	0.80	0.50	0.70	0.90	0.40
2	-	-	-	0.90	0.60	0.40	0.50	0.90	0.80
3	-	-	-	1.20	0.80	0.70	0.60	1.00	0.60
4	-	-	-	0.90	0.70	0.90	0.90	0.80	0.80
pH									
Start	4.18	3.80	3.72	5.02	4.65	4.42	6.80	6.50	6.28
End	3.85	3.90	3.80	4.55	4.40	4.48	5.48	5.50	5.20
				First Crop, M_2 level					
1	0.70	1.60	1.00	2.50	3.30	1.70	1.00	1.20	1.00
2	1.10	2.50	3.20	1.70	1.40	1.80	0.40	0.40	1.70
3	0.90	1.80	3.50	1.30	3.80	1.40	0.50	1.00	1.30
4	1.90	3.20	2.50	1.60	1.50	1.60	0.50	0.90	1.90
pH									
Start	4.68	4.95	4.64	6.18	5.98	5.80	7.12	6.78	7.32
End	4.60	4.50	4.58	5.47	5.55	5.50	6.73	6.48	6.58
				First Crop, M_3 level					
1	1.60	1.60	1.30	0.70	1.10	0.90	1.40	0.90	0.40
2	3.90	1.60	2.00	1.50	1.30	0.80	0.50	0.60	0.50
3	1.70	2.00	1.40	1.30	1.10	1.00	0.40	0.80	0.60
4	2.80	3.30	2.40	0.90	1.00	1.00	0.20	0.70	0.50
pH									
Start	6.00	5.41	5.52	7.35	7.18	7.30	7.10	7.30	7.45
End	5.55	5.40	5.20	6.70	6.50	6.65	7.10	7.30	7.45

The pH measurements were made on composite samples drawn from the jars of the same treatments.

