THE FIXATION AND RELEASE OF POTASSIUM

IN FIVE EASTERN OKLAHOMA SOILS

By

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I. INTRODUCTION

The mechanism of potassium fixation and release in soils has been the subject of much study in recent years. The literature on this subject presents a number of reports that often appear contradictory in nature. Results of investigations in various soil and climatic conditions often do not agree with reports of investigations in other similar situations.

The complex nature of the systems being investigated in combination with difficulties of methods of measurement contribute much to the confusion on this subject. Soils are dynamic systems, ever changing in physical, chemical, and biological characteristics during the period of study. Efforts to stabilize or change the dynamic nature of soil systems in order to standardize measurement of these properties often result in reducing the value of these investigations for applied practical problems.

A systematic long-time study has been instituted to determine the status of the potassium ion in representative Oklahoma soils.

Harper (18)* showed that the soils most likely to be deficient in potassium for crop production in Oklahoma are principally in the eastern one third of the state.

A number of field experiments carried out during successive years in eastern Oklahoma (10) showed decreasing response to a constant amount of potassium applied annually, indicating a build-up of potassium in

* Figures in parenthesis refer to "Literature Cited."

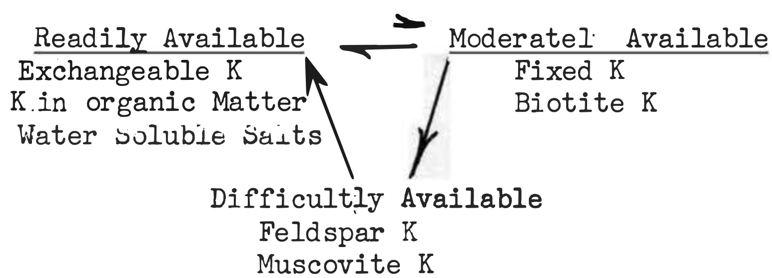
the soil resulting from the continued application of potassium as fertilizer to preceding crops.

The study reported herein of the fixation and release of potassium in several eastern Oklahoma soils was undertaken with the objective of obtaining additional information on factors affecting potassium status of those soils.

II. REVIEW OF LITERATURE

Many concepts have been proposed to characterize the forms of potassium available to plants in the soil. Those suggested by Wood and De Turk (51) are the most commonly accepted at present. These workers propose an equilibrium in the status of the various forms of soil potassium in the following equation: I Primary mineral K $\rightarrow$ II Fixed potassium (Acid insoluble Acid soluble) $\rightleftharpoons$ III Replaceable K $\rightleftharpoons$ IV Water soluble K. Groups III and IV are generally assumed to be available to most common plants, whereas groups I and II are apparently available only to a few specific plants.

Attoe and Truog (1) suggested a similar scheme graphically expressed as follows:



They maintained that the readily available form represented 1 percent of the total potassium in soils, the moderately available form 2 percent of the total potassium in the soil, and the difficultly available form comprised 97 percent of the total potassium in soil. The direction of transformation for balancing this equilibrium depends upon the relative concentration of each form. Upsetting the equilibrium by removal of the readily available forms will cause a shift toward the depleted portion of the scheme in order to re-establish the potassium equilibrium.

Barshad (4) postulated that replaceability of adsorbed cations is dependent upon the cation accessibility. Two possible systems were proposed:

(a) Cations in an expanding type layered lattice are replaceable by any kind of cation.

(b) Cations in a contracted type layered lattice are replaceable only by those cations that when adsorbed, cause the layers of the crystal lattice to expand, eventually exposing even the innermost layers.

Having specifically the potassium and ammonium ions in mind, Barshad proposed the following:

(a) Non replaceable cations: Cations resisting replacement during any kind of base-exchange reaction.

(b) Fixed cations: Cations present in a mineral with a contracted type layered lattice resisting replacement by cations that are unable to expand the crystal lattice.

Because of the association between soil texture and fertility level of soils, it is of interest to note which particle size fraction contributes most toward the supply of potassium in soils.

Pratt (39) calculated the percentage distribution of potassium release from several Iowa soils. Among the various fractions, the clay sized fractions contributed 60 percent and the coarser fractions 40 percent of the whole soil.

Merwin and Peech (33), studying representative soils of northeastern United States, found that, except for the Gloucester soil series, the sand fraction contributed little to the total amount of potassium released. The silt fraction contributed from 15 to 51 percent of the total, while the clay fraction contributed 40 to 83 percent of the total potassium released.

Kelly and Jenny (23) noted an increase in base exchange capacity when feldspars, micas, and soil colloids were ground below a size of one micron.

De Turk, et al. (13) found that various soil fractions of a size below one micron all possessed the ability to fix potassium.

Various clay minerals appear to influence the ability of a soil to fix potassium. While studying California soils in which vermiculite was found, Barshad (4) showed that mineral to have about an equal capacity for fixing the ammonium and potassium ion. Coleman, et al. (12) noted that the vermiculite found in several North Carolina soils exhibited much the same characteristics as those noted by Barshad (4).

Wear and White (50) found an inverse relationship between the amount of potassium in the original mineral structure and the relative volume of swelling of one gram of clay when hydrated. When a sample of Bentonite was hydrated, the swelling volume was very high. When a sample of Illite was hydrated the swelling volume was very low. A direct relationship appeared to exist between a clay mineral's relative swelling volume and its ability to fix potassium.

Raney and Hoover (40) applied equivalent amounts of soluble potassium to a Montmorillonitic and Kaolinitic soil. After a period of moist storage, the soils were analyzed for avaliable potassium. The Montmorillonitic soil fixed large amounts of potassium, whereas the Kaolinitic soil exhibited an insignificant amount of potassium fixation.

Ayers and Hagihara (3) found that Hawaiian soils having a one-to-one lattice type clay mineral did not fix potassium supplied as potassium chloride.

Stanford (43) found Illite to be capable of fixing potassium under moist conditions as well as upon drying, while minerals having an expanding type lattice fixed potassium only upon drying.

Joffe and Kolodny (22) noted that only the crystalline clay colloids having definite lattice structure can fix potassium. Synthetic amorphous alumino-silicates having a very high base exchange capacity failed to fix potassium.

Grim (16) reviewed the concepts advanced by many workers who have studied the clay minerals commonly encountered in soil research. Taking cognizance of the fact that the structural diagrams presented for the principal clay minerals found in soils are seldom that ideal under field conditions, reports on the activity of a specific cation in relation to these minerals can be divergent without being in error.

Attoe (2) found that drying at room temperatures of soils low in exchangeable potassium resulted in an increase of exchangeable potassium from 4 percent to 90 percent of that present in the moist soil in nine of ten soils tested. When these same soils were fertilized with potassium and stored in a moist condition for two months, fixation of the applied potassium occurred in eight of the ten soils treated. When these soils were dried at room temperatures, all ten soils fixed potassium in amounts ranging from 11 percent to 52 percent of the amounts added. The amount of potassium fixed was inversely related to the moisture content of the soils after drying.

Bray and De Turk (8) found a release of potassium from the non-replaceable form to occur under moist storage conditions when the original exchangeable potassium had been removed prior to storage. Without removal of the exchangeable potassium, little or no potassium release could be found. When the exchangeable fraction was increased by soluble potassium salt additions, a portion of this added potassium appeared to have been converted to nonreplaceable forms. Heating the soils to 200° C. tended to allow a fixation or release to be noted, depending upon the direction in which the equilibrium forces were moving at the beginning of heat treatment.

Joffe and Kolodny (22) found the soils they studied to have a maximum amount of potassium fixed at 200° C. Raising the temperature above 200° C. tended to cause a release of potassium. At a temperature of 550° C. these soils completely lost their capacity to fix potassium.

Kolterman and Truog (24) found that heating soils to 500° C. for two hours did not result in breakdown of primary potassium minerals. These workers found that the potassium which was released at this temperature originated from the fixed portion of the soil potassium if the replaceable potassium had been removed by ammonium acetate extraction before the soil was heated. Not all of this fixed potassium could be removed by one heating and subsequent ammonium acetate leaching. The results obtained indicated that an equilibrium state had been reached, since considerable amounts of nonexchangeable potassium were released upon retreatment. The exchangeable portion of the potassium released by heating had to be removed before any additional release from the nonexchangeable form could be effected by heating to 500° C.

Stanford and Pierre (42) while studying ammonium-potassium fixation relationships in Iowa soils noted that there could be a fixation of potassium under moist conditions in some soils.

York, et al.(52) upon storing samples of a Mardin soil under moist conditions found there was a fixation of potassium that was independent of that induced by drying. This effect was noted on potassium fertilized samples as well as nonfertilized samples.

Fine, et al. (14) concluded that most soils tend to liberate fixed potassium upon freezing, but a Miami soil and a Carrington soil studied appeared to fix potassium upon freezing.

Attoe (2) suggested that freezing and thawing parallels the action of wetting and drying processes in relation to soil potassium. No specific data were presented by Attoe in this paper to support his theory, however.

The presence of hydrogen and calcium ions in soils greatly modifies the activity of the potassium ion.

Martin, et al. (27) found that some soils lost their ability to fix potassium when treated with hydrogen. They suggested that certain cations can pass from a loosely held state to a strongly held state thereby occupying positions normally available to potassium ions.

Volk (49) found that certain soils completely lose their ability to fix potassium when leached with acid. Volk attributes this to an alteration in the fixation complex of the soil.

