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POTASSIUM FIXATION OF  
SELECTED SOILS  
IN LEBANON

By  
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A THESIS

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POTASSIUM FIXATION

BHUTTO

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## AN ABSTRACT OF THE THESIS OF

Muhammad Chhuttal Bhutto for M.S. in Soils.

Title: Potassium fixation of selected soils in Lebanon.

Three soils, the brown Zaoutar series, the black Innsar series, and the gray Bazouriye series, of Lebanon, were selected for the study of potassium fixation. Soils fertilized with a high level of potassium contained greater amounts of exchangeable and fixed potassium than soils receiving a low level of potassium. The three soils contained almost equal amounts of fixed potassium when compared at each of the two levels of applied potassium.

The order of amounts of added potassium fixed by the soils was: black > brown > gray. The amounts of potassium fixed in the black soil ranged from 2.54 to 9.13 me per 100 g of soil. The corresponding values in the brown and gray soils were 1.02 to 6.54 and 0.81 to 5.17 me per 100 g of soil, respectively.

Potassium fixation increased with an increase in the concentration of added potassium; but the percentage of added potassium fixed was less as the concentration was increased.

The fixation of potassium increased as time of wetting was increased. Air drying brought additional increases in the fixed potassium. The time to fix potassium could be reduced by increasing the cycles of wetting and drying. The amount of potassium extracted with sodium acetate was greater than with ammonium acetate. Thus the amounts of potassium considered as fixed when sodium acetate was used were less than those with ammonium acetate.

The clay fraction fixed greater amounts of potassium than the silt plus sand fraction. The amounts of potassium fixed in the clay and the silt plus sand fractions ranged from 3.87 to 14.81 and 0.32 to 1.06 me per 100 g of the fractions, respectively. On percentage basis, the fixation of potassium was greater in the silt plus sand fraction than the clay fraction at lower concentration of added potassium; but at the higher concentration, the percent

fixation in both fractions was almost equal.

The cation exchange capacity of the soils decreased with increase in potassium fixation. The reduction in the cation exchange capacity was approximately equal to the amounts of fixed potassium in the brown and black soils but slightly different in the gray soil.

It is recommended that further studies be made on the variations in fixed potassium content resulting from drying and wetting under field conditions with different moisture regimes. It is further recommended that a mineralogical study be made on the clay and silt plus sand fractions of the three soils used in this investigation.

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## I. INTRODUCTION

Potassium in soil ranges from the soluble state through the states of decreasing mobility to that of an essential constituent of certain primary minerals. In many soils, the entire range of known forms of potassium occurs while in others, some may be missing, usually because of the absence of some types of primary or secondary minerals (34, p. 114).

Potassium in soils is generally classed as soluble, exchangeable, and non-exchangeable potassium which includes both native non-exchangeable potassium and fixed potassium. Various states of soil potassium generally are related and comprise a system in which an increase in one form occurs at the expense of one or more other forms and in which the net movement may occur from highly available to less available states or the reverse depending on the particular stress (34, pp. 115-116). All the forms of potassium tend to remain in equilibrium (16, 30). Thus, potassium added in the form of fertilizers undergoes changes in the soil to form an equilibrium with the soil potassium. However, the degree of equilibrium and relation of one form with the other is different with different soils and conditions (28).

Available potassium is dependent on vegetation and time factors and consequently fixed potassium is at present, more precisely defined as applied potassium which is not readily replaceable by usual cation exchange reactions using neutral salts such as ammonium acetate. (1; 34, p. 135; 40).

The effects of potassium fixation in terms of crop nutrition are usually considered to be wasteful, in that a portion of applied potassium does not remain instantly available to plants. On the other hand they may be considered beneficial, in that rapid leaching is prevented giving subsequent residual effects through later release (6; 34, pp. 136-137), even from soils of high fixing capacity (25). However, the potassium fixing capacity is different with different soils depending upon clay mineral content, other soil characteristics and the condition of fixation.

No work has so far been published on potassium fixation in the soils of Lebanon. The study was undertaken during 1965-66 in the Division of Soils and Irrigation of American University of Beirut on three soils representing three soil series of South Lebanon. The study was carried out with the following objectives:

1. To determine the amounts of fixed potassium in soils receiving both high and low levels of potassium previously.

2. To find out the extent of potassium fixation under different concentrations of added potassium.
3. To study the effect of different wetting and drying conditions on potassium fixation.
4. To determine the efficiency of ammonium acetate and sodium acetate as potassium extractants.
5. To determine potassium fixation by the clay and the silt plus sand fractions.
6. To study the effect of potassium fixation on cation exchange capacity.

## II. REVIEW OF LITERATURE

As reported by Agarwal (1) Kellner in 1887 was perhaps the first to recognise that large quantities of added soluble potassium salts in some soils become so transformed that it was not possible to recover them by boiling in dilute acids. Dyer in 1894, reviewed by Agarwal (1), while preparing the balance sheet of potassium in some plots of long-term experiments on the Hoos fields at Rothamsted, found that a large proportion of the applied potassium had gone into a state from which it only became available to crops with difficulty. Frear and Erb (15, pp. 74-79) examined the potassium status of a plot of Hagerstown silt loam which had received 1800 lbs of  $K_2O$  per acre during a 36-year period. They found out that crop removal and the status of a control plot accounted for one-fourth of the added amount, half of the remainder was extractable by 0.3 N ammonium chloride and the rest had been converted to non-extractable forms. This phenomenon has since been termed potassium fixation and has received the attention of a large number of workers because of its importance in the practical management of potassium nutrition to field crops (34, p. 135).

## Mechanism of Potassium Fixation

The conversion of soluble K to difficultly replaceable forms has been studied considerably. One mechanism that has been considered to be more active in this process is the trapping of K ions between lattice unit sheets of 2:1 type clays (11, 24, 29, 42). The size of the K ions probably accounts for the susceptibility to fixation by this process (29, 42). Page and Baver (29) observed a decrease in potassium fixation by keeping the basal spacing larger through the introduction of large organic cations. They further found that in case of pure clay minerals, montmorillonite cannot fix potassium in the moist state, but that, when such clays were saturated with potassium and then dried, potassium was entrapped and fixed. This was due to the contraction of the lattice sheets of K-saturated montmorillonite during the process of drying. This theory of contraction of the sheet layers of the clay minerals on the introduction of K ions explains the behavior of potassium fixation (4, p. 68; 25, pp. 168-172).

Wear and White (44, pp. 9-11) proposed that as potassium saturated clay was dried, the potassium ion lost its hull of oriented water, the molecular water between the plates was removed, and the plates collapsed. The dehydrated potassium ion fitted into the void in the hexagonal oxygen rings. When there is sufficient

potassium present, the positive electrostatic force of the potassium ions shared with the electronegative oxygen ions keep the plates collapsed against forces of rehydration. Wear and White (44, pp. 12-14) gave an explanation of the mechanism of potassium fixation on the basis of the stronger and weaker attractive charges by which potassium is held on the crystal lattice. The attractive forces arising out of the octahedral layer charges are considered weak in comparison to similar forces arising out of the tetrahedral charges, which produce stronger attractive forces at the clay surface.

Barshad (4, p. 61) considered that the magnitude of inter-layer charge, rather than its origin, determined potassium fixation. According to him, a charge of 200 or more me per 100 g will give more stable combination, whereas a charge of 110 or less will result in a weak binding.

#### Soil Separates and Potassium Fixation

Agarwal (1) in his review stated that extensive work done in many countries has shown that the mineral part of the soil is mainly responsible for potassium fixation and it has been recognized that the clay is the only active soil fraction which takes part in fixation process. The organic part or humus, is not capable of fixing potassium (22).



Welte and Niederbudde (45) found much greater potassium fixation in river alluvial than in loess soils. The high values of fixation were attributed by them to the large contents of clay consisting mainly of expanded 2:1 layer minerals. Potassium fixation was greater in the B horizon than in the A horizon which they considered to be due to the clay migration in the profile. The lesser fixation in the A horizon was also considered due to the increasing acidity at upper layers causing the non-reversible migration of Al into the interlayers of the remaining expanded 2:1 layer minerals. Rich and Lutz (37) found that potassium fixation on a unit weight basis increased with decrease in particle size by studying 14 surface soils. McLean and Brydon (26, pp. 131-132), in a study on the release of non-exchangeable potassium with H-resin and boiling in  $\text{HNO}_3$  in 11 Canadian soils, found that K released from the clay fraction was twice that in fine silt, about 4 times that in medium silt, and about 11 times that in coarse silt and sand. The degree of K fixation usually decreased with increasing particle size.