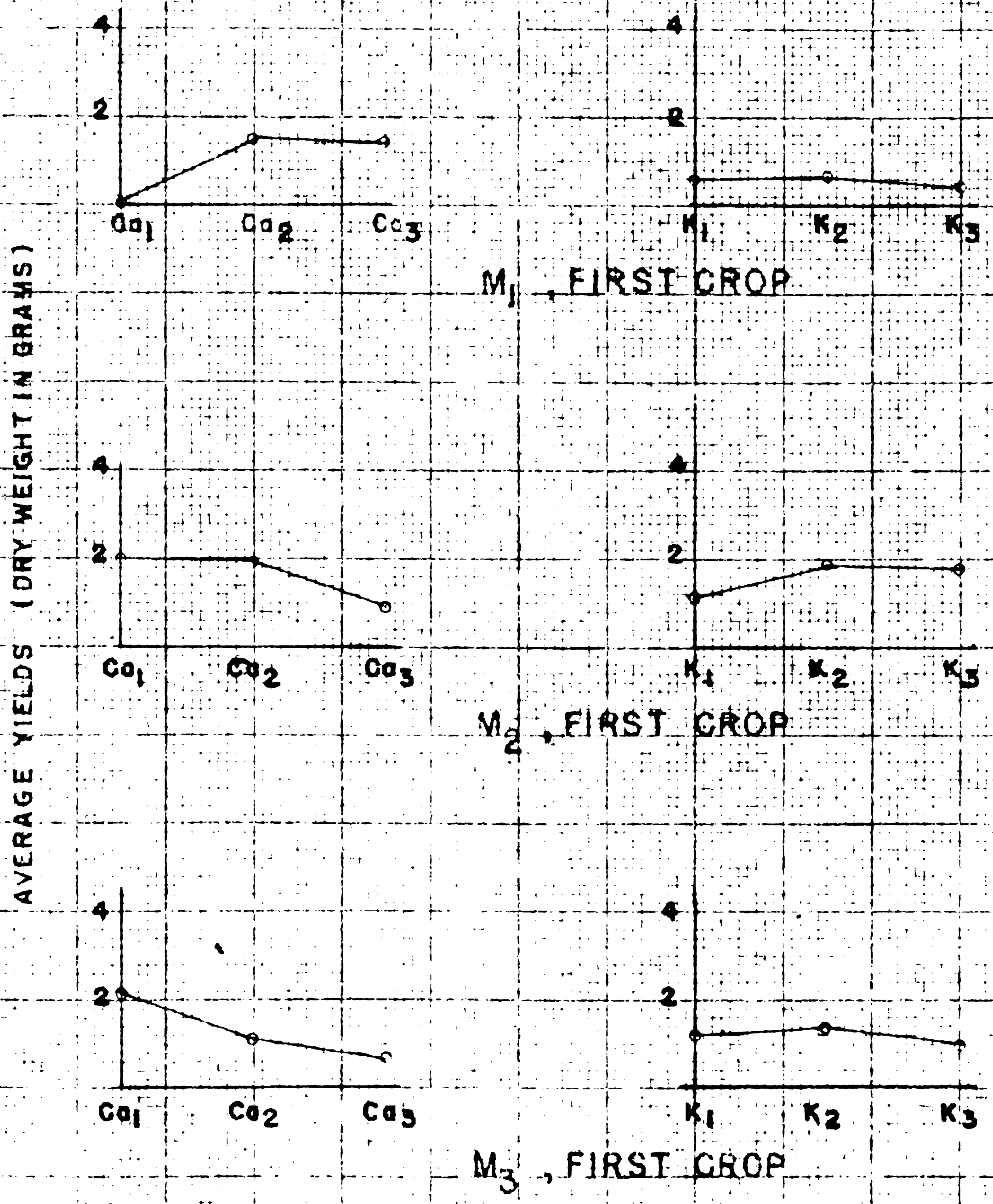
Table 9

THE OVEN-DRY WEIGHT OF SUDAN GRASS PRODUCED PER JAR EXPRESSED IN GRAMS

Replications	Ca_1 Treatment			Ca_2 Treatment			Ca_3 Treatment		
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
				Second Crop, M_1 level					
1	0.15	0.35	0.18	0.20	0.50	0.50	1.10	1.70	0.85
2	0.21	0.25	0.20	0.50	0.40	0.35	1.95	1.10	1.20
3	0.20	0.18	0.22	0.37	0.40	0.50	1.80	1.20	1.70
4	0.20	0.60	0.20	0.80	0.85	0.30	2.57	1.60	1.90
pH									
Start	3.71	3.65	3.68	4.34	4.38	4.29	5.30	5.20	5.15*
End	3.45	3.38	3.30	3.60	3.62	3.60	4.60	4.48	4.45
				Second Crop, M_2 level					
1	0.45	0.65	0.60	5.40	5.30	4.30	5.15	5.95	4.65
2	0.45	0.90	2.95	4.85	5.25	4.90	1.00	4.25	8.50
3	1.30	3.00	1.80	3.75	5.40	7.20	1.10	6.50	6.70
4	1.25	3.55	2.20	4.30	5.85	3.75	2.00	4.80	7.40
pH									
Start	4.40	4.51	4.40	5.40	5.20	5.32	6.50	6.40	6.36
End	3.70	3.84	3.80	4.65	4.38	4.36	5.80	5.90	5.85
				Second Crop, M_3 level					
1	7.00	7.15	6.40	5.70	8.20	7.25	5.55	7.55	4.85
2	6.10	7.40	7.30	5.45	5.20	6.85	5.60	5.95	5.10
3	6.60	10.00	8.60	6.65	8.10	6.30	4.10	9.00	6.30
4	6.95	7.10	6.70	5.40	7.70	6.65	6.35	7.50	6.60
pH									
Start	5.48	5.30	5.15	6.52	6.41	6.38	7.10	7.20	7.31
End	4.65	4.60	4.55	5.95	6.08	5.95	7.00	7.18	7.21

* The pH measurements were made on composite samples drawn from four jars of the same treatment.

FIGURE Va THE YIELD OF SUDAN GRASS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS.



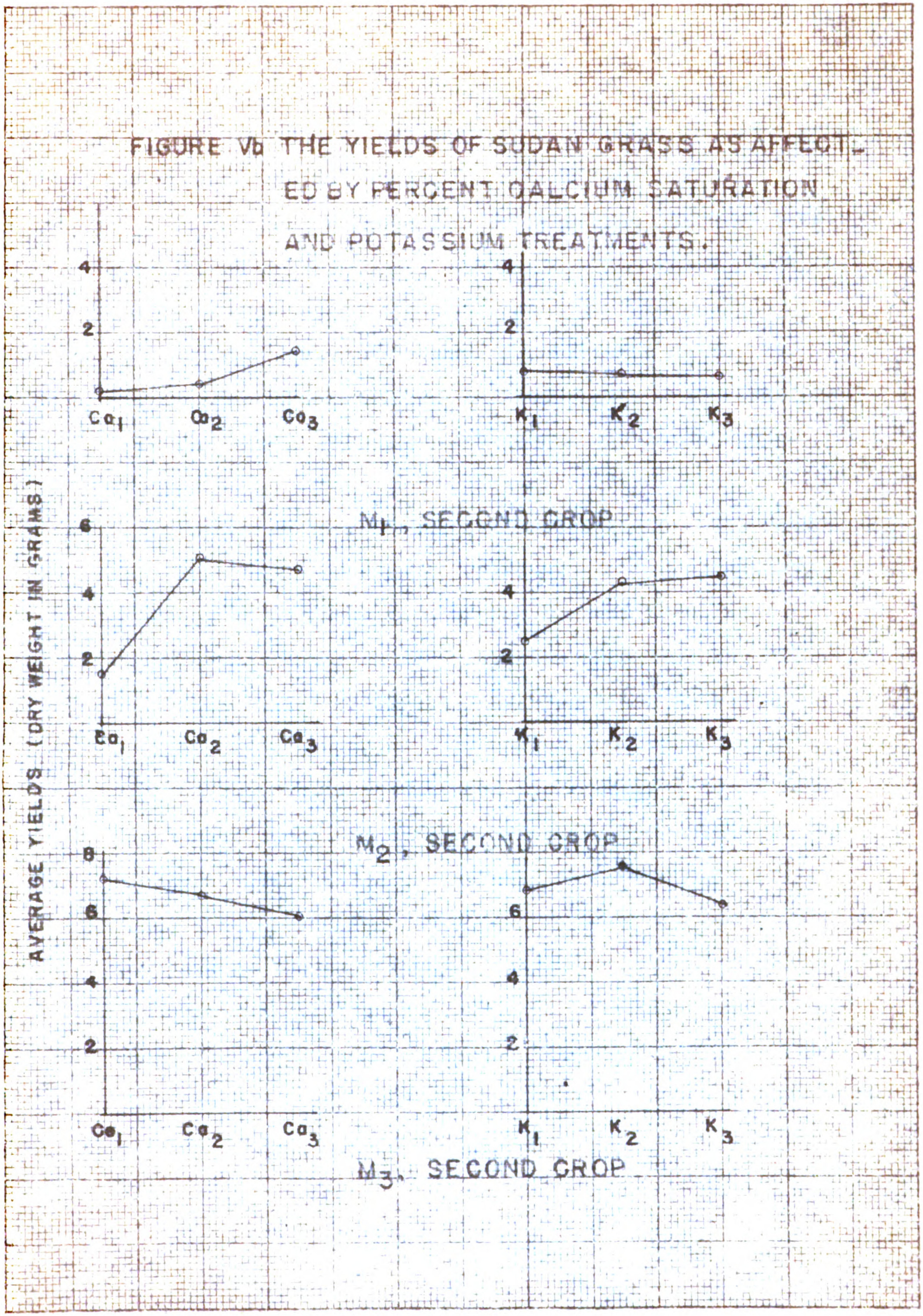


FIGURE Vb THE YIELDS OF SUDAN GRASS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS.
AVERAGE YIELDS (DRY WEIGHT IN GRAMS)
M_1, SECOND CROP
M_2, SECOND CROP
M_3, SECOND CROP
Ca_1 Ca_2 Ca_3
K_1 K_2 K_3
2 4 6 8

The analysis of variance of the yields of sudan grass are reported in Tables 10, 11, 12, 13 and 14.

As has been pointed out, each cation exchange level constituted an independent group; M_1, M_2, and M_3 both in the first and second crop.

In each group there were 9 treatments which, for the purpose of analysis of variance, gave 8 combinations. Each treatment was associated with a single degree of freedom.

The error term statistically associated with each treatment has 3 degrees of freedom. In a preliminary analysis of variance each of the 8 error terms were calculated. Since it was suspected that they may not be statistically different from each other a test of homogeneity was carried out. After running Bartlett's test (5), as it is illustrated by Snedecor (46), it was found that there was no evidence of heterogeneity in the various error term mean squares. Therefore, all treatments were tested for significance using the pooled error term as the experimental error.

Besides the mean squares calculated for each treatment comparison as shown in the respective tables, mean squares, associated with other treatment comparisons, were calculated and are listed in Tables 10, 11, 12, 13 and 14.