York, et al. (52) found that acid-leached Mardin soil lost the ability to fix potassium, but when this acid treated soil was limed, the potassium fixing power was restored.

Attoe (2) limed a potassium fertilized Spencer soil and found an increase in potassium fixation under moist storage conditions. Upon drying, a further fixation of potassium was noted. Attoe suggests that two types of fixation are active. One type, which proceeds in a moist soil, is increased by liming and fixes potassium in a form which is fairly soluble in 0.5 normal hydrochloric acid. The second type, which proceeds only on drying, is independent of soil pH, and fixes potassium in a form which is quite resistant to extraction with 0.5 normal hydrochloric acid.

McLean and Marshall (30) found the ionic activity of potassium to be greater in a potassium-calcium system than in a potassium-hydrogen system as determined with clay membranes. In a later paper, McLean (31) concluded that sodium, potassium, and calcium ions mutually interact with each other in a clay membrane system such that varying the concentration of one of these cations exerts a profound effect upon the ionic activities of the other two ions.

As reported by Mehlich and Reed (32) the complementary ion effect is pronounced between sodium and potassium when these cations are intimately mixed; however, localized placement of these ions, not in a homogenous solution, results in their independent action, and very little substitution.

York, et al. (53) found sodium effective in overcoming potassium-deficiency symptoms noted in alfalfa grown in a Mardin soil and reasoned that sodium was able to substitute, in part, for the potassium requirement of alfalfa.

Pierre and Allaway (37) observed marked potassium deficiencies to occur in some crops grown on high-lime soils of Iowa, although the exchangeable potassium content was higher in these soils than was found to be optimum for similar crop growth on associated soils having less free lime in the soil profile.

Lynd and Turk (26) found that liming an acid sandy soil could suppress the uptake of potassium by plants growing in this soil to the point where these plants showed distinct potassium deficiency symptoms.

Van Itallie (48) presented evidence that a varied rate of application of calcium, magnesium, sodium, and potassium ions to a soil considerably altered the amounts of these ions found within plants grown in this soil; however, the sum of these four cations within the plants remained approximately constant ranging from 182.5 to 215 m. e.. Van Itallie concluded that in this experiment the mutual replacement of the cations in the plant was nearly equivalent. York et al. (53) found their data to be in agreement with that of Van Itallie.

Attention is drawn to the effect of certain anions upon the potassium fixation phenomenon of soils. De Turk et al. (13) found the amount of added potassium fixed by a Tama soil to be nearly doubled when supplied as potassium phosphate over that supplied as potassium chloride.

Ayers and Hagihara (3) in studying several Hawaiian soils found little potassium fixation to occur when potassium was added in the form of potassium chloride, considerable fixation with potassium sulfate, and a marked fixation with potassium phosphate.

Truog and Jones (47) suggested that fixation of applied potassium could be minimized by addition of organic matter. Tam and Magistad (44) associated an increase in available potassium in a soil under field conditions with the breakdown of previously incorporated organic matter.

Blume and Purvis (6) suggested that the inverse relationship between the fixed potassium and water soluble potassium fraction observed could be attributed to microbiological action in the soils studied.

McCalla (28) found various soil bacteria possessed a cation absorbtion capacity ranging from 35 to 57 m. e. per 100 grams of bacteria and proposed that this absorbtion is purely a physico-chemical phenomena since equivalent amounts of dead bacteria showed essentially the same adsorbative capacity. Sodium and potassium ions were not absorbed to any great extent but remained exchangeable. In a later paper, McCalla (29) proposed that bacteria may obtain their mineral needs by contact exchange of adsorbed ions between the bacterium and clay particles, with a series of equilibrium reactions occurring between the soil colloid and the bacteria.

Hurwitz and Batchelor (20) reported that Wooster silt loam which received organic amendments fixed as much as 200 pounds per acre of potassium. This fixation they attributed to microbiological action, ignoring the possibility of an inorganic fixing mechanism within the system.

Soil aeration and its relation to the uptake of potassium by plants has been studied. Lawton (25) found that restricted aeration caused by either soil compaction or excessive moisture resulted in a serious repression of potassium uptake by corn plants growing in Clarion and Clyde soils. Forced aeration resulted in a marked increase in the potassium uptake by the corn plants.

Peterson (36) in his extensive review of the work on aeration and plant growth found evidence of the essential role that proper aeration plays in potassium utilization.

Hoagland and Arnon (19) point out that roots have to expend energy to absorb nutrients against a pressure gradient induced by the ions themselves. These workers found the potassium ion to be markedly affected by the oxygen status of the soil.

Soil and atmospheric temperatures affect a plant's ability to effect an uptake of nutrients from the soil. Belehradek (5) proposed that the rate of biological processes generally increases on heating and decreases on cooling within the limits of the biokinetic temperatures. Temperature changes within the biokinetic zone produce changes in chemical, physical, and morphological properties of organisms.

Jenny (21) presents evidence in support of his theory that plant roots in contact with potassium clays can exchange hydrogen ions on their surfaces for potassium ions on the clay particle.

Breazeale et al. (9) found that by attaching the negative lead of an electropode to a plant and attaching the positive lead to the conductive container filled with the nutrient solution, the uptake of potassium at its respective potential is markedly increased.

III. SOILS USED IN INCUBATION, GREENHOUSE AND FIELD STUDIES

Eufaula Sand

The Eufaula series (15) includes light-colored, acid, deep, loose sands of the drier zone of Red and Yellow Podzolic soils. The series differs from Stidham and Nimrod in having no distinctly loamy subsoil, or heavier layer, to a depth of more than three feet. Topography is upland, nearly level, slopes rarely being over five percent. Drainage is rapid, mostly internal. Native vegetation is post oak, blackjack and hickory. These soils are low in native fertility and suceptible to serious wind erosion and loss of nutrients by leaching when cleared. Mainly used for pastured woodland though some areas have been cleared and planted to peanuts, cotton and corn. These soils respond to intensive soil management practices.

A soil sample of this series was taken from a field ten miles south of Bristow, Creek County, Oklahoma.

Bowie Sandy Loam

The Bowie series (11) are Yellow Podzolic soils having friable subsoils that are yellow in the upper part but mottled red in the lower portions. The parent materials are acid sandy materials of the Gulf Coastal Plain. Topography is nearly level to gently rolling with a slope of one to four percent. External drainage is slow to rapid. Internal drainage is moderate. Native vegetation is mainly post oak and blackjack. The fertility level is low, but these soils respond very well to good soil management practices. Cotton, corn, peanuts and vegetables are the principal crops grown.

A soil sample of the Bowie series was taken from a field near Bentley, Atoka County, Oklahoma.

Darnell Sandy Loam

The Darnell series (15) are forested lithosols developed on noncalcareous reddish sandstones in a broad transition zone between the zones of Red and Yellow Podzolic and Reddish Prairie soils. Topography is erosional upland with gradients up to fifteen percent. Surface and internal drainage is rapid. Native vegetation is scrub forest of blackjack and post oak and is used mainly as woodland pastures of low carrying capacity. Though shallow and erosive in nature, these soils respond to good soil management practices. Permanent pastures of adapted grass and legume combinations having a high carrying capacity can be established and maintained.

A soil sample of the Darnell series was taken from an untreated field on the Coalgate Pasture Fertility Experiment Station located near Coalgate, Coal County, Oklahoma.

Parsons Silt Loam

The Parsons series (15) includes light colored Planosols of the Prairie and Reddish-Prairie soil zones, developed from noncalcareous gray and brown shales. Topography is nearly level to moderately sloping, ranging from one to five percent. Surface drainage is medium to slow. The permeability is slow and internal drainage is poor. Native vegetation is tall prairie grasses, chiefly bluestems. Some of the land is left to its original grass cover which is cut for hay. Oats, wheat and sorghums are the principal cultivated crops. Coupled with low fertility is a poor physical condition, making these soils difficult to manage. Crop yields are uncertain and erratic.

A soil sample of the Parsons series was taken from a field six miles southeast of Checotah, McIntosh County, Oklahoma.

Renfrow Loam

The Renfrow series (15) are Reddish Prairie soils developed from weakly calcareous clayey Red Beds. Topography is undulating with a slope of two to seven percent. Surface drainage is moderate to rapid and internal drainage is very slow. Native vegetation is tall prairie grasses. Large areas are cultivated and planted to wheat, oats and sudan grass. Where slopes are steep, native vegetation is often cut for hay.

These soils are moderately fertile and respond to good soil management practices.

A soil sample of the Renfrow series was taken from a field seven miles east of Stillwater in Payne County, Oklahoma.

The soils sampled were thoroughly mixed and passed through a $\frac{1}{4}$ inch mesh screen to provide a homogenous source of material for the incubation and greenhouse studies which were performed on the five soil series previously described.

IV. EXPERIMENTAL PROCEDURES

INCUBATION STUDIES

The objective of this study was to determine the amounts and rates of potassium release and fixation as a result of alternate freezing and thawing and wetting and drying in five soils that had received various chemical treatments.

The three soil treatments employed in this study were as follows:

1. Soil incubated as it was taken from the field with no prior chemical treatment.

2. Exchange capacity of the soil saturated with hydrogen.

3. Exchange capacity of the soil saturated with calcium.

Soils were hydrogen saturated by leaching 100 gram portions of each soil used in the experiment with 500 ml. of 0.1 N hydrochloric acid and the excess hydrogen removed by passing a sufficient volume of distilled water through the soil until no free chloride was indicated in the leachate.

