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Calcium-Potassium Interactions in Soils and Plants: I. Lime-Induced Potassium Fixation in Mardin Silt Loam

Die Kaliumaufnahme der Pflanzen
in Abhängigkeit vom Kalkzustand des Bodens

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L'absorption du potassium par les plantes en fonction de la teneur du sol en chaux

●

La absorción de Potasio por las plantas bajo la dependencia
de la situación caliza del suelo

●

A absorção de potassa por parte das plantas em dependência
do teôr de cal no solo

●

L'assorbimento di potassio delle piante in relazione al calcio presente nel terreno

●

Toprağın kireç vaziyetine bağlı olarak bitkinin kalium'u alması

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Foreword. Ehrenberg points out in his lime-potash law that with high concentrations of Ca in the soil the plants cannot take up sufficient potassium to cover their need for this important nutrient. Moreover, other agricultural chemists came to the conclusion that the K/Ca relations in the soil determine the K/Ca ratio in the plants. The present work deals with these problems.

I. Fixation of Potassium by liming in a silt loam (Mardin Silt Loam). It is shown that by liming considerable K quantities may be fixed in the soil in a non-exchangeable form. This fixed potassium, however, can be rendered completely exchangeable again by ammonium acetate, so that, supposedly, it can be utilised by plants. It was found that by lime applications which saturated the sorption complex of the soil up to 78% with Ca, the potassium content in the soil solution decreases but that it rises again in presence of the free K_2CO_3 of the potassium content in the soil solution.

II. Lime-Potash antagonism in the plants. In this work an attempt is made to explain the fixed conditions in the soil in relation to their effect upon the potassium uptake of the plants. In the pot experiments the same silt loam soil (Mardin Silt Loam) of pH value 5.0 was used. Lucerne served as the experimental plant. The different series of experiments were adjusted to pH values of 5.0, 5.9, 6.8 and 7.9. The potassium applications amounted to 0, 50, 200 ppm K (mg/kg). It was found that the potassium content of the plants decreased only a little with the increasing degrees of saturation. In presence of free K_2CO_3, however, it again rose. In order to ascertain whether the potassium taken up by the plants is removed predominantly from the soil solution or from the exchangeable form, a comparable experiment was carried out with KCl and K_2CO_3. By the use of KCl on unlimed soil, about four times as much potash was taken up by the plants as compared with the equivalent K_2CO_3 application. The lime concentration of the soil solution had, therefore, decisively influenced the potassium uptake by the plants. The experimental results suggest that the fixed potassium obtained by conventional methods of estimation (with ammonium acetate at pH 7.0) is in reality largely available to plants.

In spite of these results, the authors are of the opinion that it is expedient to supply more potash to limed soils. The higher yields obtained by the liming of acid soils demand correspondingly more potassium, as potassium deficiency might intervene in certain cases, even if the liming does not restrict directly the K uptake.

Vorbemerkung. Ehrenberg weist in seinem Kalk-Kaligesetz darauf hin, daß bei hohen Ca-Konzentrationen im Boden die Pflanzen nicht genügend Kalium aufnehmen können, um ihren Bedarf an diesem wichtigen Nährstoff zu decken. Auch andere Agrikulturchemiker kamen zu dem Ergebnis, daß die K/Ca-Beziehungen im Boden maßgebend für das K/Ca-Verhältnis in der Pflanze seien. Mit diesen Fragen beschäftigt sich auch die vorliegende Arbeit.

I. Durch Kalkung verursachte Kaliumfestlegung in schluffigem Lehm (Mardin Silt Loam). Es wird aufgezeigt, daß durch eine Kalkung beträchtliche K-Mengen im Boden in nicht austauschbarer Form festgelegt werden können. Jedoch konnte dieses festgelegte Kalium durch Ammonazetat völlig wieder ausgetauscht werden, so daß zu vermuten war, daß es auch von den Pflanzen

Prefácio. Na sua lei «cal-potassa», Ehrenberg informa que as plantas, com grandes concentrações de Ca no solo, não podem absorver potassa em quantidade suficiente para satisfazer as necessidades que têm desta importante substância nutritiva. Outros agro-químicos tambem chegaram à conclusão que as relações de K/Ca, no solo, são decisivas para a relação de K/Ca na planta. Destas questões trata tambem o presente trabalho.