Table 10

ANALYSIS OF VARIANCE OF SUDAN GRASS YIELDS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS

Source of Variation	D.F.	S.S.	M.S.	F Tests
Unit M_2, First Crop				
Total	35	26.41		
Replications	3	0.24		
(Ca_3-Ca_1)	1	6.10	6.10	13.86**
$(Ca_3-Ca_1+2Ca_2)$	1	1.84	1.84	4.18
(K_3-K_1)	1	3.01	3.01	6.84*
$(K_3+K_1-2K_2)$	1	1.10	1.10	2.50
$(Ca_3-Ca_1)(K_3-K_1)$	1	0.30	0.30	0.68
$(Ca_3+Ca_1-2Ca_2)(K_3-K_1)$	1	0.28	0.28	0.64
$(Ca_3-Ca_1)(K_3+K_1-2K_2)$	1	2.26	2.26	5.14*
$(Ca_3+Ca_1-2Ca_2)(K_3+K_1-2K_2)$	1	0.80	0.80	1.82
Experimental Error	24	10.48	0.44	
Other Comparisons				
(Ca_2-Ca_1)	1	0.00	0.00	-
(Ca_3-Ca_2)	1	5.80	5.80	13.18**
(K_2-K_1)	1	0.00	0.00	-
(K_3-K_2)	1	3.05	3.05	6.85*
$(Ca_2-Ca_1)(K_2-K_1)$	1	0.16	0.16	0.36
$(Ca_2-Ca_1)(K_3-K_2)$	1	1.32	1.32	3.00
$(Ca_3-Ca_2)(K_2-K_1)$	1	0.20	0.20	0.45
$(Ca_3-Ca_2)(K_3-K_2)$	1	2.18	4.95	4.95*

AVERAGE YIELD VALUES - GRAMS PER JAR

	Ca_1	Ca_2	Ca_3	
K_1	1.15	1.77	0.60	1.17
K_2	2.27	2.50	0.88	1.88
K_3	2.55	1.62	1.48	1.88
	1.99	1.96	0.98	

Table 11

ANALYSIS OF VARIANCE OF SUDAN GRASS YIELDS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS

Source of Variation	D.F.	S.S.	M.S.	F Tests
Unit M_3, First Crop				
Total	35	24.91		
Replications	3	1.85		
(Ca_3-Ca_1)	1	13.65	13.65	44.03**
$(Ca_3+Ca_1-2Ca_2)$	1	0.66	0.66	2.13
(K_3-K_1)	1	0.71	0.71	2.29
$(K_3+K_1-2K_2)$	1	0.15	0.15	0.48
$(Ca_3-Ca_1)(K_3-K_1)$	1	0.36	0.36	1.16
$(Ca_3+Ca_1-2Ca_2)(K_3-K_1)$	1	0.05	0.05	0.16
$(Ca_3-Ca_1)(K_3+K_1-2K_2)$	1	0.08	0.08	0.26
$(Ca_3+Ca_1-2Ca_2)(K_3+K_1-2K_2)$	1	0.04	0.04	0.13
Experimental Error	24	7.36	0.31	
Other Comparisons				
(Ca_2-Ca_1)	1	6.51	6.51	21.00**
(Ca_3-Ca_2)	1	1.31	1.31	4.22
(K_2-K_1)	1	0.07	0.07	0.02
(K_3-K_2)	1	0.57	0.57	1.84
$(Ca_2-Ca_1)(K_2-K_1)$	1	0.28	0.28	0.90
$(Ca_2-Ca_1)(K_3-K_2)$	1	0.00	0.00	-
$(Ca_3-Ca_2)(K_2-K_1)$	1	0.00	0.00	-
$(Ca_3-Ca_2)(K_3-K_2)$	1	0.01	0.01	0.03

AVERAGE YIELD VALUES - GRAMS PER JAR

	Ca_1	Ca_2	Ca_3	
K_1	2.50	1.10	0.66	1.41
K_2	2.12	1.25	0.75	0.75
K_3	1.77	0.93	0.50	1.06
	2.13	1.09	0.62	

Table 12

ANALYSIS OF VARIANCE OF SUDAN GRASS YIELDS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS

Source of Variation	D.F.	S.S.	M.S.	F Tests
Unit M_1, Second Crop				
Total	35	14.85		
Replications	3	0.80		
(Ca_3-Ca_1)	1	10.10	10.10	132.89**
$(Ca_3-Ca_1-2Ca_2)$	1	1.49	1.49	19.60**
(K_3-K_1)	1	0.17	0.17	2.24
$(K_3+K_1-2K_2)$	1	0.01	0.01	0.13
$(Ca_3-Ca_1)(K_3-K_1)$	1	0.19	0.19	2.50
$(Ca_3+Ca_1-2Ca_2)(K_3-K_1)$	1	0.19	0.19	2.50
$(Ca_3-Ca_1)(K_3+K_1-2K_2)$	1	0.04	0.04	0.53
$(Ca_3+Ca_1-2Ca_2)(K_3+K_1-2K_2)$	1	0.03	0.03	0.39
Experimental Error	24	1.83	0.076	
Other Comparisons				
(Ca_2-Ca_1)	1	0.30	0.30	3.39
(Ca_3-Ca_1)	1	7.04	7.04	92.63**
(K_2-K_1)	1	0.04	0.04	0.52
(K_3-K_2)	1	0.04	0.04	0.52
$(Ca_2-Ca_1)(K_2-K_1)$	1	0.00	0.00	-
$(Ca_3-Ca_2)(K_3-K_2)$	1	0.00	0.00	-
$(Ca_3-Ca_2)(K_2-K_1)$	1	0.28	0.28	3.68
$(Ca_3-Ca_2)(K_3-K_2)$	1	0.02	0.02	0.26

AVERAGE YIELD VALUES - GRAMS PER JAR

	Ca_1	Ca_2	Ca_3	
K_1	0.20	0.47	1.85	0.84
K_2	0.35	0.54	1.40	0.76
K_3	0.20	0.41	1.41	0.68
	0.25	0.47	1.55	