Soils were calcium saturated by adding an amount of calcium equivalent to the exchange capacity to each soil in the form of calcium oxide.

Three hundred grams of the treated and untreated soils from each series were weighed into wide-mouth pint mason jars and brought to a moisture content equal to twice the moisture equivalent of the particular soil. These jars were then sealed with a vapor tight lid.

A sufficient number of soils were prepared to have triplicate samples of each soil treatment available for the freezing and thawing and wetting and drying phases of the study.

The chemically treated soils previously described were divided into two groups. The first group of soils was frozen for seventy-two hours at -26° C., and then allowed to thaw for seventy-two hours at room temperature. The lids were removed from the jars, and a weight of moist soil equivalent to fifty grams dry soil was removed for analysis. The lids were replaced and the samples were then ready to begin the next freezing and thawing cycle.

A number of jars were selected to be weighed at the end of each cycle. The calculated soil moisture weights remained constant from cycle to cycle, indicating that the seals remained vapor tight and no loss in soil moisture could be detected.

The second group of soils were moistened, sealed and allowed to stand for seventy-two hours at room temperature. The lids were then removed and the jars placed in an oven and the soil dried for seventy-two hours at 105° C. The jars were removed and allowed to cool to room temperature. Fifty grams of soil were removed for analysis. The remaining soil was brought up to the original moisture content and the lids replaced. The samples were then started on the next wetting and drying cycle. Available potassium and pH were determined on each sample taken and the results recorded in Tables 2, 3, 4, 5, and 6.

Samples were analyzed at the end of the first, second, third, fourth and eighth cycles. The values reported in Tables 2, 3, 4, 5, and 6 represent the mean of three replications, on the Eufaula, Bowie, Darnell, Parsons and Renfrow soils.

Exchangeable potassium as used throughout this report is that potassium which is removed from a soil by extraction with neutral normal ammonium acetate. Potassium in the filtrate was determined with a Perkin-Elmer flame photometer model 52-C, using lithium as the internal standard.

All pH determinations were made with a Beckman glass electrode pH meter model H_2.

Greenhouse Studies

The objective of this portion of the study was to determine the effects of two levels of potassium fertilization on crop growth when applied with and without lime, nitrogen and phosphorus.

The four soils selected for this study varied in texture, organic matter, soil reaction and fertility level as indicated by a summary of their physical and chemical properties presented in Table 1.

Ammonium nitrate, monocalcium phosphate, potassium chloride and calcium carbonate were used in combinations that enabled the potted soils to be fertilized at rates equivalent to 50 pounds of elemental N, 200 pounds of P_2O_5, 100 and 200 pounds of K_2O calculated on an acre basis. Lime was applied at a rate equivalent to 4, 4 and 2 tons on the limed pots of the Eufaula, Bowie, and Darnell soil series respectively, calculated on an acre basis.

The treatments were designated as follows:

Check	No treatment
L	Lime only
NP	Nitrogen and phosphorus
LNP	Lime, nitrogen and phosphorus
NPK_1	Nitrogen, phosphorus, and potassium
$LNPK_1$	Lime, nitrogen, phosphorus, and potassium
NPK_2	Nitrogen, phosphorus, and potassium (x 2)
$LNPK_2$	Lime, nitrogen, phosphorus, and potassium (x 2)

Four thousand grams of soil from each series were weighed into a sufficient number of one gallon glazed earthenware pots to enable all treatments to be made in triplicate.

On April 14, 1953, soils from the Eufaula, Bowie, and Darnell series were potted, treated as previously described, and brought to a moisture content of approximately seventy-five percent of their field capacity with distilled water. The pots were planted to Lincoln soybeans, (Glycine max). After the seedlings were growing well, they were thinned to a uniform stand of five plants per pot.

On May 29, 1953 the above ground portions of the plants were harvested. The relative growth of this crop as indicated by the dry weight of plant tissue, soil pH and the available soil potassium is presented in Table 7.

The soil from each pot was thoroughly mixed and a sample taken from each of the three replicates. After sampling, the soils were returned to their original pots and prepared for the next planting.

Analyses of the harvested plant tissue of this crop for nitrogen, phosphorus, potassium, calcium, magnesium and sodium are presented in Tables 13, 14, and 15.

Blackeye cowpeas (Vigna sinensis) were planted on June 6, 1953 and grown in the same manner as the soybeans. They were harvested on July 12, 1953. Red spiders killed the plants on the N+P, $N+P+K_1$, and $N+P+K_2$ pots of the Eufaula series. The relative growth of this crop as indicated by the dry weight of plant tissue, soil pH and available soil potassium is presented in Table 8.

Analyses of the harvested plant tissue of this crop for nitrogen, phosphorus, potassium, calcium, magnesium, and sodium are presented in Tables 13, 14, and 15.

Soybean and blackeye cowpea forages were analyzed by the following methods: potassium, sodium and calcium by methods of Toth, et al. (45), magnesium by method of Peech, et al. (34), phosphorus by method of Shelton, et al. (41), and nitrogen by method of Piper (38).

The soils were sampled and mixed in the same manner as after the first crop. In addition, a second application of the original rates of N, P, and K was added to the appropriate pots. No further addition of lime was made.

The Parsons series was included in the studies at this time. This soil was fertilized at the rate of 100 pounds of elemental N, 400 pounds of P_2O_5, 200 and 400 pounds of K_2O calculated on an acre basis. Four tons of lime, calculated on an acre basis, was added to the limed replicates. All pots were planted to Stokesdale tomatoes (Lycopersicum esculentum) on July 15, 1953 and grown in essentially the same manner as were the preceding crops. The tomato plants were harvested on August 30, 1953. Dry vegetative yields and available soil potassium are reported in Tables 9 through 12. The soils were sampled and mixed in the same manner as after the first crop.

All pots were planted to Wintok oats (Avena sativa) on September 20, 1953 and grown essentially as were the previous crops. The oats were harvested on November 29, 1953. Dry vegetative yields and available soil potassium after the crop was harvested are reported in Tables 9 through 12.

Field Studies

In order to study the effect of potassium on crop growth under field conditions, an experiment was set up on the field from which the Renfrow soil sample was taken.

Sweet sudan grass seed was planted at the rate of twenty pounds to the acre with a grain drill equipped with a fertilizer attachment. A site of uniform slope and soil conditions large enough to accommodate twelve, rod square plots was selected from the field. Six split-plot rod square plots in this area received 150 pounds of 10-20-0 fertilizer applied at planting time on June 3, 1953. The other six rod square split plots received no starter fertilizer at seeding time.

On July 5, 1953 these twelve plots were top dressed by hand with potassium chloride and ammonium nitrate. The plots designated as check received no potassium fertilizer, the plots designated as K_1 and K_2 received potassium at the rates of 30 and 60 pounds as K_2O per acre respectively. One half of each plot was fertilized with ammonium nitrate at a rate equivalent to thirty pounds of elemental nitrogen per acre.

On August 2, 1953 a three by ten foot swath was harvested from each plot. The air dried forage yields converted to pounds per acre are reported in Table 16.

Another portion of this field was planted to Sumac 1712 sorghum on July 18, 1953. Four row plots having a forty inch spacing and fifty feet long were planted. The following fertilizer treatments were replicated three times.

Designation	Treatment
Check	No treatment
P	40 #/A. P_2O_5
P+K	40 #/A. P_2O_5 and 40 #/A. K_2O
N_1	20 #/A. elemental nitrogen
N_1+P	20 #/A. elemental nitrogen and 40 #/A. P_2O_5
N_1+P+K	20 #/A. elemental nitrogen, 40 #/A. P_2O_5 and 40 #/A. K_2O
N_2	40 #/A. elemental nitrogen
N_2+P	40 #/A. elemental nitrogen and 40 #/A. P_2O_5
N_2+P+K	40 #/A. elemental nitrogen, 40 #/A. P_2O_5 and 40 #/A. K_2O
N_3	80 #/A. elemental nitrogen
N_3+P	80 #/A. elemental nitrogen and 40 #/A. P_2O_5
N_3+P+K	80 #/A. elemental nitrogen, 40 #/A. P_2O_5 and 40 #/A. K_2O

A ten foot row section was harvested from each plot on October 19, 1953. The dry weight yield was converted to twenty percent moisture forage and this yield reported as pounds per acre in Table 16.

V. EXPERIMENTAL RESULTS AND DISCUSSION

Incubation studies

At the end of the first cycle all soils, except the calcium saturated Renfrow loam in the freeze and thaw phase, Table 5, exhibited a characteristic pattern as to the relative amount of potassium that was extracted by neutral normal ammonium acetate.

Darnell sandy loam, freezing and thawing phase, is representative of this pattern, Table 4. Considering the amount of potassium extracted at the end of the first cycle as a base, the amounts of potassium extracted at the end of the second cycle in ascending order calculated as pounds per acre of potassium are: hydrogen saturated 84, calcium saturated 358, field pH 434. An average of the amounts of potassium extracted from the end of the second cycle to the end of the eighth cycle shows no change of pattern but a change in amount, viz. hydrogen saturated 88, calcium saturated 379, and field pH 428 pounds per acre of potassium.

The maximum release of potassium was effected by the end of the fourth cycle in nearly all soils and treatments. A fixation of a portion of the released potassium occurred in most of these soils by the end of the fourth cycle.