I. — Fixacção de Potassa em Barro lodoso (Mardin Silt Loam) por meio de Aplicação de Cal. Mostra-se que, por meio de aplicação de cal, consideraveis quantidades de K poderão ser fixas no solo em forma não permutavel. No entanto, foi possivel permutar completamente, com o auxílio de acetato de amônio, essa potassa fixada, de modo que é permitido supor-se que a potassa tambem podia ser aproveitada pelas plantas. Verificou-se que com aplicação de cal na quantidade suficiente para saturar o complexo de absorção do solo com até 78% de Ca, o teôr de K diminue na solução de solo, mas que, na presença de K_2CO_3 livre, o teôr de K na solução de solo aumenta novamente.

II. — Antagonismo entre Cal e Potassa nas Plantas. Neste trabalho tenta-se explicar as relações encontradas no solo e seu efeito sobre a absorção de K pelas plantas. Nás experiências feitas em recipientes, empregouse o mesmo solo argilo-lodoso (Mardin Silt Loam) de pH 5,0. A alfafa serviu de planta de ensaio. As diversas séries de ensaio foram acertadas aos valores pH de 5,0 5,9 6,8 e 7,9. A potassa foi aplicada nas quantidades de 0, 50, 200 ppm K (mg/kg). Verificou-se que o teôr de potassa nas plantas diminuiu um pouco com o aumento do grau de saturação, aumentando, porém, novamente na presença de K_2Co_3 livre. Afim de se verificar se a potassa absorvida pelas plantas foi, essencialmente, tirada da solução de solo ou da forma permutavel, foi feita uma experiência comparativa com KCl e K_2Co_3. No emprego de KCl em solo sem cal, foi, em comparação com a aplicação equivalente de K_2CO_3, absorvido, pelas plantas, o quadruplo da quantidade de K. A concentração de cal na solução de solo, portanto, influenciou de modo decisivo a absorção de potassa pelas plantas. Os resultados das experiências permitem a conclusão que a potassa «fixada», verificada pelos convencionais métodos de determinação (com acetato de amônio de pH 7,0), està, de fato, em grande parte à disposição das plantas.

Apesar dessas verificações, são os autores de opinião de ser conveniente aplicar maior quantidade de potassa aos solos enriquecidos de cal. As safras mais volumosas, possibilitadas pela aplicação de cal em solos àcidos, requerem um correspondente aumento de potássio, de forma que, eventualmente, poderia hàver carência de potássio, mesmo na eventualidade da aplicação de cal não dificultar, diretamente, a absorção de K.

Prefazione. Ehrenberg, nella sua legge sul rapporto Calcio-potassio, fa presente che, con alte concentrazioni di calcio nel terreno, le piante non possono assorbire sufficienti quantitativi di potassio per coprire il loro fabbisogno di questa importante sostanza nutritiva. Anche altri chimici agrari sono giunti alla conclusione che il rapporto K-Ca nel terreno influisce sul rapporto K-Ca nella pianta.

I. — Fissazione del potassio provocata dalla calcitazione, in terreno limoso-argilloide (Mardin Silt Loam). E' stato constatato che, attraverso la calcitazione, possono essere fissati nel terreno dei notevoli quantitativi di potassio in forma non scambiabile. Però questo potassio fissato può divenire di nuovo completamente scambiabile attraverso l'acetato ammonico, così che si può supporre che possa essere utilizzato anche dalle piante. E' stato altresì constatato che, con delle dosi di calce che saturino il complesso di assorbimento del terreno con Ca fino al 78%, il contenuto di potassio diminuisce nella soluzione del terreno; tale contenuto può però aumentare di nuovo in presenza di K_2CO_3 libero.