El-Damaty et al. (14, pp. 161-164) found that exchangeable potassium was the lowest in coarse textured soils and highest in fine textured soils of United Arab Republic. A highly significant correlation coefficient between the clay percent and exchangeable potassium, obtained by them, was highly correlated with cation

exchange capacity and total potassium. Scott and Reed (41) found that the rate of removal of potassium was inversely related to particle size. DeMumbrum (9) found that the coarse clay (2 to 0.2 micron) and fine silt (5 to 2 micron) fractions of the soil contribute most to the fixing capacity of the separates.

Mehta and Shah (28, p. 277) found that exchangeable potassium and base exchange capacity increased with decrease in size of soil particles. They observed that silt has more than 60 percent of the potassium fixing capacity of clay, and sand about 10 percent. Karim and Malek (23) got 11 percent higher fixation in a soil having 33 percent clay and 20 percent silt which exhibited the importance of silt fraction in potassium fixation.

Effect of Time and Moisture Condition  
on Potassium Fixation in Clay  
Minerals and Soils

Many workers have established that potassium fixation increases with time. Fixation of K initially occurs at a fast rate, but the establishment of equilibrium takes time and 80 to 90 percent of the total K fixed takes place within a period of hours (1). Mehta and Shah (28, p. 269) found that at low concentration of applied salt, fixation amounted to almost 90 percent of the maximum quantity of potassium fixed during the first 30 days while at high concentration, this percentage dropped down to 70.

They also observed that maximum potassium fixation took place when the soil was kept in moist contact with 15 me potassium per 100 g of soil for a period of 210 days. Karim and Malek (23) got 55 to 69 percent of total fixed potassium in four typical soils of East Pakistan in a period of two months. Working only with a silty loam soil, De Turk and Bray (12) concluded that K fixation increased with time and reached equilibrium in about 6 months. However, a wide variation in potassium fixation is reported by different workers under different conditions.

Stanford (42) got little fixation in illite and none in bentonite in the moist state. Volk (43, p. 268) observed relatively little fixation of potassium when soils were kept moist as compared to that by alternate wetting and drying at 70°C. But Blume and Purvis (6, p. 866), Hoover (18), and Bower (8) obtained a good amount of fixation under a moist condition. Mehta and Shah's (28, p. 267) results on three Indian soils showed that appreciable amounts of potassium were fixed even in moist storage. DeMumbrum and Hoover (10) reported that oven drying of vermiculite caused almost 100 percent fixation of 10 me K per 100 g clay.

Richards (38, pp. 129-139) found that illite and bentonite fixed added potassium during moist storage. Release occurred in bentonite when air dried but not when oven dried. Rewetting had little effect on the potassium

fixation in the air dried or oven dried samples of bentonite. In illite additional amounts of K were fixed on drying. Air drying fixed greater amounts than oven drying. Similarly, Dennis and Ellis (14) found increase in K fixation of different levels of added K in a vermiculite system by dehydration. Downy and Hutcheson (13) found that on drying, fixation of K took place when the level of exchangeable K was above  $0.45 \pm 0.10$  me per 100 g and release of K occurred when the initial K level was below this.

Numerous workers have associated potassium fixation in soils at different conditions, with the presence of certain clay minerals. Rany and Hoover (33) studied potassium fixation on montmorillonite and kaolinitic soils and found that the montmorillonitic soil fixed a much greater percentage of applied potassium than a kaolinitic one. Richards and McLean (40) also attributed little fixation to kaolinite even on drying.

Some workers who associated potassium fixation to specific clay minerals have found that montmorillonite is responsible for this phenomenon (13, 40, 42). Stanford (42) obtained potassium fixation by montmorillonite only upon drying. Others have attributed a great deal of potassium fixation to illite (13, 42), and vermiculite (9, 10, 13, 42). DeMumbrum (9) attributed most of the fixation to vermiculite. With single mineral studies,

DeMumbrum and Hoover (10) found that vermiculite fixed large amounts of K; whereas, illite fixed no applied K against aqueous extraction even after drying.

Montmorillonite, after saturation with K under a moist condition, can fix K if subsequently dried (1).

Van der Marel (25) reported that an illite mineral with open lattices, which he called open illite or ammersooite, in Dutch basin soils, can fix K strongly by contraction of its sheets on treatment with K.

Comparing standard clays and soil clays, Richards and McLean (40) found that soil clays fixed about two times as much potassium as standard clays. They suggested that this may be due to the greater weathering of K out of the soil clays. Richards (38, p. 131) found that potassium fixation in natural clays from soils exceeded that fixed by the comparable synthetic mixtures of pure clays.

Binnie et al. (5) using 0, 100, 200, and 300 ppm of K and incubating for 11, 22, and 42 days at 20 percent moisture in alluvial and associated upland soils of Indiana, failed to find any statistical correlation between the mineralogical composition of the soil and the K released. DeMumbrum (9) working on black, red, and yellow soils of prairies, found that the dark colored soils had higher K fixing capacities than the other soils and the weathered chinks had high fixing capacities compared to the unweathered material. The K fixing ability of these soils

was presumed by him to be caused primarily by vermiculite which was thought to be formed during weathering. Mehta and Shah (28, p. 269) also found greater K fixation in black cotton soil than Kairi and Goradu soils.

#### Method of Determining Fixation of Added K

Agarwal (1) pointed out that the basic principle underlying all methods for laboratory determination of potassium fixation is by adding a known amount of K to soil. After a certain time, the soil is leached with a normal solution of ammonium acetate and the content of K is determined in the leachate. The amount of K not recovered is fixed in the soil, and this method can be adopted both for wet and dry fixation.

Many extractants have been used by different workers to determine the amount of potassium which could not be extracted. Agarwal (1) stated that workers in the United States employ 0.5 N ammonium acetate which Vander Marel and Venekamp considered undesirable, because ammonium ions may exchange for a part of the fixed K ions in the soil. They suggested leaching with 0.5 N magnesium acetate or 0.5 N sodium chloride. There is also controversy on the ratio between soil K and K in solution and on the reaction time used in such estimation; both are arbitrary and have not been standardized in order to obtain universally comparable results (1).

DeMumbrum (9) used 0.01 N KCl solution at the rate of 10 me per 100 g of soil and extracted exchangeable K with 0.5 N sodium acetate under wetting and drying moisture conditions. Welte and Niederbudde (45) extracted K with 0.5 N ammonium acetate for 2 hours keeping a 1:10 soil and extractant ratio. Richards and McLean (40) added K at the rate of 10 me per 100 g of soil and used N ammonium acetate solution as an extracting agent after subjecting the soil samples to different treatments of moisture conditions.

Mehta and Shah (28) stirred the soil with different amounts of KCl and extracted K with N ammonium acetate after storing the soil for different period at 40 percent water holding capacity.

El-Damaty et al. (14, p. 143) found a highly significant correlation coefficient between the exchangeable potassium and non-exchangeable potassium. They also found that the amount of exchangeable potassium extracted with 0.04 N calcium lactate was found to be 50 to 60 percent of that extracted by N ammonium acetate in soils of the United Arab Republic. On the other hand, Barshad (4, pp. 68-77) found that the replacement of interlayer  $K^+$  with cations other than  $NH_4^+$  was easier. He suggested that the relative power of the cations in normal neutral chloride solution to replace  $K^+$  was as follows:  $Ba > Mg > Na > Ca$ .

Reitemeier (34, p. 130) reported that by employing the acetates of a number of cations, the release values in pounds of K per acre for Dunkirk soil were as follows: Mg - 75, Ca - 45, Na - 13, Ba - 12, H - 6, and  $\text{NH}_4$  - 4. The corresponding values for Honeoye soil were: 92, 64, 53, 34, 32, and 4. In both soils, ammonium tended to block the release of potassium. Rich (36) studying K exchange in Nason subsoil of Virginia, found that ammonium acetate and magnesium chloride could release K but not magnesium acetate. He remarked that the extent of K exchange is determined largely by the diameter of the exchanging solvated cation and by the pH of the system.

Effect of Initial Level of Soil K and  
Concentration of Added K on  
Potassium Fixation

It has been shown (17, 27) that the ability of a soil to fix K is increased by extensive cropping. Whether drying a soil in the oven fixes or releases K depends upon the initial level of K in soil (3, 19, 29, 35). Usually, drying increases the exchangeable K in soils which are low in K and increases fixation in soils which are high in K (27). El-Damaty et al. (14, p. 161) established a highly significant correlation coefficient of 0.821 between the exchangeable potassium and  $\text{N HNO}_3$  extractable potassium which was considered the fixed K. They also established significant correlation between the fixed K and the total K



in the soils of the United Arab Republic.