Alternate freezing and thawing, or wetting and drying, resulted in similar action on the release and/or fixation of potassium in all soils. Alternate wetting and drying resulted in a greater initial release of nonexchangeable potassium to the exchangeable form in most soils.

All soils exhibited a tendency to establish an equilibrium between their exchangeable and nonexchangeable potassium fractions. Acid treated

Eufaula, and Bowie soils established this equilibrium quickly, owing in part to their low content of colloidal material, note Tables 2 and 3. The average exchangeable potassium content of all soils at the end of the eighth cycle was lowest in the acid saturated soils, highest in the untreated soils, and intermediate for the calcium saturated soils. This held true for all soils and treatments except the Bowie soil, Table 3, freezing and thawing phase, which showed the same exchangeable potassium content in the calcium and untreated samples.

Considering the potassium extracted after the end of the first cycle as 100 percent, the hydrogen and calcium saturated soils were able to effect a greater percentage wise release of potassium at the end of the second cycle from the nonexchangeable to the exchangeable form in most soils. Since all exchangeable potassium had been removed from the acid treated soils prior to incorporation into the study, movement of potassium as the soils approached an equilibrium would be from the nonexchangeable form to an available form. This trend was demonstrated for all soils in the wet and dry phase, likewise for the Bowie and Parsons soils in the freeze and thaw phase, (see Tables 3 and 6). The Eufaula, Bowie, and Darnell soils in the freeze and thaw phase did not follow this pattern, (see Figure 1).

Microbiological activity throughout the incubation period was pronounced. Mold colonies were in evidence on the surface of the acid treated soils. Calcium saturated and untreated sandy soils developed a pleasant plowed-earth odor. Calcium saturated and untreated loam and silt loam soils developed a foul,unpleasant odor.

Since the total elapsed time that the incubation studies were in effect was only slightly under fifty days, a longer incubation period might have shown a more definite pattern with regard to the net release or fixation of potassium in the soils studied.

A fluctuation in the pH of all soils studied was noted. In most soils, an increase in available potassium content was accompanied by an increase in the pH of the moistened soil sample. A fixation of potassium from the exchangeable form was accompanied by a decrease in the pH of the moistened soil.

Greenhouse Studies

Unlimed nitrogen and phosphorus fertilized pots produced a lower yield of soybean forage than did the check pots of the Eufaula and Bowie series. The pots that received potassium at the rate of 200 pounds of K_2O per acre in addition to nitrogen and phosphorus produced the greatest soybean forage yield.

The Darnell series did not follow this trend, in that the unlimed and limed nitrogen and phosphorus fertilized pots produced the highest yield of all treatments.

All limed pots of the Eufaula, Bowie, and Darnell series produced a greater yield of soybean forage than did their unlimed counterparts with the exception of the Darnell series fertilized with potassium at the 200 pound per acre rate, note Table 7.

All crops grown on the limed pots of all soil series benefited by the inclusion of potassium fertilizer. Though the pots that received potassium at the rate of 200 pounds per acre of K_2O showed a lower crop yield than those pots that received potassium at the rate of 100 pounds per acre in nine of the fourteen treatments where these combinations were used, in no instance was the forage yield as low as that recorded

Table 1. Physical and Chemical Characteristics of Soils Used in Incubation Studies, Greenhouse, and Field Experiments

Soil Type	Soil Texture[1] % Sand	% Silt	% Clay	Soil pH_2	Nitrogen Percent[3]	Milliequivalents per 100 Grams Soil: Exchange Capacity[2]	K_4	Ca_4	Mg_5	Na_4	H_6	P_7
Eufaula Sand	92.0	6.50	1.50	5.6	0.017	0.905	0.067	0.099	0.015	0.049	0.675	0.148
Bowie Sandy Loam	76.0	20.25	3.75	5.4	0.022	1.411	0.107	0.330	0.090	0.052	0.832	0.161
Darnell Sandy Loam	62.0	31.25	6.75	6.5	0.163	7.128	0.471	3.66	0.450	0.061	2.486	0.483
Parsons Silt Loam	36.25	54.50	9.25	5.8	0.077	5.775	0.128	3.30	0.700	0.162	1.485	0.230
Renfrow Loam	46.25	32.00	21.75	6.2	0.157	13.50	0.174	7.80	2.50	0.140	2.886	0.145

1. Determined essentially by method of Bouyoucos. (7)

2. Determined essentially by method of Peech, et al. (35)

3. Determined by method of Piper, C. S. (38)

4. Determined by method of Toth, et al. (46)

5. Determined essentially by method of Peech, et al. (34)

6. Assumed by difference of total exchangeable bases K, Ca, Mg, Na and cation-exchange capacity.

7. Determined by method of Harper. (17)

Table 2. The Effect of Alternate Freezing and Thawing and Wetting and Drying on Various Soil Types H^+ Saturated, Ca^{++} Saturated, Untreated (field pH) on Potassium Release and Fixation and Soil Reaction.*

Eufaula Sand

		End of First Cycle Lbs.K/Acre	pH	End of Second Cycle Lbs.K/Acre	pH	End of Third Cycle Lbs.K/Acre	pH	End of Fourth Cycle Lbs.K/Acre	pH	End of Eighth Cycle Lbs.K/Acre	pH
Freeze and Thaw	H^+ Sat.	17	4.3	15	4.9	16	5.0	18	5.0	24	5.3
	Lbs.K/Acre Fix. or Rel.			(-2)		(+1)		(+2)		(+6)	
	Ca^{++} Sat.	36	7.6	39	7.7	39	7.6	41	7.7	46	7.7
	Lbs.K/Acre Fix. or Rel.			(+3)		(0)		(+2)		(+5)	
	Field pH	46	5.7	43	5.8	47	5.8	42	5.6	47	5.7
	Lbs.K/Acre Fix. or Rel.			(-3)		(+4)		(-5)		(+5)	
Wet and Dry	H^+ Sat.	24	4.9	22	4.8	22	5.1	21	5.1	20	5.1
	Lbs.K/Acre Fix. or Rel.			(-2)		(0)		(-1		(-1)	
	Ca^{++} Sat.	40	7.6	45	7.5	40	7.5	35	7.4	33	7.4
	Lbs.K/Acre Fix. or Rel.			(+5)		(-5)		(-5)		(-2)	
	Field pH	42	6.0	37	6.2	41	6.4	41	6.5	40	6.4
	Lbs.K/Acre Fix. or Rel.			(-5)		(+4)		(0)		(-1)	

* Potassium fixation as used herein refers to the conversion of water soluble and exchangeable potassium to forms not extractable with 1.N ammonium acetate, pH 7.0. A cycle as used herein is 144 hours for both freezing and thawing and wetting and drying phases, (-) indicates fixation, (+) indicates release. Each value reported is the mean of three replications.

Table 3. The Effect of Alternate Freezing and Thawing and Wetting and Drying on Various Soil Types H^+ Saturated, Ca^{++} Saturated, Untreated (field pH) on Potassium Release and Fixation and Soil Reaction.*

Bowie Sandy Loam

		End of First Cycle Lbs.K/Acre	pH	End of Second Cycle Lbs.K/Acre	pH	End of Third Cycle Lbs.K/Acre	pH	End of Fourth Cycle Lbs.K/Acre	pH	End of Eighth Cycle Lbs.K/Acre	pH
Freeze and Thaw	H^+ Sat.	22	4.4	28	4.8	24	4.9	24	4.8	29	4.9
	Lbs.K/Acre Fix or Rel.			(+6)		(-4)		(0)		(+5)	
	Ca^{++} Sat.	71	7.4	74	7.3	79	7.4	72	7.3	75	7.4
	Lbs.K/Acre Fix. or Rel.			(+3)		(+5)		(-7)		(+3)	
	Field pH	77	5.2	74	5.5	77	5.5	72	5.3	77	5.5
	Lbs.K/Acre Fix. or Rel.			(-3)		(+4)		(-5)		(+5)	
Wet and Dry	H^+ Sat.	29	4.8	34	4.8	32	5.1	27	4.8	34	4.8
	Lbs.K/Acre Fix. or Rel.			(+5)		(-2)		(-5)		(+7)	
	Ca^{++} Sat.	71	7.2	73	7.5	73	7.1	70	7.0	65	7.0
	Lbs.K/Acre Fix. or Rel.			(+2)		(0)		(-3)		(-5)	
	Field pH	72	5.7	71	5.9	75	6.4	74	6.3	75	6.4
	Lbs.K/Acre Fix. or Rel.			(-1)		(+4)		(-1)		(+1)	

* Potassium fixation as used herein refers to the conversion of water soluble and exchangeable potassium to forms not extractable with 1.N ammonium acetate, pH 7.0. A cycle as used herein is 144 hours for both freezing and thawing and wetting and drying phases, (-) indicates fixation, (+) indicates release. Each value reported is the mean of three replications.