II. — Antagonisco Calcio-potassio nelle piante. In questo lavoro si è cercato di chiarire quale effetto abbiano i preesistenti rapporti del terreno sull'assorbimento di potassio da parte della pianta. Nelle esperienze in vaso venne usato lo stesso terreno limoso-argilloide (Mardin Silt Loam) di pH 5,0, e quale coltura sperimentale fu impiegata l'erba medica. Le diverse file di esperienze vennero regolate a pH 5,0; 5,9; 6,8; e 7,9. Le dosi potassiche impiegate furono di 0, 50, 200 pm K (mg/Kg). Si poté accertare che il contenuto potassico delle piante diminuiva notevolmente con l'aumentare del grado di saturazione, mentre aumentava in presenza di K_2CO_3 libero. Per sa pere se il potassio assorbito dalle piante provenisse dalla soluzione del terreno oppure dalla forma scambiabile, venne fatta una prova di confronto con KCl e K_2CO_3.

Con l'impiego di KCl in terreno non calcitato, in confronto con una dose equivalente di K_2CO_3, venne assorbita dalle piante una quantità quasi quadrupla di potassio. La concentrazione di calcio nella soluzione del terreno ha quindi influenzato decisamente l'assorbimento del potassio da parte della pianta. I risultati sperimentali fanno supporre che il potassio «fissato», determinato con i metodi convenzionali (acetato ammonico a pH 7,0), sia in gran parte a disposizione delle piante.

Malgrado questi risultati, gli autori sono del parere che sia opportuno di approvvigionare i terreni calcitati con maggiore quantità di potassa. Gli incrementi di produzione possibili attraverso una calcitazione dei terreni richiedono parallelamente maggiori quantitativi di potassa, di modo che potrebbe verificarsi in determinate circostanze una carenza potassica, anche quando la calcitazione non ostacoli direttamente l'assorbimento di potassio.

Giriş. Toprakta fazla kireç konsantrasyonu bulunduğu takdirde bitkilerin Kalium ihtiyaclarını kapatmak için bu mühim besin maddesini kâfi mikdarda alamadıklarını, Ehrenberg kendi Kireç-Kalium kanunu ile göstermiştir. Diğer Ziraat Kimyagerleri de topraktaki K/Ca münasebetlerinin bitkideki K/Ca — nisbetine ölçü olabileceği neticesine varmışlardır. Bu mesai de aynı meseleler ile meşgul olmaktadır.

I. Kireçleme çok ince kumlu tınlı toprakta (Mardin Silt Loam) Kalium'un gayri münhal hale geçmesine sebeb oldu: Kireçleme ile toprakta fazla mikdarda Kalium'un kabili mubadele olmıyan formada tesbit olunabildiği açıklanmış bulunuyor. Mamafih bu tesbit olunan Kalium'un Amonasetat vasıtası ile tekrar mubadele edilebileceği ve böylece mubadele edilen bu Kalium'un bitkiler tarafından da sömürülebileceği tahmin olunabilir. Toprağin sorptionkomplexleri kireç verilerek %78 kadar Ca ile doyuruldukları takdirde K — mikdarının toprak mahlülünde azaldığı, fakat serbest K_2CO_3 muvacehesinde toprak mahlulundeki Kalium mikdarının tekrar yükseldiği tesbit edilmiştir.