Table 13

ANALYSIS OF VARIANCE OF SUDAN GRASS YIELDS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS

Source of Variation	D.F.	S.S.	M.S.	F Tests
Unit M_2, Second Crop				
Total	35	177.29		
Replications	3	1.29		
(Ca_3-Ca_1)	1	63.20	63.20	38.07**
$(Ca_3+Ca_1-2Ca_2)$	1	26.14	26.14	15.75**
(K_3-K_1)	1	23.52	23.52	14.17**
$(K_3+K_1-2K_2)$	1	3.90	3.90	2.35
$(Ca_3-Ca_1)(K_3-K_1)$	1	12.27	12.27	7.39*
$(Ca_3+Ca_1-2Ca_2)(K_3-K_1)$	1	7.05	7.05	4.25
$(Ca_3-Ca_1)(K_3-K_1-2K_2)$	1	0.09	0.09	0.05
$(Ca_3+Ca_1-2Ca_2)(K_3+K_1-2K_2)$	1	0.06	0.06	0.04
Experimental Error	24	39.77	1.66	
Other Comparisons				
(Ca_2-Ca_1)	1	1.96	1.96	2.36
(Ca_3-Ca_2)	1	1.04	1.04	1.25
(K_2-K_1)	1	21.90	21.90	13.40**
(K_3-K_2)	1	0.53	0.53	0.36
$(Ca_2-Ca_1)(K_2-K_1)$	1	0.06	0.06	0.07
$(Ca_2-Ca_1)(K_3-K_2)$	1	0.02	0.02	0.01
$(Ca_3-Ca_2)(K_2-K_1)$	1	0.36	0.36	0.43
$(Ca_3-Ca_2)(K_3-K_2)$	1	1.56	1.56	1.87

AVERAGE YIELD VALUES - GRAMS PER JAR

	Ca_1	Ca_2	Ca_3	
K_1	0.86	4.65	2.31	2.58
K_2	2.02	5.45	5.37	4.29
K_3	1.89	5.03	6.81	4.58
	1.59	5.02	4.83	

Table 14

ANALYSIS OF VARIANCE OF SUDAN GRASS YIELDS AS AFFECTED BY PERCENT CALCIUM SATURATION AND POTASSIUM TREATMENTS

Source of Variation	D.F.	S.S.	M.S.	F Tests
Unit M_3, Second Crop				
Total	35	51.28		
Replications	3	6.45		
(Ca_3-Ca_1)	1	6.88	6.88	8.29**
$(Ca_3+Ca_1-2Ca_2)$	1	0.12	0.12	0.14
(K_3-K_1)	1	2.25	2.25	2.71
$(K_3+K_1-2K_2)$	1	13.72	13.72	16.53**
$(Ca_3-Ca_1)(K_3-K_1)$	1	0.08	0.08	0.09
$(Ca_3-Ca_1)(K_3+K_1-2K_2)$	1	1.36	1.36	1.64
$(Ca_3+Ca_1-2Ca_2)(K_3-K_1)$	1	0.25	0.25	0.30
$(Ca_3+Ca_1-2Ca_2)(K_3+K_1-2K_2)$	1	0.35	0.35	0.42
Experimental Error	24	19.82	0.83	
Other Comparisons				
(Ca_2-Ca_1)	1	70.50	70.50	43.46**
(Ca_3-Ca_2)	1	0.21	0.21	0.13
(K_2-K_1)	1	0.11	0.11	0.13
(K_3-K_2)	1	0.04	0.04	-
$(Ca_2-Ca_1)(K_2-K_1)$	1	0.07	0.07	0.04
$(Ca_2-Ca_1)(K_3-K_2)$	1	0.08	0.08	0.06
$(Ca_3-Ca_2)(K_2-K_1)$	1	4.79	4.79	2.88
$(Ca_3-Ca_2)(K_3-K_2)$	1	3.75	3.75	2.26

AVERAGE YIELD VALUES - GRAMS PER JAR

	Ca_1	Ca_2	Ca_3	
K_1	6.66	5.80	5.40	5.95
K_2	7.91	7.30	7.50	7.50
K_3	7.25	6.76	5.71	5.71
	7.27	6.62	6.20	

The significance of the effect of the treatments were determined by means of the F tests at the 5 and 1 percent levels of probability. They are shown with one and two asterisks respectively.

An interpretation of the analysis of variance will be presented under "discussion."

The Relationship of Percent Calcium Saturation and Concentration of Exchangeable Potassium in Soils with the Contents of Calcium and Potassium in the Plant

The results of analysis for the calcium and potassium content in the soil after cropping and the plant materials are reported in Tables 15, 16, 17, and 18 for both the first and second crops.

The contents of exchangeable calcium and potassium in the soil increased in accordance with the initial saturation concentrations (Tables 15 and 17).

In the plant materials the analysis of calcium and potassium reveal that the contents of these two cations have a relationship with the percent calcium saturation and the content of exchangeable potassium in the soil. An examination of the data shown in Tables 16 and 18 reveals the fact that an increase in percent calcium saturation in the soil decreases the calcium uptake by the plants except in case of M_1 group.

The potassium content in the plant material increased as the concentration of exchangeable potassium in the soil is raised.

Table 15

CALCIUM AND POTASSIUM CONTENT IN SOIL AFTER CROPPING

FIRST CROP

Treatment: Ca Saturation	Treatment: K level	Weight Sample	Ca, ppm	Ca, m.e. per 100 grams	Weight Sample	K, ppm	K, m.e. per 100 grams
M_1 level: Cation exchange capacity 5.83 m.e./100 grams.							
Ca_1	1	25.00	228	1.144	20.00	3	0.054
	2	25.00	96	0.480	20.00	20	0.333
	3	25.00	154	0.772	20.00	38	0.655
Ca_2	1	25.00	271	1.356	20.00	6	0.077
	2	25.00	335	1.676	20.00	23	0.310
	3	25.00	314	1.568	20.00	61	0.780
Ca_3	1	25.00	558	2.792	20.00	4	0.051
	2	25.00	478	2.392	20.00	34	0.435
	3	25.00	595	2.976	20.00	61	0.780
M_2 level: Cation exchange capacity 10.85 m.e./100 grams.							
Ca_1	1	25.00	578	2.388	20.00	54	0.690
	2	25.00	500	2.500	20.00	53	0.678
	3	25.00	436	2.180	20.00	66	0.844
Ca_2	1	25.00	702	3.508	20.00	10	0.128
	2	25.00	829	4.144	20.00	41	0.524
	3	25.00		4.092	20.00	78	0.997
Ca_3	1	25.00	818	5.448	20.00	13	0.166
	2	25.00	1089	4.889	20.00	38	0.486
	3	25.00	1042	5.208	20.00	80	1.020
M_3 level: Cation exchange capacity 19.13 m.e./100 grams.							
Ca_1	1	25.00	1009	5.049	20.00	7	0.090
	2	25.00	978	4.890	20.00	142	1.816
	3	25.00	1248	6.240	20.00	212	2.711
Ca_2	1	25.00	1509	7.544	20.00	7	0.090
	2	25.00	1099	5.498	20.00	44	0.563
	3	25.00	1494	7.468	20.00	91	1.936
Ca_3	1	25.00	2163	10.816	20.00	53	0.680
	2	25.00	1861	9.302	20.00	79	1.015
	3	25.00	2094	10.471	20.00	100	1.287