Richards (38, p. 74) considered that if there was considerable potassium within the crystal, the addition of small amounts of KCl followed by moist storage would cause collapse of the mineral and entrapment of K in fixable positions. Pratt and Goulben (32) found that the fixation percentage of applied potassium decreased with increase in rate of application. Mehta and Shah (28, p. 269) found that as the concentration of added potassium increased, fixation of potassium increased. This increase, however, was not found to be linear as there was no further effect on fixation if concentration increased beyond 15 me per 100 g soil.

Larger proportions of applied K were fixed at lower K additions. Near the addition of an amount of K equivalent to the exchange capacity, the proportion of fixation decreased abruptly (21).

Richards and McLean (40) found that with the addition of 10 me per 100 g vermiculite, 62 and 71 percent of the added K were fixed by air drying and oven drying, respectively. With the addition of 100 me of K, 40 and 44 percent were fixed by air drying and oven drying. Dennis and Ellis (11) added various concentrations of K ranging from 15 to 1500 me per 100 g and obtained 8 to 32 me per 100 g of fixed K against 1 N ammonium acetate extraction in samples of vermiculite with a cation exchange capacity

of 150 me per 100 g. In all cases they found that as the concentration of added K increased, K fixation increased.

#### Effect of Potassium Fixation on Cation Exchange Capacity

Usually the cation exchange capacity of the system is decreased by an amount approximately equivalent to the K converted to fixed form (42). The cation exchange capacity is a function of the negative charges on the clay particle. The phenomenon of K fixation, by virtue of K ion being entrapped between the lattice unit sheets of clays neutralizes the negative charges on the clay and reduces the cation exchange capacity of the soil. Reitemeier, (34, pp. 137-138) reported that K is fixed in positions which normally contribute to the exchange capacity and that fixation results in the reduction in magnitude, at least temporarily. However, the magnitude of the alteration in cation exchange capacity is found to be different in different soils under different conditions. Wear and White (44, pp. 3-5) considered the reduction in cation exchange capacity of clays as a measure of the extent of cation fixed. Pratt and Goulben (32) found that K fixation under moist conditions was accompanied by a reduction in cation exchange capacity, but there was a lack of equivalence between them.

### III. MATERIALS AND METHODS

#### Soils

Soil samples from three different soils of South Lebanon were supplied by the Agricultural Research Institute, Tell Amara, Lebanon. The soils were: the brown Zaoutar series, and the black Innsar series, both from Babliye, and the gray Bazouriye series from Nabatiye Zaoutar (2, pp. 26-33). Bulk soil samples of 200 kg were collected during May, 1964. Samples were taken to a depth of 30 cm from 6 to 8 spots in the field. Each field was a few dunums in size. Each sample was thoroughly mixed and divided into four quarters. Samples of 2 kg from each soil were placed in two different pots to conduct a fertilizer pot experiment to evaluate the fertility status of these soils, using wheat as an indicator crop. The two pots, selected for the potassium fixation study reported here, were fertilized with a low and a high rate of potassium, 25 mg per 2 kg of soils and 400 mg per 2 kg of soils, respectively. In addition, a uniform application of a mixture, in solution, of phosphorus, sulphur, magnesium, and nitrogen was given to both pots of each soil at the rate of 100 mg per 2 kg of soil for each nutrient (Table 1). A crop of wheat was grown for about

Table 1. Amounts of various fertilizers added, mg per 2 Kg of soil, before planting wheat (Tell Amara study).

Pot 1, receiving low level of K			Pot 2, receiving high level of K		
Source of nutrient	Nutrient	Amount	Source of nutrient	Nutrient	Amount
$Mg(H_2PO_4)_2$	P	100.0	$KH_2PO_4$	P	100.0
	Mg	39.2		K	125.9
$Mg(NO_3)_2$	Mg	60.8	$Mg(NO_3)_2$	Mg	86.8
	N	70.0		N	100.0
$K_2SO_4$	K	25.0	$K_2SO_4$	K	244.0
	S	10.2		S	100.0
$(NH_4)_2SO_4$	N	30.0	$KHCO_3$	K	30.1
	S	34.4			
$CaSO_4$	S	55.4	$MgOAc$	Mg	13.2
Total K		25.0	Total K		400.0

six months. Following the harvest of wheat, the soil from the pots was ground, passed through a 28 mesh sieve, and stored in glass jars for the study of potassium fixation.

### Analytical Methods

pH: The pH values of soils were determined at a 1:5 soil-water ratio using a Beckman glass electrode model G pH meter.

Cation exchange capacity: Cation exchange capacity was determined by saturating the samples with sodium acetate (pH 8.2) and extracting the exchangeable sodium with ammonium acetate (pH 7.0) after washing out the excess sodium with alcohol (39, p. 101). The sodium concentration was then determined photometrically by the use of a Beckman spectrophotometer model DU with flame photometer attachment.

Calcium carbonate: The alkaline earth carbonates were determined by the manometer method proposed by Woodward (46).

Mechanical analysis: The percentages of sand, silt, and clay in different soils were determined by the Bouyoucos method (7) using sodium hexametaphosphate as the dispersing agent. Textural classes were determined from the conventional textural triangle.

Exchangeable potassium: Two extractants, N ammonium acetate and N sodium acetate, were used separately for extracting exchangeable potassium from the soil samples.

Four soil samples were placed in centrifuge tubes and 25 ml of the extractants were added. After shaking the contents for 8 minutes, the tubes were centrifuged and the supernatant liquid was filtered into a volumetric flask. The above procedure was repeated four times. The potassium content in the solution was then determined by the flame photometer.

Fixed potassium: The fixed potassium in the soil samples receiving high and low potassium levels was determined by the method suggested by Pratt (31). Two g of each soil were boiled in 25 ml of  $\underline{N}$   $\text{HNO}_3$  for 10 minutes. The fixed potassium was calculated by subtracting the exchangeable potassium from the potassium extracted by the  $\underline{N}$   $\text{HNO}_3$ .

Total potassium: The Jackson method (20, pp. 283-284) for determining total potassium was used by digesting 0.2 g of soil with 1 ml of perchloric acid and 8 ml of 48 percent hydrofluoric acid at 200 to 225<sup>0</sup>C in a platinum crucible. After heating the contents to dryness, the residues were dissolved by slightly boiling with 6  $\underline{N}$  hydrochloric acid and diluting with distilled water on a radiator. The resultant solution was then transferred to a 100 ml volumetric flask and the potassium was determined by the flame photometer.

Determination of potassium fixing capacity: The basic principle of determining potassium fixing capacity of soils was followed, as suggested by many workers (1, 9, 23, 28,

pp. 267-268). The portion of the added potassium not recovered by extraction with the extracting agents under different conditions was considered as the fixed potassium.

Effect of concentration on potassium fixation: Potassium was added to the soils in three different concentrations as follows: first, 4 g soil sample was saturated with potassium by adding 25 ml of N KCl in a centrifuge tube, and shaking for 8 minutes. After each shaking the contents were centrifuged and the supernatant liquid was decanted. The above procedure was repeated four times. The soluble salts were washed twice with distilled water followed by three washings with ethanol until no positive test for chloride was observed. By this method, it is expected that the amount of K adsorbed by the soil is equivalent to the cation exchange capacity of that soil. The samples were then stored under different conditions of moisture described below for the fixation of potassium. The second concentration used was the addition of potassium at the rate of one-half of the cation exchange capacity of the soils. A 4 g soil sample was placed in a centrifuge tube and the required amount of potassium was added in 3 ml of KCl solution which was just sufficient to bring the moisture state to saturation. The samples were then subjected to the same moisture condition. The third concentration was maintained at the rate of one-third of the cation exchange capacity of the soils by adding the

required amount of potassium in 3 ml of KCl solution to a 4 g soil sample. The samples were also subjected to the same moisture conditions.

Effect of time and moisture condition on potassium

fixation: In order to study the effect of time on the rate of potassium fixation under different moisture conditions, the following treatments were applied on the soil samples treated with the three concentrations of potassium:

1. 3 hours wet storage
2. 3 hours wet storage and drying
3. 8 hours wet storage
4. 8 hours wet storage and drying
5. 60 hours wet storage
6. 60 hours wet storage and drying
7. 16 days wet storage
8. 16 days wet storage and drying
9. 8 hours wet storage, drying, and rewetting for 60 hours.
10. 8 hours wet storage, drying, rewetting for 60 hours, and drying.

Wetting was maintained by keeping the samples in the centrifuge tubes with air tight stoppers after the addition of potassium. Drying of the samples was done by placing the opened centrifuge tubes for about 8 hours in the oven with a temperature of 29°C. An electrical oven, model



blue M, with an air circulation device was used. The extractants previously discussed, N ammonium and N sodium acetate, were used. The portion of the added potassium not recovered by the extractants was considered as the fixed potassium.