Table 4. The Effect of Alternate Freezing and Thawing and Wetting and Drying on Various Soil Types H^+ Saturated, Ca^{++} Saturated, Untreated (field pH) on Potassium Release and Fixation and Soil Reaction.*

Darnell Sandy Loam

		End of First Cycle Lbs.K/Acre	pH	End of Second Cycle Lbs.K/Acre	pH	End of Third Cycle Lbs.K/Acre	pH	End of Fourth Cycle Lbs.K/Acre	pH	End of Eighth Cycle Lbs.K/Acre	pH
Freeze and Thaw	H^+ Sat.	77	4.3	84	4.7	94	4.8	87	4.7	88	4.7
	Lbs.K/Acre Fix. or Rel.			(+7)		(+10)		(-7)		(+1)	
	Ca^{++} Sat.	285	7.4	358	7.4	387	7.5	395	7.5	376	7.5
	Lbs.K/Acre Fix. or Rel.			(+73)		(+29)		(+8)		(-19)	
	Field pH	343	6.7	434	6.8	478	6.8	389	6.7	411	6.8
	Lbs.K/Acre Fix. or Rel.			(+91)		(+44)		(-89)		(+22)	
Wet and Dry	H^+ Sat.	102	4.6	114	4.7	111	5.0	128	5.1	129	5.1
	Lbs.K/Acre Fix. or Rel.			(+12)		(-3)		(+17)		(+1)	
	Ca^{++} Sat.	320	7.4	400	7.5	363	7.2	409	7.6	412	7.7
	Lbs.K/Acre Fix. or Rel.			(+80)		(-37)		(+46)		(+3)	
	Field pH	362	6.6	402	6.5	371	6.5	421	6.8	423	6.8
	Lbs.K/Acre Fix. or Rel.			(+40)		(-31)		(+50)		(+2)	

* Potassium fixation as used herein refers to the conversion of water soluble and exchangeable potassium to forms not extractable with 1.N ammonium acetate, pH 7.0. A cycle as used herein is 144 hours for both freezing and thawing and wetting and drying phases, (-) indicates fixation, (+) indicates release. Each value reported is the mean of three replications.

Table 5. The Effect of Alternate Freezing and Thawing and Wetting and Drying on Various Soil Types H^+ Saturated, Ca^{++} Saturated, Untreated (field pH) on Potassium Release and Fixation and Soil Reaction.*

Renforw Loam

		End of First Cycle Lbs.K/Acre	pH	End of Second Cycle Lbs.K/Acre	pH	End of Third Cycle Lbs.K/Acre	pH	End of Fourth Cycle Lbs.K/Acre	pH	End of Eighth Cycle Lbs.K/Acre	pH
Freeze and Thaw	H^+ Sat.	75	3.9	85	4.4	95	4.7	85	4.4	84	4.4
	Lbs.K/Acre Fix. or Rel.			(+10)		(+10)		(-10)		(-1)	
	Ca^{++} Sat.	101	7.7	121	7.6	113	7.4	102	7.3	104	7.4
	Lbs.K/Acre Fix. or Rel.			(+20)		(-7)		(-11)		(+2)	
	Field pH	97	6.3	108	6.6	110	6.7	101	6.3	105	6.4
	Lbs.K/Acre Fix. or Rel.			(+11)		(+2)		(-9)		(+4)	
Wet and Dry	H^+ Sat.	129	4.4	161	4.4	151	4.7	158	4.7	169	4.7
	Lbs.K/Acre Fix. or Rel.			(+42		(-10)		(-7)		(+11)	
	Ca^{++} Sat.	163	7.5	192	7.7	179	7.2	178	7.1	188	7.2
	Lbs.K/Acre Fix. or Rel.			(+29)		(-13)		(-1)		(+10)	
	Field pH	195	5.7	219	5.7	206	6.1	211	5.7	217	6.1
	Lbs.K/Acre Fix. or Rel.			(+24)		(-13)		(+5)		(+6)	

* Potassium fixation as used herein refers to the conversion of water soluble and exchangeable potassium to forms not extractable with 1.N ammonium acetate, pH 7.0. A cycle as used herein is 144 hours for both freezing and thawing and wetting and drying phases, (-) indicates fixation, (+) indicates release. Each value reported represents the mean of three replications.

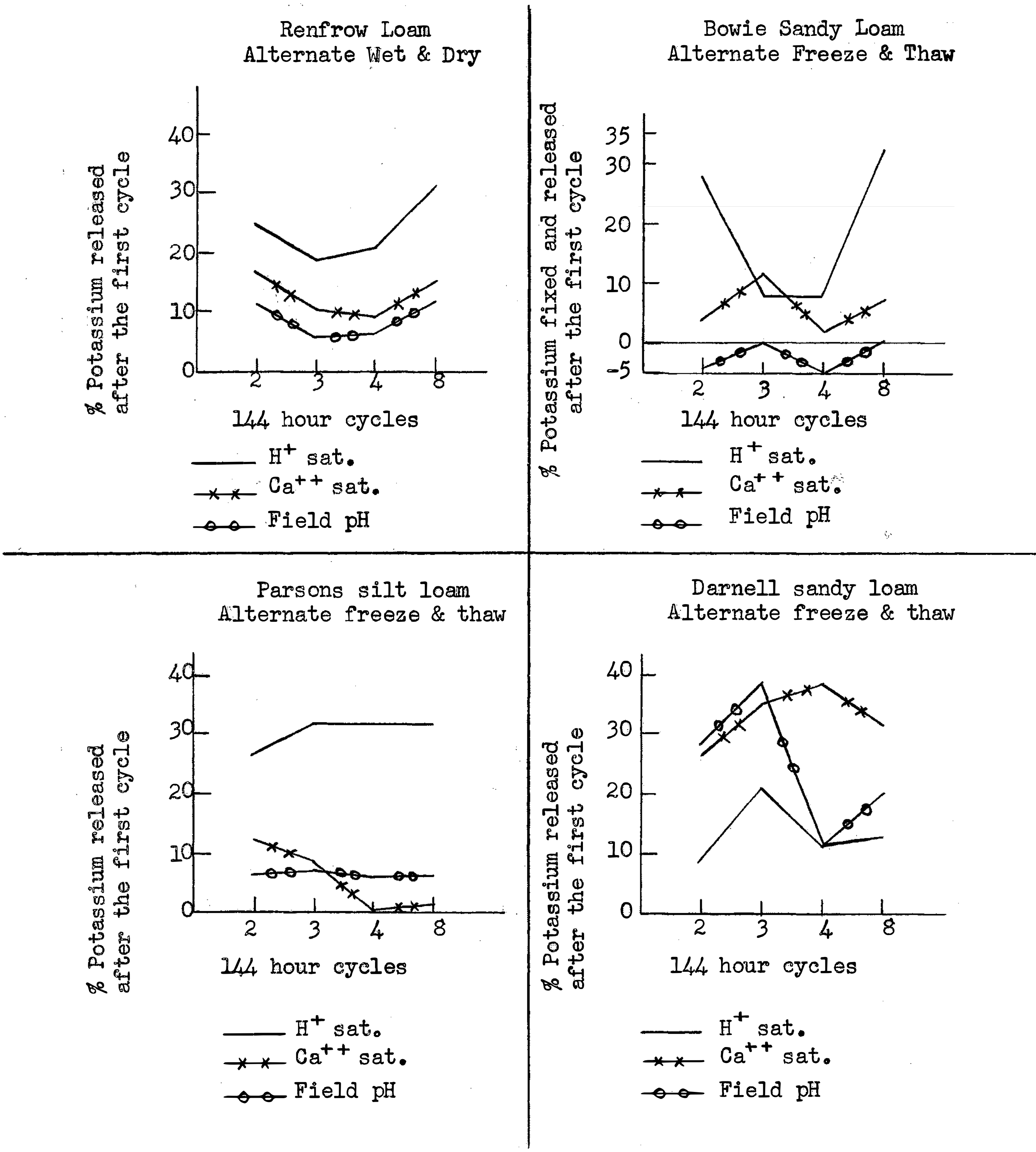
Table 6. The Effect of Alternate Freezing and Thawing and Wetting and Drying on Various Soil Types H^+ Saturated, Ca^{++} Saturated, Untreated (field pH) on Potassium Release and Fixation and Soil Reaction.*

Parsons Silt Loam

		End of First Cycle Lbs.K/Acre	pH	End of Second Cycle Lbs.K/Acre	pH	End of Third Cycle Lbs.K/Acre	pH	End of Fourth Cycle Lbs.K/Acre	pH	End of Eighth Cycle Lbs.K/Acre	pH
Freeze and Thaw	H^+ Sat.	26	4.1	33	4.5	34	4.7	34	4.7	34	4.7
	Lbs.K/Acre Fix. or Rel.			(+7)		(+1)		(0)		(0)	
	Ca^{++} Sat.	74	7.4	82	7.4	81	7.3	74	7.3	75	7.4
	Lbs.K/Acre Fix. or Rel.			(+8)		(-1)		(-7)		(+1)	
	Field pH	84	6.4	90	6.5	91	6.5	89	6.5	89	6.5
	Lbs.K/Acre Fix. or Rel.			(+6)		(+1)		(-2)		(0)	
Wet and Dry	H^+ Sat.	48	4.5	53	4.5	48	4.8	39	4.3	62	4.5
	Lbs.K/Acre Fix. or Rel			(+5)		(-5)		(-9)		(+23)	
	Ca^{++} Sat.	86	7.6	95	7.5	87	7.5	72	7.4	88	7.5
	Lbs.K/Acre Fix. or Rel.			(+9)		(-8)		(-15)		(+16)	
	Field pH	95	6.1	99	6.3	90	6.4	75	6.1	87	6.3
	Lbs.K/Acre Fix. or Rel.			(+4)		(-9)		(-15)		(+12)	

* Potassium fixation as used herein refers to the conversion of water soluble and exchangeable potassium to forms not extractable with 1.N ammonium acetate, pH 7.0. A cycle as used herein is 144 hours for both freezing and thawing and wetting and drying phases, (-) indicated fixation, (+) indicates release. Each value reported id the mean of three replications.