Table 16

CALCIUM AND POTASSIUM CONTENT IN PLANT MATERIALS

FIRST CROP

Treatment: Ca Saturation	Treatment: K level	Sample Weight*	Calcium Percent	Ca, m.e. per 100 grams	Sample Weight*	Potassium Percent	K, m.e. per 100 grams
M_1 level: Total cation exch. capacity 5.83 m.e./100 gms							
Ca_1	1	-	-	-	-	-	-
	2	-	-	-	-	-	-
	3	-	-	-	-	-	-
Ca_2	1	1.00	0.720	36.40	0.50	1.40	35.09
	2	1.00	0.722	36.10	0.50	1.52	38.88
	3	1.00	0.460	23.00	0.50	1.92	49.11
Ca_3	1	1.00	0.568	28.42	0.50	1.28	32.74
	2	1.00	0.526	26.32	0.50	1.64	41.95
	3	1.00	0.368	18.40	0.50	1.82	46.55
M_2 level: Total cation exch. capacity 10.85 m.e./100 gms							
Ca_1	1	1.00	0.938	46.90	0.50	1.38	35.30
	2	1.00	0.864	43.20	0.50	2.20	56.27
	3	1.00	0.774	38.70	0.50	2.32	59.34
Ca_2	1	1.00	0.906	45.30	0.50	1.44	36.83
	2	1.00	0.836	41.80	0.50	1.76	45.02
	3	1.00	0.692	34.60	0.50	1.60	40.92
Ca_3	1	1.00	0.658	32.90	0.50	1.00	25.58
	2	1.00	0.830	41.50	0.50	1.14	29.16
	3	1.00	0.622	31.10	0.50	1.34	34.27
M_3 level: Total cation exch. capacity 19.13 m.e./100 gms							
Ca_1	1	1.50	0.761	57.53	0.50	1.08	27.02
	2	1.50	0.647	48.66	0.50	1.88	48.10
	3	1.50	0.523	39.20	0.50	1.90	48.60
Ca_2	1	1.50	0.662	49.60	0.50	1.02	26.10
	2	1.50	0.625	46.93	0.50	1.40	35.81
	3	1.50	0.217	17.00	0.50	1.38	35.56
Ca_3	1	1.50	0.417	31.33	0.50	1.30	33.25
	2	1.50	0.522	39.20	0.50	1.24	31.72
	3	1.50	0.358	26.87	0.50	1.88	48.10

The sample weights reported are the equivalents to the aliquot used in the analysis.

Table 17

CALCIUM AND POTASSIUM CONTENT IN SOIL AFTER CROPPING

SECOND CROP

Treatment: Ca Saturation	Treatment: K level	Weight Sample	Ca, ppm	Ca, m.e. per 100 grams	Weight Sample	K, ppm	K, m.e. per 100 grams
M_1 level: Cation exchange capacity 5.83 m.e./100 grams.							
Ca_1	1	20.00	140	0.700	20.00	3	0.038
	2	20.00	163	0.815	20.00	30	0.380
	3	20.00	272	1.359	20.00	53	0.678
Ca_2	1	20.00	660	3.300	20.00	3	0.038
	2	20.00	544	2.720	20.00	23	0.319
	3	20.00	606	3.030	20.00	56	0.716
Ca_3	1	20.00	1136	5.630	20.00	4	0.051
	2	20.00	932	4.660	20.00	20	0.256
	3	20.00	1281	6.405	20.00	55	0.709
M_2 level: Cation exchange capacity 10.85 m.e./100 grams.							
Ca_1	1	20.00	606	3.030	20.00	30	0.380
	2	20.00	611	3.105	20.00	29	0.371
	3	20.00	637	3.185	20.00	44	0.561
Ca_2	1	20.00	1126	5.630	20.00	4	0.051
	2	20.00	1320	6.600	20.00	22	0.281
	3	20.00	1344	6.720	20.00	50	0.639
Ca_3	1	20.00	1438	7.690	20.00	4	0.051
	2	20.00	1591	7.955	20.00	18	0.230
	3	20.00	2019	10.095	20.00	46	0.588
M_3 level: Cation exchange capacity 19.13 m.e./100 grams.							
Ca_1	1	20.00	1087	5.435	20.00	29	0.371
	2	20.00	994	4.970	20.00	2	0.026
	3	20.00	1009	5.045	20.00	3	0.038
Ca_2	1	20.00	1942	9.710	20.00	11	0.141
	2	20.00	1700	8.500	20.00	11	0.141
	3	20.00	1911	9.555	20.00	32	0.409
Ca_3	1	20.00	1599	7.495	20.00	46	0.588
	2	20.00	2175	10.875	20.00	56	0.716
	3	20.00	2524	12.620	20.00	110	1.408