II. Bitkilerde Kireç — Kalium Antagonisması: Bitkilerin K-alması üzerine toprakta tesbit edilmiş olan münasebetlerin tesirini izah etmek için şu deneme yapılmıştır: Saksı denemelerinde PH'sı 5,0 olan aynı incekumlu toprak (Mardin Silt Loam) kullanıldı ve deneme bitkisi olarak da yonca ekildi. Muhtelif deneme serilerinde PH-değerleri 5,0, 5,9, 6,8, 7,9 olarak düzenlendi. 0, 50, 200 ppm K (mg/Kg) verildi. Bitkilerin Kalium mikdarı artan işba derecesile hafif azaldı, serbest K_2CO_3 muvacehesinde ise tekrar yükseldi. Bitkilerin Kalium'u daha ziyade toprak mahlülunden mi, yoksa kabili mubadele formadan mı aldıklarını aydınlatmak için, KCl ve K_2CO_3 ile bir mukayese denemesi yapıldı. Bitkiler kireçlenmemiş toprakta ekivalant K_2CO_3 ya nazaran KCl den takriben dört misli daha fazla K sömürdüler. Deneme neticelerine istinaden, alelâde tayin metodları ile (Ammonium Asetat ile PH 7 de) bulunmuş olan „bağlı" Kalium'un hakikatten büyük bir kısmının bitkiler tarafından alınabileceği tahmin olunabilir.

Bu neticelere rağmen müelliflerin fikri, kireçlenmiş toprakların daha fazla Kalium'a ihtiyaç gösterdiği, kireçlenen asit topraklardan mümkün mertebe fazla mahsul almak için, her nekadar kireçleme direkt olarak K - alınmasını önlemese de, kireç mikdarına uygun bir şekilde daha fazla Kalium ile gübrelenmeleri ve bu vaziyet tahtında bir Kalium noksanlığının giderilebileceği merkezindedir.

Calcium-Potassium Interactions in Soils and Plants: I. Lime-induced Potassium Fixation[1] in Mardin Silt Loam

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The influence of calcium-potassium interactions in soils and plants on growth and chemical composition of plants has been the subject of extensive investigation. Pierre and Bower (22) and Peech and Bradfield (20) have summarized the literature dealing with (*a*) the influence of lime upon the level of exchangeable or water-soluble potassium in soils and (*b*) the effect of lime or other sources of calcium on the absorption of potassium by plants.

The economic significance of this problem is found in the many observations (4, 5, 6, 13, 27, 28) that lime or potassium applied alone to soils may often be of little value; in some instances applications of either lime or potassium have had a deleterious effect on crop yields, whereas the two materials have been highly beneficial when applied together. Such observations have led to the concept of the necessity for a proper balance between calcium and potassium in soils.

Many investigators have demonstrated that addition of lime to soils often decreases absorption of potassium by plants and have accepted the hypothesis of Ehrenberg (8) that calcium ions may inhibit absorption of potassium by plants. There is good evidence, however, that lime may also influence the concentration of exchangeable as well as water-soluble potassium in soils. Limed and naturally calcareous soils are known to have relatively high capacities for fixing applied potassium into nonexchangeable forms (1, 2, 5, 9, 24, 28).

The principal object of this investigation was to determine whether the observed calcium-potassium interaction in the plant is due to a physiological antagonism between the ions or to calcium-potassium interactions induced in the soil. The present paper deals with interactions of calcium and potassium in soils, with particular emphasis on the problem of lime-induced potassium fixation. Subsequent papers will consider the significance of these soil interactions upon the reciprocal relationship between calcium and potassium in plants.

Lime-induced Potassium fixation in moist and dried soil

Laboratory studies on potassium fixation involved determination of the changes in exchangeable potassium content of soil upon moist incubation. The soil used in all phases of this investigation was Mardin silt loam with an initial pH of 5.0. The cation-exchange capacity was 13.1 me. per 100 g., and the exchangeable K was 75 pounds per acre determined by the method of Peech (21).