Potassium fixation in soil separates: The clay and the silt plus sand fractions were separated from the soil by shaking the soil samples with sodium carbonate solution (1 g  $\text{Na}_2\text{CO}_3$  in 9 liters) and centrifuging the contents at 750 rpm for five minutes to separate the clay fraction from the sand plus silt fraction. About six washings were usually sufficient for the above separation. To determine the extent of potassium fixation by the clay and by the silt plus sand fractions, potassium was added to each fraction in two concentrations as follows: first, at the rate of the cation exchange capacity, and secondly, at the rate of one-third of the cation exchange capacity of each fraction, by the same procedure as mentioned for soils. The samples were stored for 8 hours in wet condition and the potassium was then extracted with each of the extractants, ammonium acetate and sodium acetate, as in the case of the soils. The potassium not recovered by the extractant was considered the fixed potassium.

Effect of potassium fixation on cation exchange capacity:

The soil samples in which potassium was added at the rate of one-half cation exchange capacity, were selected for the

study of the effect of potassium fixation on cation exchange capacity. The samples, after being extracted four times with sodium acetate, for extracting the exchangeable potassium, were washed four times with ethanol to wash the excess soluble salts. The exchangeable sodium was then extracted by ammonium acetate (39, p. 101) and determined by the flame photometer.

#### IV. RESULTS AND DISCUSSION

The results of the chemical and the physical analyses of the soils used for the investigation of potassium fixation (Table 2) showed that all the three soils were alkaline in reaction. The gray and the black soils were calcareous and contained 71.0 and 3.7 percent calcium carbonate, respectively. The brown soil was non-calcareous. The mechanical separates of the soils showed the brown and the black soils to be clay, and the gray soil to be silty clay.

##### Amounts of Fixed Potassium in the Soils

The amounts of fixed potassium found in the soils (Table 3) indicated that all the soils under investigation contained a considerable amount of fixed potassium. Soils fertilized with the high level of potassium contained greater amounts of fixed potassium as compared to those which received low level applications. Differences between soils were small. The application of a high level of potassium resulted in an increase in the exchangeable, nitric acid extractable, and total potassium of all the soils under study, because these forms tend to remain in equilibrium with each other (16, 30, 34). Pratt and

Table 2. Chemical and physical properties of soils.

Properties	Soils		
	Brown	Black	Gray
pH	7.3	8.2	8.4
CEC me per 100 g	39.0	68.1	25.1
CaCO <sub>3</sub> , %	0.0	3.7	71.0
Clay, %	46.8	50.8	42.8
Silt, %	40.0	34.2	41.0
Sand, %	13.2	15.0	16.2
Textural class	Clay	Clay	Silty clay

Table 3. Original amounts of fixed potassium in different soils fertilized with low and high levels of potassium.

	me per 100 g					
	Brown Soil		Black Soil		Gray Soil	
	Low K	High K	Low K	High K	Low K	High K
Total K	15.7	16.4	10.3	11.4	9.5	11.8
HNO <sub>3</sub> extracted K <sup>x</sup>	2.49	3.07	2.63	3.53	2.41	2.97
<u>Exchangeable K</u>						
a) With NH <sub>4</sub> OAc	0.71	1.03	0.81	1.47	0.65	0.98
b) With NaOAc	1.47	1.80	1.60	2.05	1.23	1.68
<u>Fixed K<sup>xx</sup></u>						
a) With NH <sub>4</sub> OAc	1.78	2.04	1.82	2.06	1.76	1.99
b) With NaOAc	1.02	1.27	1.03	1.48	1.18	1.29
CEC of soils	39.1	38.9	68.3	67.9	25.2	25.0

<sup>x</sup> The HNO<sub>3</sub> extractable potassium is equal to the exchangeable plus the fixed potassium.

<sup>xx</sup> Fixed potassium was calculated by subtracting the exchangeable from the HNO<sub>3</sub> extracted potassium.

Goulben (32) reported similar results under their long term fertility trials with citrus. They found that greater amounts of potassium were fixed with an increase in the rate of applied potassium.

Sodium acetate extracted a greater amount of exchangeable potassium than ammonium acetate extractant. Thus, the calculated values of the fixed potassium with the sodium acetate extractant were low as compared to those of the ammonium acetate. The hydration properties of the two cations and thus the corresponding expansion of the lattice of the clay minerals largely explain their differential potassium extracting capacity. On entering the interplanar space of the mineral lattice, the hydrated sodium ion being much larger than the ammonium ion causes greater expansion of the lattice and thus replaces more of the potassium from the clays (4, pp. 68-77; 29, 34, p. 130).

The total potassium in the brown soil was greater than that of the black and the gray soils. A possible explanation for these larger amounts of potassium in the brown soil may be due to the presence of greater amounts of potassium bearing minerals. The values of the exchangeable and the nitric acid extractable potassium were greater in the black soil than in the brown soil, and the latter was greater than in the gray soil. It is noteworthy that the exchangeable and the nitric acid

extractable potassium, of all the soils under all the treatments, could be related to the cation exchange capacity of the respective soils (Table 3). As the cation exchange capacity of the soils increased, the values of the exchangeable and the nitric acid extractable potassium increased accordingly. A similar type of relationship was found by El Damaty et al. (14, pp. 161-164) in the soils of the United Arab Republic.

#### Effect of Extractants on Potassium Fixation

Data of potassium fixation in the different soils (Tables 4, 5, 6) indicated that the amount of potassium considered fixed was greater with ammonium acetate than with sodium acetate extractant. The sodium acetate extractant was found to be more effective in extracting potassium, thus leaving smaller amounts of potassium on the clay complex in all the treatments. This relationship stems from the differences in the effects of sodium and ammonium ions on the clay complex. Expansion of the lattice along the C axis, which varies with the kind of cation adsorbed, determines the ease of removal of the interlattice potassium. The ammonium ions produce a contracted lattice and hence prevent replacement of the potassium ions, which produce the same type of contracted lattice. On the other hand, the sodium ions expand the lattice along the C axis, and, therefore, replace more of

Table 4. Potassium fixation under different treatments in the brown soil.

Treatment No.	Moisture conditions	Extractants	me K per 100 g			Percent fixation		
			C <sub>1</sub> +	C <sub>2</sub> +	C <sub>3</sub> +	C <sub>1</sub> +	C <sub>2</sub> +	C <sub>3</sub> +
1	3 hours wet storage	NH <sub>4</sub> OAc	4.32	2.78	1.92	11.1	14.2	14.8
		NaOAc	2.02	1.35	1.02	5.2	6.9	7.8
2	3 hours wet storage and drying	NH <sub>4</sub> OAc	4.77	3.12	2.60	12.2	16.0	20.0
		NaOAc	3.64	2.61	2.17	9.3	13.4	16.7
3	8 hours wet storage	NH <sub>4</sub> OAc	4.37	2.88	2.39	11.2	14.8	18.4
		NaOAc	2.24	1.37	1.12	5.7	7.0	8.6
4	8 hours wet storage and drying	NH <sub>4</sub> OAc	4.89	3.12	2.61	12.5	16.0	20.1
		NaOAc	4.14	2.61	1.95	10.6	13.4	15.0
5	60 hours wet storage	NH <sub>4</sub> OAc	4.60	3.04	2.52	11.8	15.6	19.4
		NaOAc	2.61	1.61	1.32	6.7	8.3	10.2
6	60 hours wet storage and drying	NH <sub>4</sub> OAc	5.16	3.71	3.09	13.2	19.0	23.8
		NaOAc	4.35	2.62	2.18	11.2	13.4	16.8
7	16 days wet storage	NH <sub>4</sub> OAc	4.76	2.86	2.38	12.2	14.7	18.3
		NaOAc	2.86	1.72	1.52	7.3	8.8	11.7
8	16 days wet storage and drying	NH <sub>4</sub> OAc	6.54	4.10	3.70	16.8	21.0	28.5
		NaOAc	5.46	3.28	2.90	14.0	16.8	22.3
9	8 hours wet storage, drying and rewetting for 60 hours	NH <sub>4</sub> OAc	5.63	3.09	3.00	14.4	15.8	23.1
		NaOAc	4.36	2.62	2.25	11.2	13.4	17.3
10	8 hours wet storage drying, rewetting for 60 hours and drying	NH <sub>4</sub> OAc	6.47	3.88	3.03	16.6	19.9	23.3
		NaOAc	5.22	3.14	2.58	13.4	16.1	19.8

+ C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> designate the concentration of added K at the rate of 39.0, 19.5, and 13.0 me per 100 g of the soil, respectively.



Table 5. Potassium fixation under different treatments in the black soil.