Table 18

CALCIUM AND POTASSIUM CONTENT IN PLANT MATERIALS

SECOND CROP

Treatment: Ca Saturation	Treatment: K level	Sample Weight*	Calcium Percent	Ca, m.e. per 100 grams	Sample Weight*	Potassium Percent	K, m.e. per 100 grams
M_1 level: Total cation exch. capacity 5.83 m.e./100 gms							
Ca_1	1	0.40	1.400	28.00	0.18	0.78	19.95
	2	0.40	1.165	23.30	0.05	1.00	25.57
	3	1.00	1.730	34.50	0.30	1.70	43.48
Ca_2	1	0.50	1.088	54.40	0.50	0.66	16.88
	2	1.50	0.517	38.83	0.50	1.58	40.41
	3	1.20	0.596	35.72	0.30	1.97	50.39
Ca_3	1	1.20	0.768	46.09	0.50	1.20	30.69
	2	1.20	0.809	48.54	0.50	1.52	38.88
	3	1.20	0.681	40.78	0.50	1.56	39.90
M_2 level: Total cation exch. capacity 10.85 m.e./100 gms							
Ca_1	1	1.00	1.088	54.40	0.50	1.46	37.34
	2	1.20	0.815	49.19	0.50	2.16	55.25
	3	1.50	0.667	50.49	0.50	2.20	56.27
Ca_2	1	2.50	0.427	53.44	0.50	1.44	36.80
	2	2.50	0.412	51.26	0.50	2.28	58.32
	3	2.50	0.192	24.80	0.50	2.52	64.46
Ca_3	1	1.00	0.660	33.00	0.50	1.24	31.72
	2	2.00	0.485	48.46	0.50	1.82	46.55
	3	2.00	0.222	27.20	0.50	2.20	56.27
M_3 level: Total cation exch. capacity 19.13 m.e./100 gms							
Ca_1	1	2.50	0.492	61.82	0.50	1.02	26.10
	2	2.50	0.347	43.49	0.50	2.48	63.43
	3	2.50	0.094	11.80	0.50	2.84	72.64
Ca_2	1	2.50	0.281	35.10	0.50	1.14	29.16
	2	2.50	0.630	78.80	0.50	1.74	44.51
	3	2.50	0.094	11.80	0.50	1.80	46.04
Ca_3	1	2.50	0.243	30.44	0.50	1.86	47.58
	2	2.50	0.315	39.46	0.50	2.20	56.27
	3	2.50	0.157	19.57	0.50	2.24	57.30

The Relationship Between the Exchangeable Forms of the Ca:K Ratio in the Soil and the Ca:K Ratio in the Aerial Plant Tissue

The Ca:K ratios in soils and in the plant materials, in terms of m.e., were calculated from the results reported in Tables 15, 16, 17, and 18.

The relation of the Ca:K ratios is shown in a scatter diagram in Figure VI. A preliminary correlation analysis gave a coefficient of $r = +0.18$ which is not significant although it suggests that there is a trend which is directly proportional. The information in Figure VI was taken without regard to cation exchange groups, or the calcium saturation level, in order to have a larger number of samples.

The Ca:K ratio in the soil varies from 1.44 to 34.59 while the Ca:K ratio in the plant tissue ranges from 0.26 to 2.36. In general, the higher the Ca:K ratio of soils the higher the yields. The yields were very low where the Ca:K ratio in the soil was less than 2. In fact, no yield was obtained in the first crop in unit M_1 at 40% calcium saturation where the Ca:K ratio was less than 2.00. With Ca:K ratios in the soil above 30 there was no further increase in yield, and in some cases a considerable decrease in yield occurred.

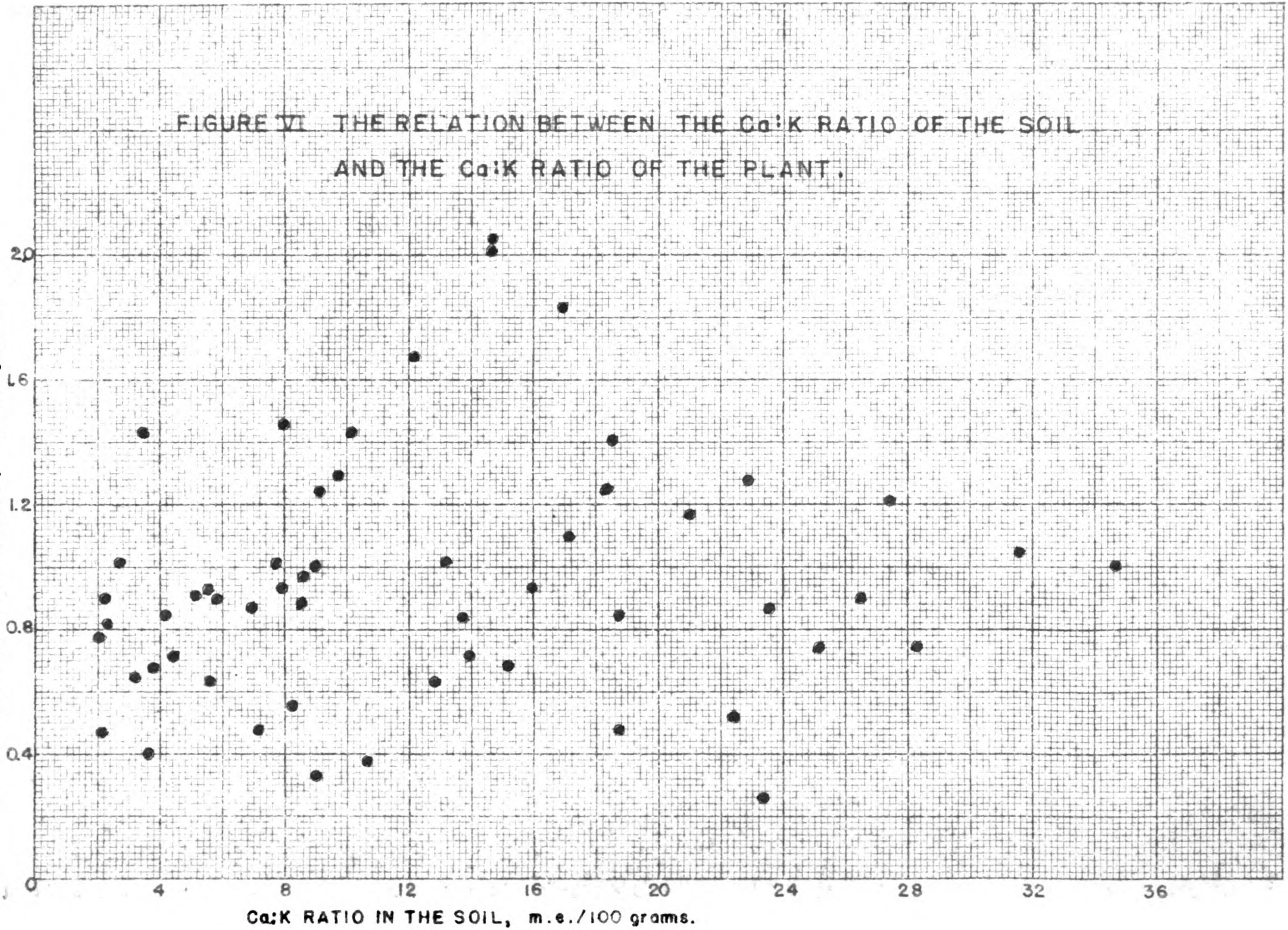


FIGURE VI THE RELATION BETWEEN THE Ca:K RATIO OF THE SOIL AND THE Ca:K RATIO OF THE PLANT.