The soil at 26 per cent moisture content was taken from the field, screened through a 2-mm. sieve, and 25-g. undried samples were weighed into 50-ml. flasks to provide four replications of the treatments indicated in figure 1. Precipitated $CaCO_3$ was added, and the moisture content was increased to 45 per cent with distilled water

[1] "Potassium fixation" as used herein refers to the conversion of exchangeable or water-soluble potassium or both to forms not extractable with *N* ammonium acetate, pH 7.0.

to facilitate more rapid reaction with the lime. KCl was applied in solution along with the distilled water. The soil was allowed to dry to approximately 30 per cent moisture before the flasks were stoppered with cotton plugs. Thereafter the moisture content was maintained at 27±2 per cent.

At the end of 2 weeks, two replications were oven-dried at 70° C. Water was then added to restore the moisture content to 27 per cent. This drying and wetting treatment was repeated twice

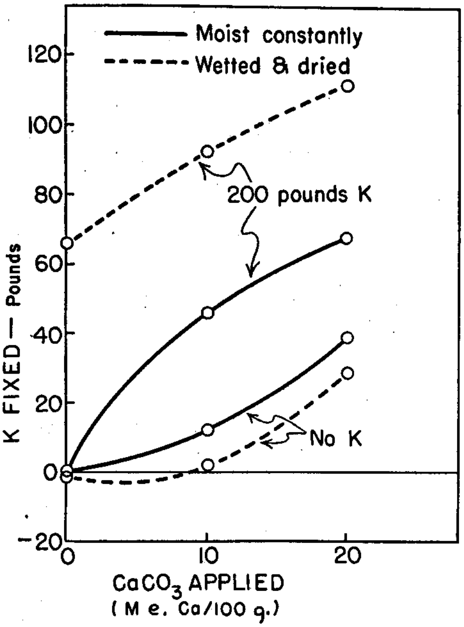

Fig. 1 Effect of Drying Mardin Silt Loam on Lime-Induced Potassium Fixation
Potassium fixed per 2,000,000 pounds soil

during the storage period at 2-week intervals. At the end of the 6 week period the moist soil was transferred to Büchner funnels and leached with a total of 200 ml. of neutral *N* ammonium acetate; the exchangeable potassium was determined by the method of Peech (21).

Figure 1 shows that approximately 34 per cent of the applied potassium was fixed at the highest level of liming. Even when no potassium was added, the exchangeable K level was reduced approximately 40 pounds by addition of lime. Though drying greatly increased the fixation of applied potassium, this fixation was apparently in no way related to the lime-induced fixation because the slopes of the curves in figure 1 representing the two conditions of incubation are essentially the same. For the soils that received no K there was a slight release of K at all lime levels as a result of drying. These data agree with the results of Attoe (2), which show that drying may increase or decrease the exchangeable K content of soil depending on the initial level of potassium in the soil.

Volk (26) was one of the first to demonstrate that large amounts of potassium may be fixed upon drying at 70° C. Truog and Jones (25) and Page and Baver (19) have suggested that potassium is trapped

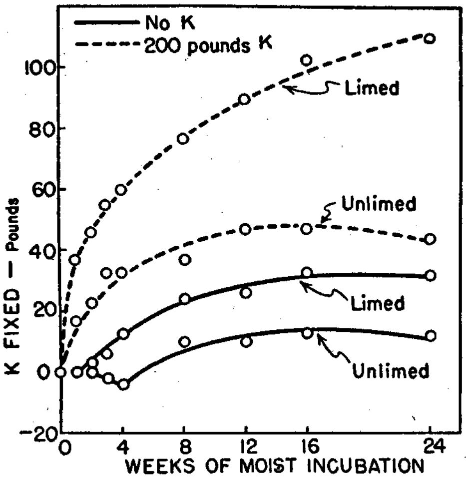

Fig. 2 Fixation of Potassium in Limed and Unlimed Mardin Silt Loam During Different Periods of Moist Storage
Potassium fixed per 2,000,000 pounds soil

between the layers of expanding lattice minerals when soils are dried. It may be concluded from figure 1 that lime-induced K fixation occurs independently of the fixation commonly observed when soils are dried. Furthermore, the mechanism proposed to explain the latter type of fixation is inadequate to account for the fixation induced by liming. Attoe (2) has also obtained data which suggest two distinct types of fixation, one which takes place in moist soil and is increased by liming, and another which occurs only on drying and is independent of soil pH.