Fig. 1. The Effects of Various Physical and Chemical Soil Treatments upon the Percentage Release and Fixation of Potassium in Four Soil Types.
(Amount of Potassium Released at the End of First Cycle Taken as 100%)



for the pots that received lime alone. Note Tables 7 through 12.

Analyses of soybean and blackeye cowpea forage for potassium, sodium, calcium, magnesium, phosphorus and nitrogen as shown in Tables 13 through 15 gave the following results.

The percentage of potassium increased in all plants with increased potassium application to the soil.

The potassium content was lower in the limed treatments than in the unlimed.

The percentage of sodium decreased in practically all plants with increased potassium application to the soil. Sodium content was higher in the limed treatments.

The percentage of calcium decreased with increased potassium application to the soil. Calcium content was higher in the limed treatments.

The percentage of magnesium decreased with increased potassium application to the soil. Plants on unlimed soils had higher magnesium contents than those grown on the limed soils.

The percentage of phosphorus was highest in the plants grown on both untreated and limed soils where potassium fertilizer was not included.

The percentage of nitrogen decreased slightly in some plants with increased potassium application to the soil.

Table 7. The Effects of Various Fertilizer and Lime Additions on the Yield of Soybeans, Soil pH and Available Potassium Content of Eufaula, Bowie and Darnell Soils in Greenhouse Experiments.*

Treatments	Yield in Grams	Avail.K Lbs./A.	Soil pH	Treatments	Yield in Grams	Avail.K Lbs./A.	Soil pH
			Eufaula Sand				
Check	1.23	45	6.0	L	1.66	43	7.45
N+P	1.10	46	6.10	L+N+P	2.30	45	7.05
N+P+K_1	1.00	118	6.20	L+N+P+K_1	2.70	107	7.0
N+P+K_2	1.50	147	5.90	L+N+P+K_2	2.57	118	7.0
			Bowie Sandy Loam				
Check	3.07	71	5.85	L	3.90	76	7.45
N+P	2.73	76	5.60	L+N+P	4.60	78	7.45
N+P+K_1	2.93	118	5.50	L+N+P+K_1	4.07	112	7.30
N+P+K_2	3.10	173	5.50	L+N+P+K_2	3.47	166	7.20
			Darnell Sandy Loam				
Check	4.93	364	6.6	L	5.03	356	7.45
N+P	7.07	356	6.45	L+N+P	7.30	356	7.45
N+P+K_1	6.47	426	6.50	L+N+P+K_1	6.63	412	7.30
N+P+K_2	6.73	464	6.40	L+N+P+K_2	6.67	449	7.20

* Yields and soil analyses represent the mean of three replicates. Crop planted 4-14-53, harvested 5-28-53.

L = Lime, Eufaula - 4 Tons/A., Bowie - 4 Tons/A., Darnell - 2 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 8. The Effects of Various Fertilizer and Lime Additions on the Yield of Blackeye Cowpeas, Soil pH and Available Potassium Content of Eufaula, Bowie and Darnell Soils in Greenhouse Experiments.*

Treatments	Yield in Grams	Avail.K Lbs./A.	Soil pH	Treatments	Yield in Grams	Avail.K Lbs./A.	Soil pH
			Eufaula Sand				
Check	3.3	52	5.60	L	2.57	58	7.40
N+P**	---	53	5.70	L+N+P	3.17	56	6.25
N+P+K_1**	---	101	5.65	L+N+P+K_1	4.73	99	7.10
N+P+K_2**	---	138	5.80	L+N+P+K_2	4.50	109	7.00
			Bowie Sandy Loan				
Check	4.47	60	5.30	L	4.23	65	7.60
N+P	5.30	59	5.35	L+N+P	4.00	67	7.35
N+P+K_1	5.13	99	5.20	L+N+P+K_1	4.97	78	7.40
N+P+K_2	5.47	132	5.25	L+N+P+K_2	4.60	97	7.30
			Darnell Sandy Loam				
Check	4.03	365	6.5	L	2.03	348	7.20
N+P	3.30	373	6.25	L+N+P	3.67	340	7.10
N+P+K_1	5.10	413	6.35	L+N+P+K_1	3.97	340	7.10
N+P+K_2	4.17	493	6.05	L+N+P+K_2	4.53	381	7.0

* Yields and soil analyses represent the mean of three replicates. Crop planted 6-6-53, harvested 7-12-53

** Crop failure.

L = Lime, Eufaula - 4 Tons/A., Bowie - 4 Tons/A., Darnell - 2 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 9. The Effects of Various Fertilizer and Lime Additions on the Yield of Tomatoes and Available Potassium Content of Eufaula and Bowie Soils in Greenhouse Experiments.*

Treatments	Yield in Grams	Avail.K Lbs./A.	Treatments	Yield in Grams	Avail.K Lbs./A.
			Eufaula Sand		
Check	0.88	42	L***	----	42
N+P	1.51	44	L+N+P	0.99	30
$N+P+K_1$	1.54	93	$L+N+P+K_1$	3.35	106
$N+P+K_2$	0.31	207	$L+N+P+K_2$	2.04	168
			Bowie Sandy Loam		
Check	****	64	L	1.10	63
N+P	****	59	L+N+P	2.42	54
$N+P+K_1$	****	144	$L+N+P+K_1$	2.12	111
$N+P+K_2$	****	180	$L+N+P+K_2$	2.93	188

* Yields and soil analyses represent the mean of three replicates. Crop planted 7-15-53, harvested 8-30-53.

** Second addition of the above rates of N, P and K were added prior to planting tomatoes. The first addition was made prior to planting the previous two crops, Soybeans and Blackeye cowpeas.

*** Forage samples lost after harvest.

**** Crop Failure.

L = Lime, Eufaula - 4 Tons/A., Bowie - 4 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 10. The Effects of Various Fertilizer and Lime Additions on the Yield of Tomatoes and Available Potassium Content of Darnell and Parsons Soils in Greenhouse Experiments.*

Treatments**	Yield in Grams	Avail.K Lbs./A.	Treatments	Yield in Grams	Avail.K Lbs./A.
		Darnell Sandy Loam			
Check	2.54	296	L	1.42	304
N+P	5.82	256	L+N+P	6.58	272
N+P+K_1	6.15	296	L+N+P+K_1	8.08	320
N+P+K_2	3.96	487	L+N+P+K_2	6.53	414
		Parsons Silt Loam			
Check	0.85	80	L	0.96	84
N+P	2.97	78	L+N+P	1.87	78
N+P+K_1	2.93	98	L+N+P+K_1	4.33	102
N+P+K_2	2.15	144	L+N+P+K_2	4.13	144

* Yields and soil analyses represent the mean of three replicates. Crop planted 7-15-53, harvested 8-30-53.

** Second addition of the above rates of N, P and K were added prior to planting tomatoes. The first addition was made prior to planting the previous two crops, Soybeans and Blackeye cowpeas.

L = Lime, Darnell - 2 Tons/A., Parsons - 4 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 11. The Effects of Various Fertilizer and Lime Additions on the Yield of Oats and Available Potassium Content of Eufaula and Bowie Soils in Greenhouse Experiments.*

Treatments**	Yield in Grams	Avail.K Lbs./A.	Treatments	Yield in Grams	Avail.K Lbs./A.
			Eufaula Sand		
Check	1.4	26	L	1.7	19
N+P	1.4	30	L+N+P	1.4	25
$N+P+K_1$	1.9	103	$L+N+P+K_1$	2.6	109
$N+P+K_2$	4.3	126	$L+N+P+K_2$	2.4	123
			Bowie Sandy Loam		
Check	1.0	31	L	0.8	34
N+P	2.1	30	L+N+P	1.3	30
$N+P+K_1$	3.5	117	$L+N+P+K_1$	1.9	123
$N+P+K_2$	3.2	170	$L+N+P+K_2$	1.4	180

* Yields and soil analyses represent the mean of three replicates. Crop planted 9-20-53, harvested 10-29-53.

** Second addition of the above rates of N, P and K were added prior to planting tomatoes. The first addition was made prior to planting the previous three crops, Soybeans, Blackeye cowpeas and tomatoes.

L = Lime, Eufaula - 4 Tons/A., Bowie - 4 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 12. The Effects of Various Fertilizer and Lime Additions on the Yield of Oats and Available Potassium Content of Darnell and Parsons Soils in Greenhouse Experiments.*

Treatments**	Yield in Grams	Avail.K Lbs./A.	Treatments	Yield in Grams	Avail.K Lbs./A.
			Darnell Sandy Loam		
Check	2.7	212	L	3.3	223
N+P	4.5	105	L+N+P	2.1	212
N+P+K_1	3.7	198	L+N+P+K_1	4.3	189
N+P+K_2	4.2	233	L+N+P+K_2	4.3	275
			Parsons Silt Loam		
Check	2.3	94	L	1.6	89
N+P	3.1	61	L+N+P	2.9	82
N+P+K_1	4.7	101	L+N+P+K_1	4.1	95
N+P+K_2	4.8	112	L+N+P+K_2	5.7	106

* Yields and soil analyses represent the mean of three replicates. Crop planted 9-20-53, harvested 10-29-53.

** Second addition of the above rates of N, P and K were added prior to planting tomatoes. The first addition was made prior to planting the previous three crops, Soybeans, Blackeye cowpeas and tomatoes.