Discussion

For the most part the results obtained in this investigation confirm current hypotheses and theories relative to cation exchange and the effect of degree of calcium saturation on the release and uptake of exchangeable calcium and potassium by plants. The complexity of the problem of plant nutrition is clearly indicated.

The non-additive effect of the organic and inorganic fractions on the cation exchange capacity of the soil is due to adsorption, although it cannot be stated which is the adsorbent and which is the adsorbate. It may well be a process of "mutual sorption." Obviously the extent of mutuality is not the same as shown by the curves in Figure II which do not correspond to those of an equilateral hyperbole where the distance from a given point in the coordinates is the same as the corresponding points in the curve. The nature of the curves indicate that the peat is playing a major role in the effect of "mutual sorption" as is revealed by the measurements of cation exchange (Table 5).

The process of "mutual sorption" which may involve a mechanism of molecular orientation and polar adsorption, resulting in a decrease in the specific surface, would cause a decrease in cation exchange capacity. The explanations offered are hypothetical and need to be tested further under varying conditions. Similar suggestions have been proposed by other workers (27).

It was found that the higher the percent calcium saturation the greater the adsorption of potassium (from KCl) irrespective of symmetry concentration of potassium added. These results are in agreement with those reported by Peech and Bradfield (41) who showed that potassium supplied as a neutral salt replaces calcium more easily than hydrogen from the exchange complex and that the adsorption of potassium from solution increased with an increase in the percent calcium saturation. This cation exchange reaction is in turn dependent upon the energy of adsorption of the cations involved (12).

The growth of plants, in general, increases with an increase in percent calcium saturation (8) as is shown in Figure IIIa. However, when the total concentration of salts in solution exceeded a certain value, 100×10^{-5} Ohms^{-1}, as determined by conductivity measurements the growth of sudan grass decreased considerably. This indicates that some of the plant nutrients are taken directly from the soil solution (42). If such is the case, then the concentration of salts near the root membranes becomes an important factor in the uptake of cations. It is apparent that the significance of osmosis and Donnan equilibrium cannot be overlooked (32).

At 40 percent calcium saturation no growth was recorded in group M_1. The scant growth obtained in the M_3 group, even at 40 percent calcium saturation, may have been due to additional nitrogen released by the peat. There is also the possibility that more potassium was released where peat was added (24) as shown in Figures IIIa, IVa, IVc, IVe.

In the second crop it is of interest to note that in the M_1 group, maximum growth occurred at 100 percent calcium saturation while in groups M_2 and M_3 best growth occurred at 70% calcium saturation. The fact that maximum growth occurred at 70% calcium saturation in groups M_2 and M_3 suggests that other factors such as the supply of nitrogen, phosphorus, or probably minor elements resulted in an improvement in fertility (28, 48). In other words, sudan grass made its best growth at 70% calcium saturation when the other nutrient elements in the soil were properly balanced. These results are in accord with those obtained by Allaway (2).

Potassium additions did not have an appreciable effect upon the growth of sudan grass (Figures IIIb and IVd). This may be explained on the basis of "selective adsorption" of this plant species. Any plant may exhibit "selective adsorption" (10). In view of these results sudan grass is a poor indicator of potassium deficiencies in soils.

As shown in Figure Va the dry matter yield of sudan varied with changes in percent calcium saturation although the effect varied in each one of the independent groups.

According to Figure Va, and the analysis of variance data presented in Tables 10 and 11, it is observed that in group M_2 there is a highly significant difference among the calcium saturation treatments. The response is, $Ca_1 > Ca_2$; $Ca_2 > Ca_3$ but $Ca_2 \cong Ca_1$. The best yield corresponds to 40% calcium saturation.

In case of the potassium treatments $K_1 < K_2 \cong K_3$. The best being K_2 and K_3 levels.

In group M_3 (Table 11) the difference in response to the various percent calcium saturation treatments is highly significant in most cases. $Ca_1 > Ca_2$ and Ca_3, but $Ca_2 \cong Ca_3$. The maximum yield is associated with 40% calcium saturation.

The yield response to potassium is not significant at any level. $K_1 \cong K_2 \cong K_3$.

In the second crop at the M_1 level (Table 12) the percent calcium saturation affected the yield of sudan grass significantly, $Ca_1 < Ca_3$; $Ca_2 < Ca_3$ but $Ca_1 \cong Ca_2$. The maximum yield corresponds to 100% calcium saturation.

The response of yield to potassium treatments is not significant at any level. It means $K_1 \cong K_2 \cong K_3$.

In group M_2 (Table 13) the yield response to percent calcium saturation is highly significant only in the comparison of the extreme levels, i.e., $Ca_3 > Ca_1$ but $Ca_2 \cong Ca_1$ and $Ca_3 \cong Ca_2$. The maximum yield corresponded to 100% calcium saturation. As is shown by the response curves the potassium treatments affected yield significantly: $K_3 > K_1$; $K_2 > K_1$; but $K_3 \cong K_2$. The highest yield was obtained with K_3 level.

In group M_3 (Table 14) the yield response to calcium saturation is highly significant for the comparison $Ca_3 < Ca_1$; $Ca_2 < Ca_1$; but $Ca_3 \cong Ca_2$ therefore the best yield corresponds to treatments Ca_1, i.e., 40% calcium saturation.

The response to potassium is not significant at any level. Essentially, $K_1 \cong K_2 \cong K_3$.

Thus, in the first crop maximum yields were obtained at 40 percent calcium saturation but were not affected by the potassium treatments.

In the second crop, the best yields correspond to 100 percent calcium saturation except in group M_3 which equaled those with 40 percent calcium saturation. Again, the potassium treatments did not affect yields significantly.

The significance of either the $(K_3 + K_1 - 2K_2)$ or $(Ca_3 + Ca_1 - 2Ca_2)$ comparisons means that the response curves of potassium and calcium deviate considerably from a straight line. The significance of $(Ca_3 - Ca_1)$ $(K_3 + K_1 - 2K_2)$ indicates that the quantities which are the products of these two expressions vary over the replications by an amount which is not due to chance.

Finally, the non-significance of the interaction of the quadratic response of calcium and the linear response of potassium would mean that the experimental values obtained do not differ by quantities different from those which are due to chance.