Changes in Potassium fixation with time

To observe the changes in K fixation after different periods of moist storage, a number of replications of four treatments (lime and no lime, with and without K) were set up as previously described. The limed treatments received 10 me. $CaCO_3$/100 g. of soil. One replicate was analyzed at the end of each week for the first month. Subsequent analyses were made at intervals of 4 weeks. The soil was kept moist during the incubation period and was not dried prior to leaching. The results are shown in figure 2.

The exchangeable K levels of all treatments decreased after a period of moist storage. Approximately 20 per cent of the applied potassium had been fixed by the unlimed soil within the first 8 weeks, and there was little change after this time. The fixation of applied K in the limed soil continued to increase after 24 weeks of moist incubation, when approximately half of the added potassium had been converted to a nonexchangeable form.

Fixation of Potassium in an acid-leached soil

Mardin silt loam was placed in large Büchner funnels and leached with 0.05 *N* acetic acid. The acid-leached soil was washed with distilled water and allowed to dry. Then 25-g. samples of the soil were placed in flasks, and half of the samples were limed with 10 me. $CaCO_3$ per 100 g. of soil as previously described.

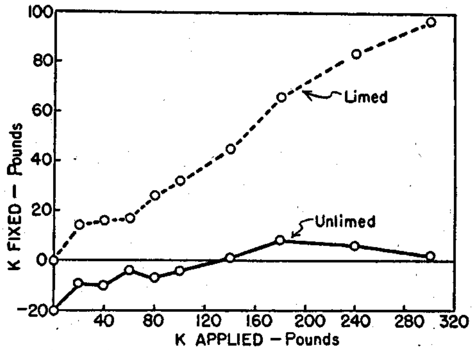

Fig. 3 Fixation of Different Amounts of Potassium by Limed and Unlimed Mardin Silt Loam in 8 Weeks

Soil initially leached with 0.05 *N* acetic acid; potassium applied and fixed per 2,000,000 pounds soil

Different amounts of KCl were added in solution to the limed and unlimed soils. The soils were kept moist for 8 weeks, and the exchangeable K was determined (fig. 3).

The amount of K fixed was directly related to the amount applied to the limed soil, approximately one third of the potassium being fixed by the limed soil at all levels of potassium. The unlimed acid-leached soil fixed little K even with the highest rate of applied potassium.

Volk (26), Stanford (24) and Martin *et al.* (18) have reported that leaching a soil with acid may reduce or completely destroy its capacity to fix potassium. Volk attributed this to a dissolution of the complex involved in fixation. The potassium-fixing capacity of the acid-leached Mardin soil used in the current investigation was restored upon liming.

Microbial fixation of Potassium

Several investigators (5, 7, 11) have suggested that the increased fixation of potassium in limed soil might result from stimulated microbiological activity. To investigate this proposed mechanism of fixation, samples of the undried Mardin soil were set up in the laboratory in the manner described previously. Chloropicrin was applied to two replicates of all treatments at the rate of 0.3 ml. per 25-g. sample of soil. The flasks were plugged with cotton and placed in an air-tight container. At the end of 6 weeks, exchangeable potassium was determined in both the treated and the untreated soil. The results showed no effect of chloropicrin upon the extent of lime-induced K fixation.

Hurwitz and Batchelor (10) have presented evidence that potassium may be fixed in the tissues of living organisms. For this type of fixation to be of any significance, however, extremely large quantities of energy material would have to be provided.