Treatment No.	Moisture conditions	Extractants	me K per 100 g			Percent fixation		
			C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>
1	3 hours wet storage	NH <sub>4</sub> OAc	6.32	4.95	3.66	9.3	14.5	16.1
		NaOAc	4.90	3.43	2.54	7.2	10.1	11.2
2	3 hours wet storage and drying	NH <sub>4</sub> OAc	7.67	5.62	4.18	11.3	16.5	18.4
		NaOAc	6.99	4.87	3.62	10.3	14.3	16.0
3	8 hours wet storage	NH <sub>4</sub> OAc	6.86	5.29	3.94	10.1	15.5	17.4
		NaOAc	5.26	4.88	2.74	7.7	10.8	12.1
4	8 hours wet storage and drying	NH <sub>4</sub> OAc	7.74	4.67	4.31	11.4	16.7	18.5
		NaOAc	7.05	5.09	3.68	10.4	14.9	16.2
5	60 hours wet storage	NH <sub>4</sub> OAc	7.04	5.44	4.03	10.3	16.0	17.8
		NaOAc	5.27	3.61	2.68	7.7	10.6	11.8
6	60 hours wet storage and drying	NH <sub>4</sub> OAc	7.85	5.90	4.38	11.5	17.3	19.3
		NaOAc	7.55	5.29	3.92	11.1	15.5	17.3
7	16 days wet storage	NH <sub>4</sub> OAc	7.60	5.82	4.33	11.2	17.1	19.1
		NaOAc	6.43	4.50	3.55	9.5	13.2	14.8
8	16 days wet storage and drying	NH <sub>4</sub> OAc	8.90	7.23	5.38	13.1	21.2	23.7
		NaOAc	8.14	6.58	4.88	11.9	19.3	21.5
9	8 hours wet storage, drying and rewetting for 60 hours	NH <sub>4</sub> OAc	8.77	6.76	5.02	12.9	19.9	22.1
		NaOAc	7.28	5.10	3.79	10.7	15.0	16.7
10	8 hours wet storage drying, rewetting for 60 hours and drying	NH <sub>4</sub> OAc	9.13	6.89	4.91	13.4	20.2	22.5
		NaOAc	7.96	5.82	4.32	11.7	17.1	19.0

+ C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> designate the concentration of added K at the rate of 68.1, 34.0, and 22.7 me per 100 g of the soil, respectively.

Table 6. Potassium fixation under different treatments in the gray soil.

Treatment No.	Moisture conditions	Extractants	me K per 100 g			Percent fixation		
			C <sub>1</sub> +	C <sub>2</sub> +	C <sub>3</sub> +	C <sub>1</sub> +	C <sub>2</sub> +	C <sub>3</sub> +
1	3 hours wet storage	NH <sub>4</sub> OAc NaOAc	2.74 1.95	1.97 1.29	1.64 1.01	10.9 7.8	15.7 10.2	19.6 12.0
2	3 hours wet storage and drying	NH <sub>4</sub> OAc NaOAc	2.97 1.47	2.13 0.98	1.77 0.81	11.8 5.8	17.0 7.8	21.1 9.7
3	8 hours wet storage	NH <sub>4</sub> OAc NaOAc	4.02 2.16	2.78 1.42	2.30 1.18	16.0 8.6	22.2 11.4	27.5 14.2
4	8 hours wet storage and drying	NH <sub>4</sub> OAc NaOAc	4.05 2.22	2.73 1.46	2.36 1.22	16.2 8.9	22.6 11.7	28.2 14.6
5	60 hours wet storage	NH <sub>4</sub> OAc NaOAc	4.78 3.25	3.40 2.15	2.83 1.79	19.0 13.0	27.1 17.1	33.8 21.4
6	60 hours wet storage and drying	NH <sub>4</sub> OAc NaOAc	4.99 3.29	3.42 2.10	2.86 1.76	20.0 13.1	27.3 16.8	34.1 21.0
7	16 days wet storage	NH <sub>4</sub> OAc NaOAc	5.17 3.44	3.74 2.27	3.12 1.89	20.6 13.7	29.8 18.1	37.3 22.6
8	16 days wet storage and drying	NH <sub>4</sub> OAc NaOAc	5.13 3.39	3.71 2.23	3.09 1.86	20.4 13.5	29.6 17.8	36.9 22.2
9	8 hours wet storage, drying and rewetting for 60 hours	NH <sub>4</sub> OAc NaOAc	4.99 3.33	3.62 2.19	3.01 1.82	19.9 13.3	28.8 17.4	35.9 21.8
10	8 hours wet storage drying, rewetting for 60 hours and drying	NH <sub>4</sub> OAc NaOAc	5.06 3.36	3.66 2.22	3.06 1.85	20.2 13.4	29.2 17.8	36.5 22.1

+ C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> designate the concentration of added K at the rate of 25.10, 12.55, and 8.37 me per 100 g of the soil, respectively.

the fixed potassium. This is mainly due to the hydration property of the sodium ion which can adsorb a larger shell of water around its nucleus than the ammonium ion, which hydrates only slightly. The above results are in agreement with the findings of Barshad (4, pp. 68-75), and Reitemeier (34, p. 130).

The difference in the percent fixation of potassium between the two extractants (Table 7) for the three soils, was less at the higher concentration of added potassium than at the lower concentration. It is noteworthy that in the brown and black soils, the difference between the values of percent fixation of potassium, determined by the two extractants, decreased upon drying the samples. This suggested that when the potassium was strongly fixed by drying, due to the collapse of the clay mineral sheets (11, 25), the effectiveness of sodium in replacing the potassium between the sheets of the clay minerals was reduced. However, drying of the gray soil did not reduce the effectiveness of sodium acetate as compared to ammonium acetate. Probably, the force with which the potassium ions were held on the minerals of the gray soil was not strong enough to resist the expansion by the hydrated sodium ions thus causing more replacement of the adsorbed potassium ion. It would then appear that the difference in the fixation of potassium in these soils is due to the presence of different types of clay minerals.

Table 7. Difference in the percent fixation of potassium between the ammonium acetate and sodium acetate extracts under different treatments in the different soils.

Treatment No.	Moisture conditions	Black soil			Brown soil			Gray soil		
		C <sub>1</sub> <sup>+</sup>	C <sub>2</sub> <sup>+</sup>	C <sub>3</sub> <sup>+</sup>	C <sub>1</sub> <sup>+</sup>	C <sub>2</sub> <sup>+</sup>	C <sub>3</sub> <sup>+</sup>	C <sub>1</sub> <sup>+</sup>	C <sub>2</sub> <sup>+</sup>	C <sub>3</sub> <sup>+</sup>
1	3 hours wetting	2.1	4.4	4.9	5.9	7.3	7.0	3.1	5.5	7.6
2	3 hours wetting & drying	1.0	2.2	2.4	2.9	2.6	3.3	6.0	9.2	11.4
3	8 hours wetting	2.4	4.7	5.3	5.5	7.8	9.8	7.4	10.8	13.3
4	8 hours wetting & drying	1.0	1.8	2.3	1.9	2.6	5.1	7.3	10.9	13.6
5	60 hours wetting	2.6	5.4	6.0	5.1	7.3	9.2	6.0	10.0	12.4
6	60 hours wetting & drying	0.4	1.8	2.0	2.0	5.6	7.0	6.9	10.5	13.1
7	16 hours wetting	1.7	3.9	4.3	4.9	5.9	6.6	6.9	11.9	14.7
8	16 hours wetting & drying	1.2	1.9	2.2	2.8	4.2	6.2	6.9	11.8	14.7
9	8 hours wetting, drying & rewetting for 60 hours	2.2	4.9	3.4	3.2	2.4	5.8	6.6	11.4	14.1
10	8 hours wetting, drying, rewetting for 60 hours and drying	1.7	3.1	3.5	3.2	3.8	2.5	6.8	11.4	14.4

+ C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> designate the concentration of the added K at the rate of the CEC, one-half CEC, and one-third CEC of the soils, respectively.

However, no definite conclusion can be drawn without mineralogical study of these soils.

#### Effect of Concentration of Added Potassium on Potassium Fixation

Data of the potassium fixation due to the effect of different concentrations of added potassium in the brown, black, and gray soils (Tables 4, 5, 6), indicated that the amount of potassium fixed increased as the concentration of the added potassium was increased. These results are in agreement with the findings of many workers (3, 14, 23, 27, 28, 32, 42). However, on a percentage basis, the fixed potassium decreased as the concentrations increased. This trend was the same with all the treatments. Similar results were also reported by Joffe and Levine (21) and Richards and McLean (40). Further discussion on this topic is presented below.

#### Effect of Time and Moisture Conditions on Potassium Fixation

Data of potassium fixation indicated that in all the soils (Tables 4, 5, 6), when the samples were stored wet, the fixation of added potassium increased with time. The results of this study are in agreement with the findings of many workers (1, 23, 28, p. 269). On the other hand, a release of potassium on wetting is also reported (38, pp. 129-131). In the black and brown soils almost all

the fixations of added potassium occurred in less than three hours while in the gray soil potassium fixation continued and had almost doubled in amount by the 16th day (Figure 1). Drying cycles tended to result in somewhat increased fixation in the black and brown soils but produced no change in the gray soil (Figure 2).