L = Lime, Darnell - 2 Tons/A., Parsons - 4 Tons/A.
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 13. The Effect of Various Fertilizer and Lime Additions on the Potassium, Sodium, Calcium, Magnesium, Phosphorus and Nitrogen Content of Soybean and Blackeye Cowpea Forage Grown in Eufaula Sand in the Greenhouse Experiment.*

Soil Treatments**	% K	% Na	% Ca	% Mg	% P	% N	Yield in Grams
			Soybean Forage				
Check	1.40	0.04	0.80	0.73	0.14	3.21	1.23
N+P	1.23	0.04	1.68	0.57	0.41	3.32	1.10
$N+P+K_1$	1.63	0.07	1.28	0.57	0.40	4.22	1.00
$N+P+K_2$	2.93	0.04	1.52	0.58	0.40	4.22	1.50
L	1.10	0.03	1.28	0.22	0.14	2.60	1.66
L+N+P	1.07	0.03	1.52	0.33	0.32	3.15	2.30
$L+N+P+K_1$	2.80	0.08	1.68	0.15	0.27	4.29	2.70
$L+N+P+K_2$	3.13	0.03	1.20	0.09	0.28	2.49	2.57
			Blackeye Cowpea Forage				
Check	2.33	0.19	1.12	0.85	0.19	3.15	3.3
N+P	***						
$N+P+K_1$	***						
$N+P+K_2$	***						
L	1.67	0.17	2.56	0.67	0.15	3.28	2.57
L+N+P	1.33	0.15	2.56	0.60	0.43	3.19	3.17
$L+N+P+K_1$	2.73	0.12	1.92	0.40	0.38	2.94	4.73
$L+N+P+K_2$	3.00	0.11	2.16	0.40	0.38	2.49	4.50

* All forage analyses performed in duplicate.

** Check - No treatment, L = Lime (4 Tons/A.)
N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

*** Crop failure.

Table 14. The Effect of Various Fertilizer and Lime Additions on the Potassium, Sodium, Calcium, Magnesium, Phosphorus and Nitrogen Content of Soybean and Blackeye Cowpea Forage Grown in Bowie Sandy Loam in the Greenhouse Experiment.*

Soil Treatments**	% K	% Na	% Ca	% Mg	% P	% N	Yield in Grams
			Soybean Forage				
Check	2.87	0.04	0.56	0.58	0.12	2.41	3.07
N+P	2.33	0.03	1.12	0.97	0.40	3.52	2.73
N+P+K_1	2.80	0.04	0.56	0.60	0.38	2.94	2.93
N+P+K_2	3.64	0.03	0.48	0.48	0.37	3.44	3.10
L	1.37	0.04	0.88	0.42	0.13	2.49	3.90
L+N+P	1.17	0.07	1.04	0.55	0.12	2.95	4.60
L+N+P+K_1	2.33	0.03	1.04	0.42	0.13	2.88	4.07
L+N+P+K_2	2.87	0.04	1.12	0.40	0.14	2.88	3.47
			Blackeye Cowpea Forage				
Check	1.47	0.12	1.12	0.80	0.22	3.14	4.47
N+P	1.63	0.16	0.96	1.07	0.45	3.35	5.30
N+P+K_1	2.60	0.13	0.96	0.80	0.33	3.13	5.13
N+P+K_2	3.20	0.12	0.88	0.77	0.37	2.87	5.47
L	1.67	0.15	2.00	0.43	0.17	2.97	4.23
L+N+P	1.57	0.17	2.16	0.73	0.33	3.16	4.00
L+N+P+K_1	1.93	0.12	2.48	0.57	0.31	2.85	4.97
L+N+P+K_2	3.27	0.13	2.32	0.55	0.29	2.95	4.60

* All forage analyses performed in duplicate.

** Check - No treatment, L = Lime (2 Tons/A.)

N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium - K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Table 15. The Effect of Various Fertilizer and Lime Additions on the Potassium, Sodium, Calcium, Magnesium, Phosphorus and Nitrogen Content of Soybean and Blackeye Cowpea Forage Grown in Darnell Sandy Loam Soil in the Greenhouse Experiment.*

Soil Treatments**	% K	% Na	% Ca	% Mg	% P	% N	Yield in Grams
			Soybean Forage				
Check	3.07	0.09	0.88	0.58	0.15	2.71	4.93
N+P	3.20	0.03	0.96	0.60	0.45	3.05	7.07
N+P+K_1	3.51	0.07	0.96	0.58	0.16	3.10	6.47
N+P+K_2	3.39	0.04	0.88	0.52	0.19	3.07	6.73
L	3.00	0.04	0.96	0.53	0.12	3.08	5.03
L+N+P	2.87	0.03	1.12	0.58	0.18	2.74	7.30
L+N+P+K_1	3.20	0.03	0.96	0.48	0.16	2.87	6.63
L+N+P+K_2	3.39	0.03	0.88	0.45	0.14	2.87	6.67
			Blackeye Cowpea Forage				
Check	3.51	0.12	1.92	0.90	0.16	3.33	4.03
N+P	3.45	0.15	1.92	1.03	0.21	3.05	3.30
N+P+K_1	3.69	0.07	1.60	1.10	0.21	3.23	5.10
N+P+K_2	3.39	0.09	2.08	0.88	0.32	3.17	4.17
L	3.45	0.13	2.16	0.78	0.19	3.35	2.03
L+N+P	3.20	0.07	2.32	0.93	0.26	3.56	3.67
L+N+P+K_1	3.39	0.07	2.16	0.88	0.23	3.24	3.97
L+N+P+K_2	3.51	0.07	2.32	0.80	0.25	3.42	4.53

* All forage analyses performed in duplicate.

** Check - No treatment, L = Lime (2 Tons/A.)

N = Nitrogen (50#/A. elemental N)
P = Phosphorus (200#/A. P_2O_5)
K = Potassium - K_1 (100#/A. K_2O), K_2 (200#/A. K_2O)

Field Studies

Sweet sudan grass grew very rapidly soon after being top dressed, due to heavy rains and warm weather at that time. The plots receiving 150 pounds of 10-20-0 at planting time with no top dressing of potassium developed scorched margins on the lower leaves of the rapidly growing plants. Those plots receiving 150 pounds of 10-20-0 at planting time and subsequent top dressing with potassium fertilizer showed no potassium deficiency symptoms.

Yields of hay on the plots not fertilized at planting time were increased by the application of 30 pounds of K_2O per acre, but depressed by the addition of 60 pounds of K_2O per acre. This held true for the plots receiving 33 pounds of nitrogen per acre as well as those not top dressed with nitrogen, Table 16.

Those plots receiving 150 pounds of 10-20-0 per acre at planting time showed an increase in hay yield from both the 30 and 60 pounds per acre rates of K_2O. The plots receiving 150 pounds per acre of 10-20-0 at planting time plus 33 pounds of nitrogen as top dressing showed a depressed yield of hay from the addition of both the 30 and 60 pound per acre rates of K_2O. A poor stand of plants on the plots receiving 30 pounds per acre of K_2O plus the nitrogen top dressing affected the total yield. The depressed yield from these plots should not be attributed to the addition of potassium fertilizer alone, Table 16.

Potassium applied to Sumac 1712 sorghum was most effective in increasing yield when used to supplement nitrogen and phosphorus fertilizers. Potassium when added, was supplied at a constant rate equivalent to 40 pounds of K_2O per acre. The largest yield of forage came from the plots fertilized with 20, 20, and 40 pounds of N, P_2O_5 and K_2O per acre respectively. The next largest yield came from the plots fertilized with 40, 20, and 40 pounds of N, P_2O_5, and K_2O respectively. Potassium depressed the yields of forage when added to plots receiving 20 pounds of P_2O_5 per acre, as well as when applied to plots receiving 80 pounds of nitrogen and 20 pounds of P_2O_5 per acre respectively. In no case, however, were yields depressed to the yield of the check plot when 40 pounds of K_2O per acre was applied, Table 17.

Table 16. The Effects of Nitrogen, Phosphorus and Potassium Treatments and Rates of Application on the Yield of Sweet Sudan Grass Hay Grown on Renfrow Loam Soil, Payne County, Oklahoma.*

No Starter Fertilizer		150#10-20-0 at Planting Time	
Treatment**	Yield in Pounds/Acre	Treatment**	Yield in Pounds/Acre
Check	1,626	Check	2,105
K_1	2,221	K_1	2,207
K_2	1,946	K_2	2,614
Check+N	1,844	Check+N	2,831
K_1+N	2,294	K_1+N	2,512***
K_2+N	1,830	K_2+N	2,712

* Yields represent the mean of two replications, planted 6-3-53, harvested 8-2-53.

** Fertilizer applied as top dressing on 7-5-53.
K_1 = 30#/A. K_2O as KCl
K_2 = 60#/A. K_2O as KCl
N = 33#/A. elemental N as NH_4NO_3

*** Poor stand.

Table 17. The Effect of Several Fertilizer Treatments and Rates upon the Yield of Sumac 1712 Sorghum Forage Grown on Renfrow Loam Soil Payne County, Oklahoma.*

Treatments**	Yields of 20 % Moisture Forage in Lbs./Acre
Check	4,983
P_1	6,547
P_1+K_1	5,426
N_1	6,063
N_1+P_1	5,526
$N_1+P_1+K_1$	8,435
N_2	4,990
N_2+P_1	6,359
$N_2+P_1+K_1$	7,852
N_3	5,291
N_3+P_1	7,142
$N_3+P_1+K_1$	5,889

* Yields represent the mean of three replications. Planted July 18, 1953, harvested October 19, 1953.