Equilibrium between exchangeable and water-soluble Potassium

A number of investigators have suggested that potassium must occupy exchange positions in order to be fixed. Joffe and Levine (12) concluded: "As more or less K is permitted to enter the exchange complex, so more or less K is fixed." They pointed out that since more potassium may enter the exchange complex as the percentage base saturation is increased, more K is available for fixation and consequently more K is fixed when an acid soil is limed. In the work of Joffe and Levine soils or minerals were dried to facilitate fixation, and these investigators' explanation of fixation is in accord with the mechanism of fixation proposed by Truog and Jones (25) and Page and Baver (19). But Joffe and Levine failed to differentiate between the fixation that takes place upon drying and that which occurs in moist, limed soil. The results of the current investigation indicate that these two types of fixation are independent.

Stanford (24) showed that hydrogen-illite fixed little potassium under moist conditions, but increasing the pH of the suspension greatly increased the capacity of illite to fix K. Stanford concluded that the fixation of potassium by micaceous minerals was an exchange reaction and that fixation was increased by removing hydrogen, aluminium, and iron from competition with potassium for exchange positions.

Blume and Purvis (5) in studying the effect of lime on K fixation set up two series of limed and unlimed soil. One series was leached with water at intervals during storage before determination of exchangeable potassium; the other series was analyzed for potassium directly without leaching with water. These investigators found that liming increased K fixation in the unleached soil; however, there was no evidence of lime-induced K fixation in the water-leached soil. They concluded that K is apparently fixed from the water-soluble fraction, and that the replaceable fraction of the element had no part in the phenomenon.

To study the relationship between the amount of applied potassium which enters the exchange complex and lime-induced K fixation, two laboratory experiments were conducted on Mardin silt loam. In one study, equivalent amounts of potassium (0.1 me. K/100 g. soil) in the form of KCl and K_2CO_3 were applied to two series of the limed and unlimed soil. After 8 weeks of moist storage, the exchangeable potassium was determined. Although liming resulted in a reduction in exchangeable potassium comparable to that observed in previous studies, the same amount of potassium was fixed from the two forms of potassium in both the limed and the unlimed soil. If the amount of K fixed in moist soil is a function of the amount that enters the exchange complex, fixation by the acid soil of potassium from K_2CO_3 should have exceeded that from KCl.

In a second experiment 1 me. of K per 100 g. of soil was applied to samples of soil, and $CaCO_3$ was applied at rates indicated in table 1. In one instance $CaSO_4$ was applied in addition to lime. The per cent base saturation at the 4 levels of liming corresponded to 1[illegible] (control), 48, 78, and an excess $CaCO_3$; the pH was 5.0, 5.9, 6.8 and 7.9. After eight weeks of moist storage two replicates were leached with 200 mls. of water and the leachate was analyzed for potassium. Two additional replicates were leached with neutral *N* ammonium acetate and the extracted potassium determined. The results are shown in table 1.

Table 1

Influence of $CaCO_3$ and gypsum on levels of exchangeable and water-soluble potassium in Mardin silt loam.

Treatment*)		K extracted from 100 g. soil	
$CaCO_3$	$CaSO_4$	By 200 ml. water	By *N* ammonium acetate, pH 7.0
		me.	*me.*
0	0	.082	.928
4,000	0	.057	.782
4,000	4,000	.090	.771
8,000	0	.028	.704
24,000	0	.052	.642

* Parts per 2 million parts of soil; 1 me. K/100 g. soil applied in all treatments.

There was a progressive reduction in the level of water-soluble and exchangeable potassium with the first two increments of lime. But the amount of potassium in the water extract increased in presence of excess $CaCO_3$, whereas the level of exchangeable potassium continued to diminish. The addition of $CaSO_4$ also increased the water-soluble potassium without affecting appreciably the level of exchangeable potassium.