It was observed that increasing the cycles of wetting and drying as shown by comparing treatments 3 and 4 to 9 and 10, resulted in increased percentages of fixed potassium for all soils for all concentrations. However, this increase was more in the gray soil (Table 6) than in the black (Table 5) and the brown (Table 4) soils. In general, wetting and drying cycles speeded up the rate of potassium fixation.

#### Potassium Fixation in the Clay and the Silt Plus Sand Fractions

It has been established by various workers (1, 9, 14, 27, 28, 42, 45) that the clay fraction of the soil is mainly responsible for the potassium fixation. However, substantial amounts of potassium are reported to be fixed by the silt and sand fractions (9, 28, 37).

The data on the fixation of potassium, in the clay and the silt plus sand fractions (Table 8), showed that considerable amounts of potassium were fixed by these fractions. However, it was found that, in all these soils, the clay fraction fixed greater amounts of potassium

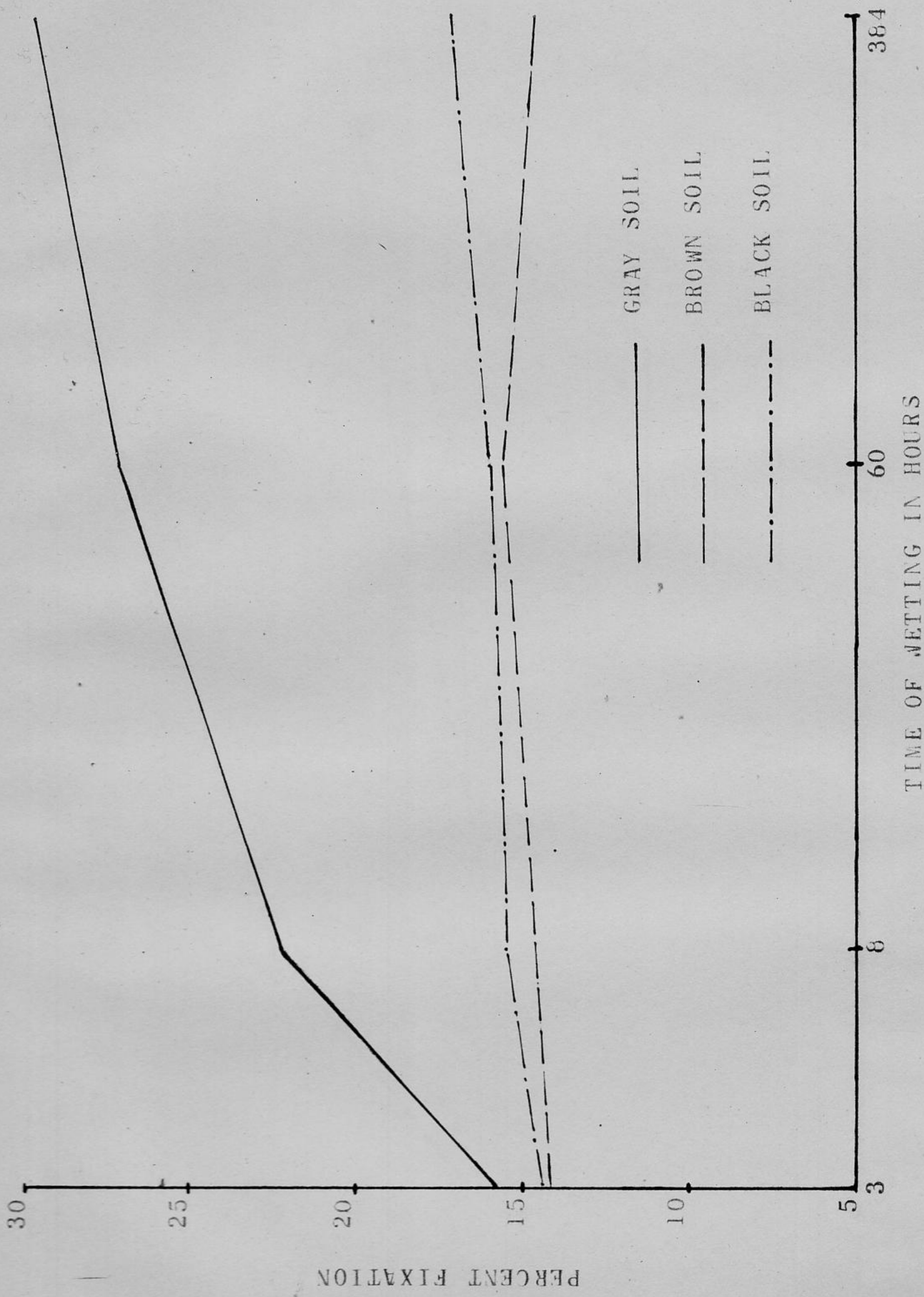


Figure 1. Effect of time on the fixation of potassium with wetting, when potassium was added at one-half cation exchange capacity of the soils.

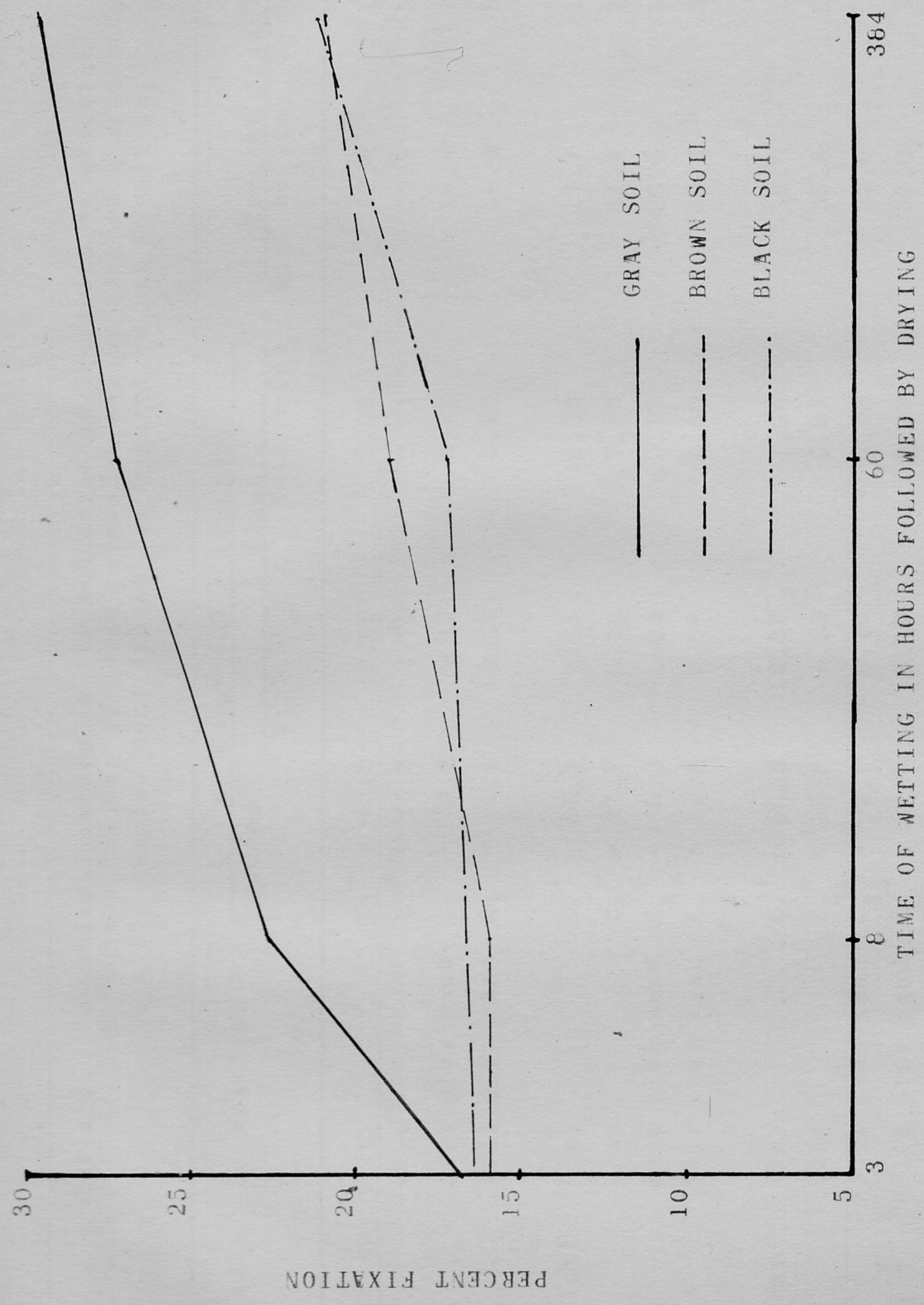


Figure 2. Effect of time on the fixation of potassium with wetting followed by drying when potassium was added at one-half cation exchange capacity of the soils.