The results showing that there is a relationship between the percent calcium saturation and potassium content in the soil with the content of calcium and potassium in the aerial plant tissues is important and shows that the concentration of the exchangeable cations in the soil colloids, other factors being equal, influences the chemical composition of the plant tissues. The fact that an increase in percent calcium saturation in the soil corresponds to a decrease in calcium uptake is not due necessarily to a direct effect of percent calcium saturation. Rather this effect may be due to an antagonistic effect of potassium (10), the ionic activity of which is enhanced significantly by the increase in percent calcium saturation (29) resulting in a relatively higher availability of potassium. These results are in accordance with the theory that the uptake of cations by plants may take place by a process of contact exchange (20) in which the adsorption of the exchangeable cations in question plays an important role (12). An additional support to these findings are the interpretations offered by Peech and Bradfield (41) who state that the hydrolytic release of potassium at a given percent of potassium saturation will increase rapidly with an increase in percent calcium saturation.

The study of the relationships of the Ca:K ratios in soils with the Ca:K ratios in plants has received a considerable amount of investigation (6, 30, 42) to determine if a definite relationship exists. So far, a definite relationship has not been found. A correlation analysis of the soil Ca:K ratios versus the Ca:K ratios in the plants was made from the analytical data obtained from the first crop (Table 15). A positive correlation was found ($r = +0.46$) which is significant at the 5% level. When the analytical results shown in Table 17 were included with those calculated from Table 15, a statistical analysis failed to give a significant positive correlation.

The failure to find a significant correlation does not mean that there is no relation at all, for it is found that perhaps a trend may exist (Figure VI).

In general, when calcium is higher than potassium in the soil, potassium will be dominant in the plant. This is attributed to a characteristic of ionic selectivity by the plants (10). This is why the Ca:K ratios in the soil has little relationship to the Ca:K ratios in plants. Similar results have been reported by other workers (6, 30).

The fact that there is not a close relationship between yields and the Ca:K ratio in soils is in agreement with results reported by other workers (6). However, it was observed in the studies herein reported that yield decreases where the Ca:K ratios are above 30 and no yield was recorded when ratios were below 2. The mean of the soil Ca:K ratios associated with the highest yields was 15.70. Bear and Toth (6) found that a Ca:K ratio of 13 gave the greatest yield of alfalfa. These results would indicate that each plant species does not give maximum yield at the same Ca:K ratio in the soil even though the other factors of growth are at an optimum.

Summary and Conclusions

This investigation was carried out with the purpose of studying the effect of cation exchange capacity and percent calcium saturation on the release and uptake of calcium and potassium and the effect of these factors on growth and yield of sudan grass.

The methods of investigation used embraced two phases: chemical investigations and greenhouse experiments.

The laboratory studies were made to determine the relationship existing between the individual cation exchange capacities of the organic and inorganic fractions and the cation exchange capacity of their mixture. It was found that the property of cation exchange capacity is not additive: the cation exchange capacity of the mixture is less than the cation exchange capacity of the individual components.

In a laboratory experiment a hydrogen saturated soil was treated with calcium at various percentage saturation levels with respect to cation exchange capacity and potassium added from potassium chloride at different symmetry concentrations. It was found that the adsorption of potassium through exchange depends on percent calcium saturation although above 75% calcium saturation no significant variations in adsorption were noticed.

In the greenhouse experiment gray-brown podzolic soil low in cation exchange capacity, acid in reaction, and low in fertility was used.

Three cation exchange capacity levels were maintained with peat. In each one of the three groups three calcium saturation levels were established corresponding to 40, 70, 100 percent. Potassium was added in amounts corresponding to 0, 250, and 500 pounds per acre to the jars in order to have each one of the calcium saturation levels treated with potassium at all levels and in all combinations with the calcium saturation treatments.

The effect of percent calcium saturation upon growth was found to depend on the levels of cation exchange capacity. In the first crop the M_1 group (C.E.C.* = 5.83 m.e./100 grams) at 40 percent calcium saturation gave no growth. At 70 and 100 percent calcium saturation levels growth was practically the same.

In M_2 group (C.E.C. = 10.85 m.e./100 grams) at 40 and 70 percent calcium saturation growth was similar and higher than that corresponding to 100 percent calcium saturation.

In group M_3 (C.E.C. = 19.13 m.e./100 grams) a decrease in growth corresponds to an increase in percent calcium saturation.

Potassium treatments did not seem to have a noticeable effect upon growth.

In the second crop, group M_1 growth was directly related to percent calcium saturation while in group M_2 and M_3 the maximum growth occurred at 70 percent calcium saturation.

Again, potassium did not affect growth noticeably. On the basis of these results it may be stated that

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* C.E.C. refers to cation exchange capacity.

sudan grass is a poor indicator of the effect of potassium on growth.

Yield data from the M_1, M_2, and M_3 groups in both crops indicate that the effect of percent calcium saturation on yields depends on the cation exchange capacity of the soil.

In the first crop, M_1 group, the yield at 40 percent calcium saturation is zero while at 70 and 100 percent calcium saturation the yield was almost the same.

Potassium treatments at K_2 and K_3 levels increased yield over K_1 level.

In the M_3 group a decrease in yield resulted as percent calcium saturation was increased. Yields did not respond to potassium additions.

In the second crop, yields were higher than in the first crop as a result of the improvement in the supply of N,P, and probably minor elements.

In group M_1 yields at 40 percent calcium saturation were almost zero but increased with an increase in percent calcium saturation.

Potassium had no effect on yield.

At 40 and 70 percent calcium saturations, in the M_2 group, the yields were higher than at 100 percent calcium saturation.

An increase in yield was obtained as the supply of potassium increased.

In group M_3, yield decreased as the percent calcium saturation was increased.

The response of yield to potassium was significant at the K_2 level. In K_1 and K_3 levels, yields were similar.

The conclusions presented, on the effect of percent calcium saturation and potassium treatments, on yields are drawn from interpretations based on the analysis of variance.

The analytical results, of calcium and potassium content of the soil and aerial plant tissues, indicate that as percent calcium saturation was increased in the soil, calcium uptake by the plants decreases.

The contents of potassium in plant tissues, within the limits of concentrations used, increased with an increase of exchangeable potassium in soils.

The Ca:K ratio in the soil varied from 1.44 to 34.59 while the Ca:K ratio in aerial sudan grass tissues ranged from 0.26 to 2.36.

The maximum yields of sudan grass were associated with a mean in soil Ca:K ratios of 15.76. Significant decreases in yield were recorded whenever the Ca:K ratio in soil was less than 2 or exceeded 30. No significant correlation was found between the soil Ca:K ratios and the Ca:K ratios of the plants.

The theoretical aspects of the problem are presented in the "Review of the Literature," and the discussion, presented in each section, is based on the results obtained in the experiments reported.

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