These data relative to the influence of lime on water-soluble potassium are in agreement with observations by other investigators. MacIntire and associates (15, 16, 17) in extensive lysimeter studies have observed that additions of limestone to soil reduced the amount of potassium leached from the soil in rainwater. Baver (3) and Lyon and Bizzell (14) have made similar observations. Peech and Bradfield (20) explained this reduction on the basis of the relative energy of adsorption of Ca, H, and K ions. Their data on the adsorption of potassium from KCl by Miami clay saturated with different amounts of calcium show clearly how the addition of lime to an acid soil containing any neutral salt of a strong acid should decrease the concentration of potassium in the soil solution with increasing degree of calcium saturation of the soil until an excess of $CaCO_3$ has been added. Once the soil has been saturated with calcium, further additions of $CaCO_3$ should greatly increase the concentration of Ca ions, which would tend to liberate the adsorbed potassium into the soil solution. On the other hand, addition of gypsum should invariably increase the concentration of potassium in soil solution regardless of the initial degree of calcium saturation of the soil.

The data in table 1 show that fixation of potassium was greatest, not when the most potassium occupied exchange positions, as indicated by the lowest amount of K extracted by water, but rather in presence of an excess $CaCO_3$. Furthermore the fact that $CaSO_4$, which tended to displace some of the adsorbed K, had no effect on K fixation indicates further that the amount of potassium on the exchange complex has little relationship to the extent of potassium fixation under moist conditions in limed soil.

Table 2

Effect of pH of extraction solution on recovery of potassium from Mardin silt loam.

Treatment*)		Exchangeable K extracted*)			
$CaCO_3$	K	Soil leached first with NH_4 Ac, pH 7.0	Second leaching with NH_4 Ac, pH 4.8	Total of two extractions	Leached directly with NH_4 Ac, pH 4.8
0	0	89	6	95	92
4000	0	71	14	85	90
0	200	266	21	287	290
4000	200	213	61	274	285

* Parts per 2 million pounds of soil.

Influence of extracting solution on "measured" Potassium fixation

During the latter phase of this investigation, attention was directed to the method commonly used to measure potassium fixation. Applications of lime and potassium were made to samples of the Mardin soil used in the earlier studies. After 8 weeks of moist incubation, one series of soil was extracted with neutral *N* ammonium acetate, followed by a second leaching with *N* ammonium acetate, pH 4.8. Another series of samples was leached directly with the *N* ammonium acetate solution at pH 4.8. The potassium extracted under these conditions is shown in table 2.

Although considerable potassium appeared to be fixed when the soil was leached with the neutral ammonium acetate, virtually all of the "fixed" K was recovered when the soil was subsequently leached with the ammonium acetate solution at pH 4.8. When the soil was leached directly with the solution at pH 4.8, there was no evidence of fixation in either the limed or unlimed soil.

Summary

Relatively large amounts of potassium were fixed in nonexchangeable forms upon addition of $CaCO_3$ to acid Mardin silt loam. This fixation occurred in moist soil and was independent of the potassium fixation that took place when the soils were dried.

Hydrogen-saturated Mardin silt loam was found to fix no potassium upon moist storage. Fixation by this soil increased in direct relation to the increase in pH.

Lime-induced K fixation apparently is not an instantaneous reaction, since the fixation of potassium by the Mardin soil increased throughout 24 weeks of moist incubation.

There was no evidence that lime-induced K fixation was related to increased microbial activity.

No direct relationship between the amount of potassium entering the exchange complex and the amount fixed by moist soils was found. Although additions of lime up to 78 per cent base saturation resulted in a reduction of both water-soluble and exchangeable potassium, the presence of excess $CaCO_3$ further reduced the exchangeable potassium while increasing the concentration of potassium in a water extract. Calcium sulfate had no effect on the level of exchangeable potassium but increased the water-soluble fraction.

The potassium fixed in limed soils upon moist storage as determined by leaching with neutral ammonium acetate was found to be released upon a subsequent leaching with *N* ammonium acetate, pH 4.8. Furthermore, there was no evidence of lime-induced fixation when the soil was leached directly with the extraction solution at pH 4.8.

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