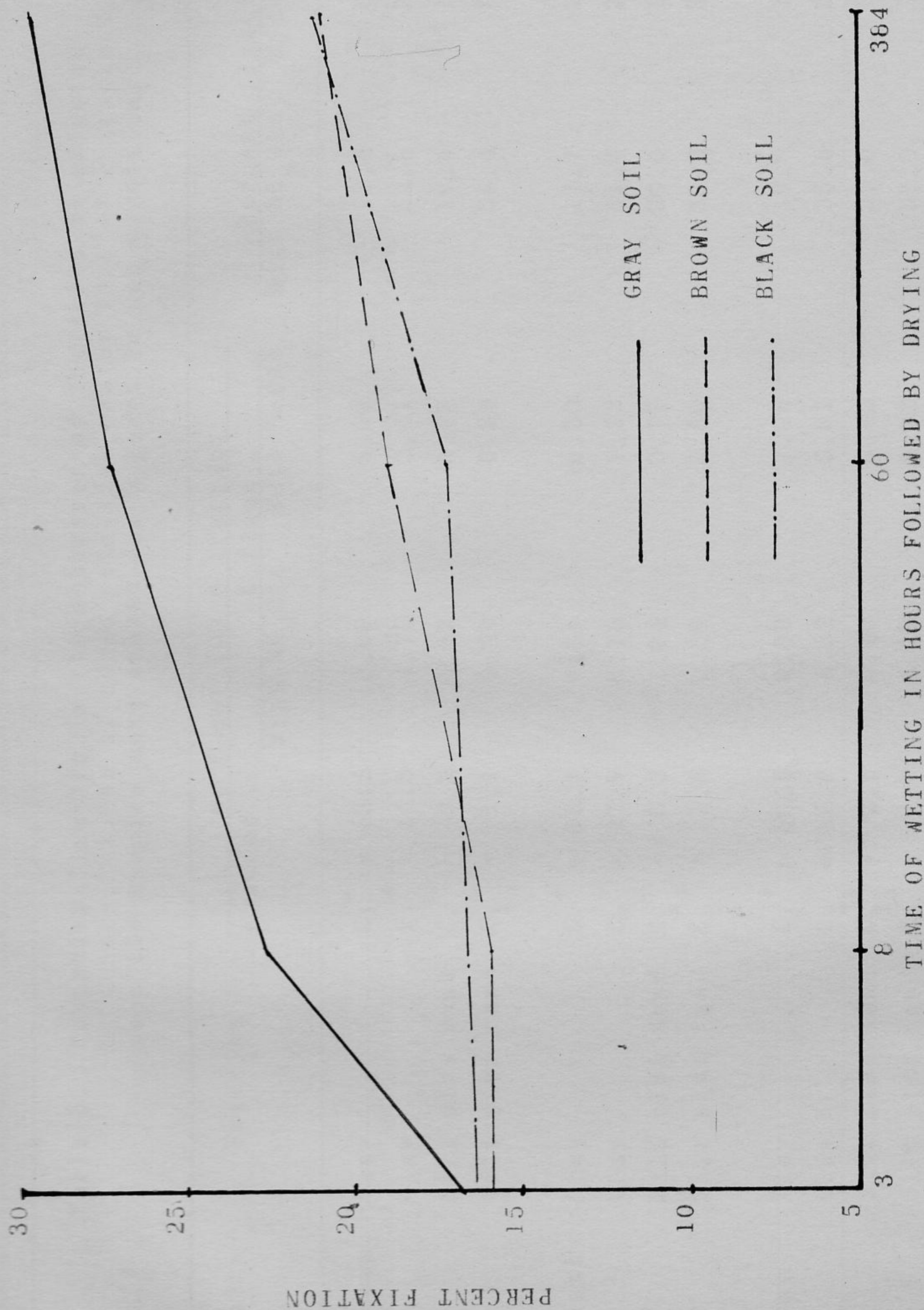


Figure 2. Effect of time on the fixation of potassium with wetting followed by drying when potassium was added at one-half cation exchange capacity of the soils.

Table 8. Potassium fixation in the separates of the soils as affected by concentrations of added potassium and by kind of extractant, when the samples were stored for 8 hours in wet condition.

Soils	Fraction	me K per 100 g fraction				Percent fixation	
		K added	With NH <sub>4</sub> OAc	K fixed	With NaOAc	With NH <sub>4</sub> OAc	With NaOAc
Brown	Clay	C <sub>1</sub> <sup>+</sup> = 43.5	8.00	6.00	18.4	13.8	
	Clay	C <sub>3</sub> <sup>+</sup> = 14.5	4.73	3.87	32.6	26.7	
	Silt plus sand	C <sub>1</sub> <sup>+</sup> = 3.2	0.62	0.45	19.4	14.1	
	Silt plus sand	C <sub>3</sub> <sup>+</sup> = 1.1	0.40	0.33	36.4	30.0	
Black	Clay	C <sub>1</sub> <sup>+</sup> = 83.7	14.81	10.30	17.7	12.4	
	Clay	C <sub>3</sub> <sup>+</sup> = 27.9	8.76	7.23	31.4	25.9	
	Silt plus sand	C <sub>1</sub> <sup>+</sup> = 5.3	1.06	0.77	20.0	14.5	
	Silt plus sand	C <sub>3</sub> <sup>+</sup> = 1.8	0.69	0.60	38.3	33.3	
Gray	Clay	C <sub>1</sub> <sup>+</sup> = 50.5	10.03	7.06	19.9	14.0	
	Clay	C <sub>3</sub> <sup>+</sup> = 16.8	6.52	5.02	35.8	29.9	
	Silt plus sand	C <sub>1</sub> <sup>+</sup> = 3.0	0.60	0.43	20.0	14.3	
	Silt plus sand	C <sub>3</sub> <sup>+</sup> = 1.0	0.38	0.32	38.0	32.0	

+ C<sub>1</sub> and C<sub>3</sub> refer to the concentrations of added potassium at the rate of the CEC and one-third CEC of the fractions, respectively.

than the silt plus sand fractions. In the brown soil, the amounts of potassium fixed by the clay and the silt plus sand fractions ranged from 3.87 to 8.0 and 0.33 to 0.62 me per 100 g of the fractions, respectively. The corresponding ranges in the black and the gray soils were 7.23 to 14.8, 0.60 to 1.06, and 5.02 to 10.03, 0.32 to 0.60 me per 100 g of the fractions, respectively. On percentage basis, the fixation of added potassium by the silt plus sand fraction of all the soils was greater than the clay fraction when potassium was added at the rate of one third cation exchange capacity. But when potassium was added at the rate of the cation exchange capacity, the percentage potassium fixed in the silt plus sand fractions was almost the same as that of the clay fractions.

Using the different concentrations of added potassium, similar trends in the results were obtained in the soil separates as in the whole soil. Greater amounts of potassium were fixed when potassium was added at the higher concentration. However, when potassium was added at the lower rate, the percentage of potassium fixed increased. Similar trends were also found, with the two extractants, by comparing the soil separates with the whole soil.

The amounts of potassium fixed by the clay as well as the silt plus sand fractions, in the three soils, differed from each other. This could be attributed to the

differences in their mineralogical constituents. However, it is not possible to substantiate the basis for the differential behaviour of the clay and the silt plus sand fractions without detailed mineralogical study of the separates.

#### Effect of Potassium Fixation on Cation Exchange Capacity

It is generally accepted that the cation exchange capacity is reduced as the fixation of potassium is increased. This relationship stems from the fact that the cation exchange capacity is a function of the negative charges on the clay. The potassium ion upon fixation, between the lattice unit sheets of clays, neutralizes some of the negative charges on the clay and reduces the cation exchange capacity. The cation exchange capacity of a system is decreased by an amount approximately equivalent to the fixation of added potassium (34, pp. 137-138, 42, 44, pp. 3-5). Similar results were found in the soils under study. In general, the cation exchange capacity of the three soils (Tables 9, 10, 11) was reduced as the time of wetting was increased. These decreases of the cation exchange capacity, from 3 hours to 16 days, were 0.96 and 0.97 me per 100 g of soil, in the black and gray soils, respectively. However, in the brown soil the decrease was 0.36 me per 100 g of soil. Upon wetting and drying, the decrease in the cation exchange capacity in the three soils

Table 9. The effect of potassium fixation under different treatments, on the CEC of the brown soil, when K was added at the rate of one-half CEC of the soil.