** All fertilizer applications made at planting time.

Check = No treatment.
N = Pounds of elemental nitrogen supplied as NH_4NO_3.
N_1 = 20#/A. N, N_2 = 40#/A. N, N_3 = 80#/A. N.
P = Pounds of P_2O_5 per acre supplied as granular super phosphate.
P_1 = 40#/A. P_2O_5.
K = Pounds of K_2O per acre supplied as KCl
K_1 = 40#/A. K_2O.

SUMMARY AND CONCLUSIONS

Incubation, greenhouse and field experiment studies were used to evaluate factors influencing the availability of potassium in five eastern Oklahoma soils, Eufaula sand, Bowie sandy loam, Darnell sandy loam, Parsons silt loam and Renfrow loam.

Incubation studies were made with these five soils to study the amount and rate of potassium fixation and release as affected by various physical and chemical treatments. Chemical treatments included hydrogen saturated, calcium saturated, and untreated soil. Physical treatments included alternate freezing and thawing and alternate wetting and drying of these chemically treated soils.

Greenhouse studies compared the growth of soybeans, blackeye cowpeas, tomatoes and oats on four soils as affected by various fertilizer treatments. Fertilizer treatments included lime and no lime, nitrogen, phosphorus and potassium applied at various levels and combinations.

Field studies were carried out on one soil, Renfrow loam, with sweet sudan grass and Sumac 1712 sorghum grown with various fertilizer treatments. Fertilizer treatments included nitrogen, phosphorus and potassium at various rates and combinations.

Soil and plant analyses were used in the incubation and greenhouse studies to determine the effects of these various treatments on soil characteristics and plant composition.

The following conclusions are drawn from the experimental results of these studies.

1. Alternate freezing and thawing or wetting and drying gave similar

results on the release and/or fixation of potassium in all soils for all treatments. All soils released a portion of their fixed potassium to the exchangeable form, then fixed a part of that released by the end of the fourth cycle of physical treatment.

2. A dynamic equilibrium between the fixed and exchangeable fractions of potassium appeared to be functioning in all soils studied.

3. Alternate wetting and drying resulted in a greater initial release of nonexchangeable potassium to the exchangeable form in all soils and chemical treatments except for the untreated Bowie sandy loam soil in the alternate wetting and drying treatment.

4. Calcium appeared to increase potassium fixation in soils in a form not extractable with neutral normal ammonium acetate.

5. The pH of all soils fluctuated during physical treatments, generally increasing with potassium release and decreasing with potassium fixation.

6. Greenhouse and field experiments demonstrated the need for considering the balance of available forms of nitrogen, phosphorus and potassium in relation to each other as well as the amounts of these elements in a soil.

7. Although plants grown in all soils responded to potassium fertilization, no simple characteristic or combination of factors were found in these experiments that were common to all soils in relation to their ability to fix and release potassium.

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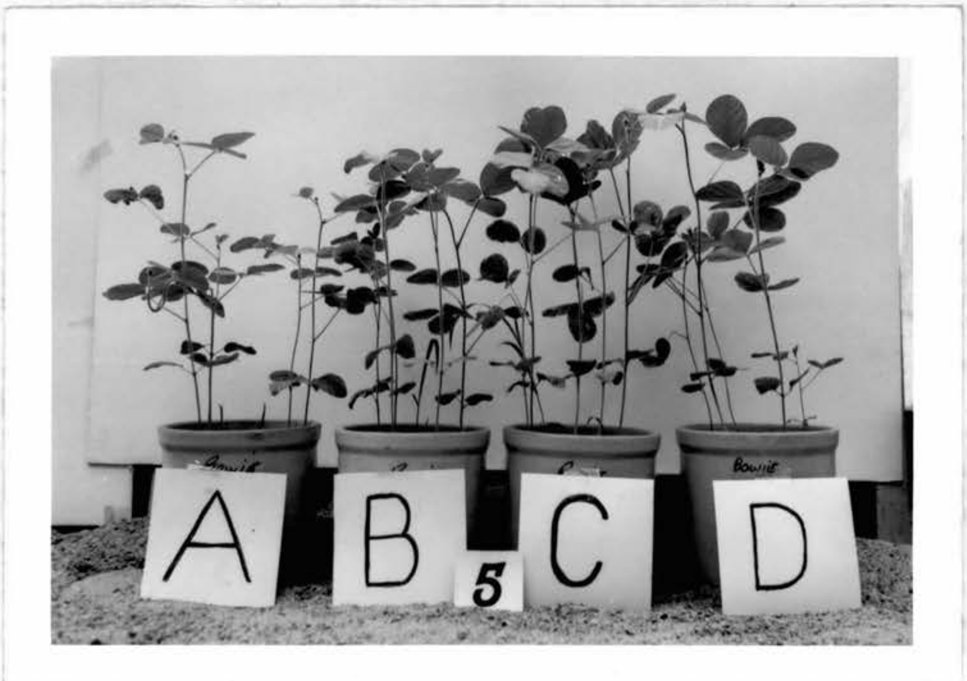
Figure 2. Effect of Various Fertilizer Treatments on Growth of Soybeans, Unlimed Bowie Sandy Loam. A. None, B. N+P, C. $N+P+K_1$, D. $N+P+K_2$ (See Table 7 for Soil Treatments and Yields)

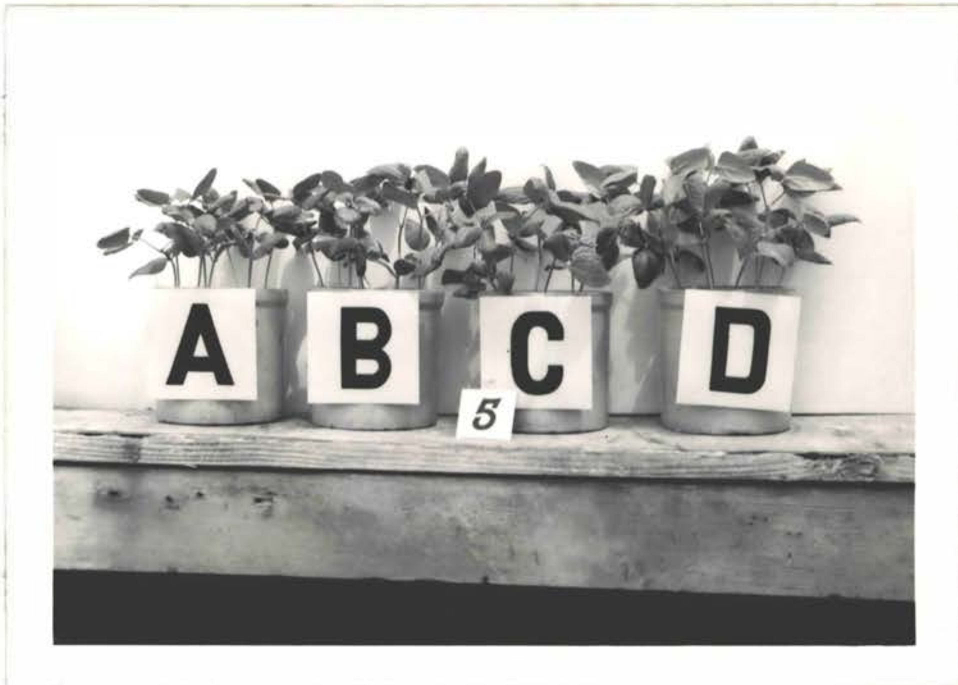


Effect of Various Fertilizer Treatments on Growth of Soybeans, Limed Bowie Sandy Loam. A. None, B. N+P, C. $N+P+K_1$, D. $N+P+K_2$ (See Table 7 for Soil Treatments and Yields)

Figure 3. Effect of Various Fertilizer Treatments on Growth of Blackeye Cowpeas, Unlimed Eufaula Sand. A. None, B. N+P, C. N+P+K_1, D. N+P+K_2 (See Table 8 for Soil Treatments and Yields)

Effect of Various Fertilizer Treatments on Growth of Blackeye Cowpeas, Limed Eufaula Sand. A. None, B. N+P, C. N+P+K_1, D. N+P+K_2 (See Table 8 for Soil Treatments and Yields)

Figure 4. Effect of Various Fertilizer Treatments on Growth of Blackeye Cowpeas, Unlimed Bowie Sandy Loam. A. None, B. N+P, C. N+P+K_1, D. N+P+K_2 (See Table 8 for Soil Treatments and Yields)



Effect of Various Fertilizer Treatments on Growth of Blackeye Cowpeas, Limed Bowie Sandy Loam. A. None, B. N+P, C. N+P+K_1, D. N+P+K_2 (See Table 8 for Soil Treatments and Yields)

Figure 5. Effect of Various Fertilizer Treatments on Growth of Tomatoes, Unlimed Darnell Sandy Loam. A. None, B.N+P, C. N+P+K_1, D. N+P+K_2. (See Table 10 for Soil Treatments and Yields)

Effect of Various Fertilizer Treatments on Growth of Tomatoes, Limed Darnell Sandy Loam. A. None, B. N+P, C. N+P+K_1, D. N+P+K_2 (See Table 10 for Soil Treatments and Yields)

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