Treatment No.	Moisture condition	me per 100 g of soil			
		Original CEC	CEC after K fixation	Reduction in CEC	Fixed K
1	3 hours wetting	39.0	37.64	1.36	1.35
2	3 hours wetting and drying	39.0	36.72	2.28	2.61
3	8 hours wetting	39.0	37.63	1.37	1.37
4	8 hours wetting and drying	39.0	36.72	2.28	2.61
5	60 hours wetting	39.0	37.39	1.61	1.61
6	60 hours wetting and drying	39.0	36.72	2.28	2.62
7	16 days wetting	39.0	37.28	1.72	1.72
8	16 days wetting and drying	39.0	35.73	3.27	3.28
9	8 hours wetting, drying and rewetting for 60 hours	39.0	36.72	2.28	2.62
10	8 hours wetting, drying, rewetting for 60 hours and drying	39.0	36.17	2.83	3.14

+ The part of the added potassium not extracted with NaOAc was used as fixed K (Table 4).

Table 10. The effect of potassium fixation under different treatments, on the CEC of the black soil, when K was added at the rate of one-half CEC of the soil.

Treatment No.	Moisture condition	me per 100 g of soil			
		Original CEC	CEC after K fixation	Reduction in CEC	Fixed <sup>†</sup> K
1	3 hours wetting	68.06	64.53	3.53	3.43
2	3 hours wetting and drying	68.06	63.25	4.81	4.87
3	8 hours wetting	68.06	64.42	3.64	4.88
4	8 hours wetting and drying	68.06	63.19	4.87	5.09
5	60 hours wetting	68.06	64.39	3.67	3.61
6	60 hours wetting and drying	68.06	62.80	5.26	5.29
7	16 days wetting	68.06	63.57	4.49	4.50
8	16 days wetting and drying	68.06	61.62	6.44	6.58
9	8 hours wetting, drying and rewetting for 60 hours	68.06	63.07	4.99	5.10
10	8 hours wetting, drying, rewetting for 60 hours and drying	68.06	62.52	5.54	5.82

<sup>†</sup> The part of the added potassium not extracted with NaOAc was used as fixed K (Table 5).

Table 11. The effect of potassium fixation under different treatments, on the CEC of the gray soil, when K was added at the rate of one-half CEC of the soil.

Treatment No.	Moisture condition	me per 100 g of soil			
		Original CEC	CEC after K fixation	Reduction in CEC	Fixed <sup>+</sup> K
1	3 hours wetting	25.10	23.77	1.33	1.29
2	3 hours wetting and drying	25.10	24.00	1.00	0.98
3	8 hours wetting	25.10	23.72	1.38	1.42
4	8 hours wetting and drying	25.10	23.50	1.60	1.46
5	60 hours wetting	25.10	23.72	1.38	2.15
6	60 hours wetting and drying	25.10	22.16	2.94	2.10
7	16 days wetting	25.10	22.80	2.30	2.27
8	16 days wetting and drying	25.10	22.41	2.69	2.23
9	8 hours wetting, drying and rewetting for 60 hours	25.10	22.80	2.30	2.19
10	8 hours wetting, drying, rewetting for 60 hours and drying	25.10	22.84	2.26	2.22

<sup>+</sup> The part of the added potassium not extracted with NaOAc was used as fixed K (Table 6).

was greater as compared to the wetting alone. Alternate wetting and drying (treatments 9 and 10) did not further increase the reduction in the cation exchange capacity as compared to the 16 days wetting and drying (treatment 8). This variation in the reduction of cation exchange capacity on potassium fixation in these soils could be attributed to the presence of different type of clay minerals.

It was found that, in the brown and black soils, the reduction in the cation exchange capacity was about the same as the amounts of potassium fixed. There were some slight differences, in the gray soil, between the reduction in the cation exchange capacity compared to the amounts of potassium fixed. No explanation could be given to these differences from the present information on the soils. The same relationship between cation exchange capacity and potassium fixation was found by Pratt and Goulben (32) who reported that the fixation of potassium was accompanied by a reduction in cation exchange capacity but there was a lack of equivalence between the two.



## V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Three soils, the brown Zaoutar series, the black Innsar series, and the gray Bazouriye series, of Lebanon, were selected for a study of potassium fixation. Each soil had received two levels of potassium application (low and high) and had grown a crop of wheat in a pot experiment. The objectives of these studies were to evaluate the amounts of fixed potassium present in the soils, and to determine the effect of various factors on the fixation of potassium. The study also included the role of the clay and the silt plus sand fractions in the fixation of potassium and the effect of potassium fixation on the cation exchange capacity.

The fixed potassium in the soils was determined by subtracting the exchangeable potassium from the nitric acid extractable potassium. The adsorbed potassium was extracted with two extractants, N ammonium acetate and N sodium acetate.

In order to determine the capacity of the soils to fix potassium, potassium was added at three concentrations: at an amount equivalent to the cation exchange capacity, one-half, and one-third of the cation exchange capacity. After the addition of potassium, samples were subjected to

different moisture conditions. One set of conditions included wet storage for 3, 8, 60 hours, and 16 days. Another set involved the same length of wet storage followed by air drying. A third set involved wetting and drying cycles. The fixed potassium was considered as the difference between added potassium and the potassium that could be extracted.

The clay and the silt plus sand fractions of the soils were separated by dispersing the soils in dilute sodium carbonate solution, followed by centrifugation. Cation exchange capacity, after the fixation of potassium, was determined on the samples treated with potassium at the rate of one-half cation exchange capacity of the soils.

Application of high level of potassium, increased the level of the exchangeable, fixed, and total potassium, in all the soils. However, the original amounts of fixed potassium were almost equal in all the three soils when compared at each of the levels of applied potassium. The exchangeable potassium was greater in the black than in the brown soils which was greater than in the gray soil.

The order of the amounts of added potassium fixed by the different soils was black > brown > gray. The amounts of potassium fixed by the black soil ranged from 2.54 to 9.13 me per 100 g of soil. The corresponding values for the brown and gray soils were 1.02 to 6.54, and 0.81 to 5.17 me per 100 g of soil, respectively.

The amount of potassium extracted with sodium acetate was greater than with ammonium acetate. Thus the amounts of potassium considered as fixed when sodium acetate was used were less than those with ammonium acetate. The difference in the percent fixation of potassium between the two extractants in all the soils was less at the higher concentration of potassium than at the lower one. In the brown and black soils this difference was less upon drying the samples, while in the gray soil it did not decrease.

The amounts of potassium fixed increased with an increase in the concentration of added potassium. The fixation, on a percentage basis, was greater at the lower concentrations of added potassium.

With increased time of wetting, the relative amount of potassium fixed was greater in the gray soil compared to the brown and black soils. Wetting and drying brought about additional increases in fixed potassium in the soils over the increases found with wetting alone. The relative amounts of fixed potassium in the gray soil with wetting and drying was greater and faster than the other two soils. The time to fix potassium could be reduced by increasing the cycles of wetting and drying. This implies that the natural potassium fixed under field conditions would be dependent upon the fluctuation of soil moisture conditions.

The clay fraction of all the soils fixed greater

amounts of potassium than the silt plus sand fraction. In the brown soil, the amounts of potassium fixed, by the clay and the silt plus sand fractions ranged from 3.87 to 8.0 and 0.33 to 0.62 me per 100 g of the fractions, respectively. The corresponding ranges in the black and gray soils were 7.23 to 14.8, 0.60 to 1.06, and 5.02 to 10.03, 0.32 to 0.60 me per 100 g of the fractions, respectively. On a percentage basis, the fixation of added potassium by the silt plus sand fraction of all the soils was greater than the clay fraction at the lower concentration of potassium but almost similar at the higher concentration. The amounts of potassium fixed by the clay as well as the silt plus sand fractions of the three soils differed from each other. This is probably due to the differences in the mineralogical constituents. It is suggested that the mineralogical analysis, on the clay and the silt plus sand fractions should be carried out.

The cation exchange capacity of the soils decreased with increase in potassium fixation. In the brown and black soils, the reduction in the cation exchange capacity approximated the amounts of potassium fixed. In the gray soil, there was slight variation between the reduction in the cation exchange capacity and the amount of potassium fixed.

It is recommended that further studies be made on

the variations in fixed potassium content resulting from drying and wetting under field conditions with different moisture regimes. The implications of this study are extensive in relation to layer silicate mineral conversion, potassium availability to plants, soil testing to determine the potassium status of soils, and potassium fertilization. It is further recommended that a mineralogical study be made on the three soils used in this investigation with regard to the relationship between the types of layer silicate clays and the amounts of fixed potassium under different moisture and drying conditions. This would help to understand the mechanism of changes on the amounts of fixed potassium.

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