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Potassium in Two Humid Tropical Ultisols under a Corn and Soybean Cropping System: II. Dynamics

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ABSTRACT

Understanding the dynamics of soil K is important for the formulation of a sound fertilizer management strategy. Two experiments were conducted to determine the behavior of K in the soil after fertilization. Five rates of K (0 to 120 kg ha^{-1}) were applied to two Typic Paleudults, a loam and a sandy loam, in the Peruvian Amazon Basin. A three-crop rotation of corn (*Zea mays* L.), corn, and soybean [*Glycine max* (L.) Merr.] was planted at each site. Three additional crops of corn were grown at the loam site. Potassium rates were applied only to the first crop of each three-crop cycle. The corn stover was returned, while the soybean stover was removed. Soil samples were taken at germination, flowering, and harvest of each crop at 20-cm depth intervals to 60 cm in the loam and 80 cm in the sandy loam. Soil K was extracted with $NaHCO_3$, NH_4OAc, and concentrated H_2SO_4. Topsoil exchangeable K increased markedly with K addition, either as fertilizer or as stover, but rapidly decreased during cropping. Changes in the exchangeable pool were characterized with an exponential model. Increases in exchangeable K below 20 cm were of minor significance for the loam. For the sandy loam, however, subsoil exchangeable K was significantly increased to 60 cm. Evidences of K fixation and release were detected in the loam where the topsoil non-exchangeable pool peaked after K additions and decreased during cropping. There was no evidence of fixation in the sandy loam. These differences suggest that higher K rates can be applied to the finer textured soils and there is less risk of loss of K from the rooting zone.

AN UNDERSTANDING of the dynamics of K in soils of the humid tropics is needed to formulate management strategies for efficient crop production. Potassium fixation and release were once considered unimportant to the dynamics of K in soils of low cation exchange capacity (CEC) (Volk, 1938; Hoover, 1945). The presence of 2:1 clay minerals in Ultisols (Kitagawa and Moller, 1979) and even in Oxisols (Sanz, 1986) in the tropics has been reported. Some of these minerals are known to affect K fixation and release. Rich (1964) and Rich and Black (1964) found non-exchangeable K in the wedge zones of hydroxy-aluminum-interlayered vermiculites and weathered micas. There is a slow conversion of non-exchangeable K to exchangeable K (Martin and Sparks, 1983), and there have been indications of K release from non-exchangeable sources in Oxisols of Brazil cropped with soybeans (Rosolem and Nikagawa, 1985; Rosolem et al., 1988).

Potassium that is fixed becomes part of the non-exchangeable pool. A method to determine the size of this pool was developed by Hunter and Pratt (1957). The aim of their method is to extract that K which is fixed in the periphery of 2:1 clay minerals and can become available during a growing season if the soil solution K is depleted.

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Potassium leaching has been considered a major factor limiting the productivity of soils of the humid tropics (Grimme, 1985). Leaching in low CEC soils has been reported by many authors (Villachica, 1978; Grimme, 1985; Ayarza, 1988). The assumption that K fixation was not a factor in low CEC soils led researchers to estimate leaching losses by the difference between that applied and that accounted for (Villachica, 1978; Seubert, 1975). This may have resulted in overestimates of K leaching since some of the K that was unaccounted for may have gone to the non-exchangeable pool rather than to lower depths.

Some researchers have found that K leaching in these soils is not significant, and that the maintenance of large portions of the labile K in the biomass minimizes losses by leaching (Ayarza, 1988; Da Silva and Ritchey, 1982). Recycling of crop biomass represents a vital component of K management in agricultural systems on low CEC soils (Vilela and Ritchey, 1985). The residual effect of K fertilizer applications has been successfully prolonged by recycling the crop biomass in Oxisols of Brazil under high input systems (Da Silva and Ritchey, 1982). The impact of stover recycling and cropping on the size of the exchangeable K pool, however, has not been reported for Ultisols of the Amazon Basin under high input systems.

This study was undertaken to (i) determine the exchangeable and non-exchangeable K in the horizons of two soils in the humid tropics under a corn and soybean cropping system, (ii) evaluate the changes in soil K in terms of potential fixation and leaching, and (iii) suggest considerations for effective K fertilization in these soils.

MATERIALS AND METHODS

Field experiments were conducted at two sites at the Yurimaguas Experiment Station located in the Peruvian Amazon Basin. The soils at both sites are classified as fine-loamy, siliceous, isohyperthermic Typic Paleudults (Tyler et al., 1978). Selected properties of the soils at the two sites before application of treatments are presented in Table 1. There was more clay and a higher CEC in the topsoil at Site 1 than at Site 2. X-ray diffraction analysis of clay samples, however, indicated that the clay mineralogy was similar at the two sites, and that its composition was constant with depth. Kaolinite was the predominant clay mineral, but small amounts of mica (weathered), highly charged smectite, lowly charged vermiculite, and quartz were also present (Uribe, 1989). The smectite/vermiculite was slightly interlayered.

The experimental design, treatments, fertilization, and sampling methods were similar for each site and were described in the preceding companion paper. Soils were sampled at 20-cm intervals to 60 cm at Site 1 and 80 cm at Site 2. Soil samples were taken before the treatments were applied and at germination, flowering, and harvest of each crop. Exchangeable K was determined by extraction with a solution of 0.5 *M* $NaHCO_3$, 0.01 *M* EDTA, and 25 mg L^{-1} Superfloc (American Cynamid Company, Wayne, NJ).

Abbreviation; CEC, cation exchange capacity.

Table 1. Selected chemical and physical properties of the soils at various depths at the two sites in the Peruvian Amazon Basin before application of treatments.

Depth	Site 1						Site 2					
	Sand	Clay	Al-Sat	OC†	CEC‡	K§	Sand	Clay	Al-Sat	OC	CEC	K
cm	%			g kg^{-1}	cmol L^{-1}		%			g kg^{-1}	cmol L^{-1}	
0–20	45	17	56	10	4.6	0.06	69	9	66	10	2.3	0.05
20–40	42	20	90	—	4.3	0.03	63	13	90	—	2.8	0.03
40–60	41	22	95	—	5.4	0.03	61	15	92	—	3.3	0.03
60–80	—	—	—	—	—	—	56	21	94	—	5.7	0.03

† Organic Carbon
‡ Effective CEC
§ $NaHCO_3$ extractable K

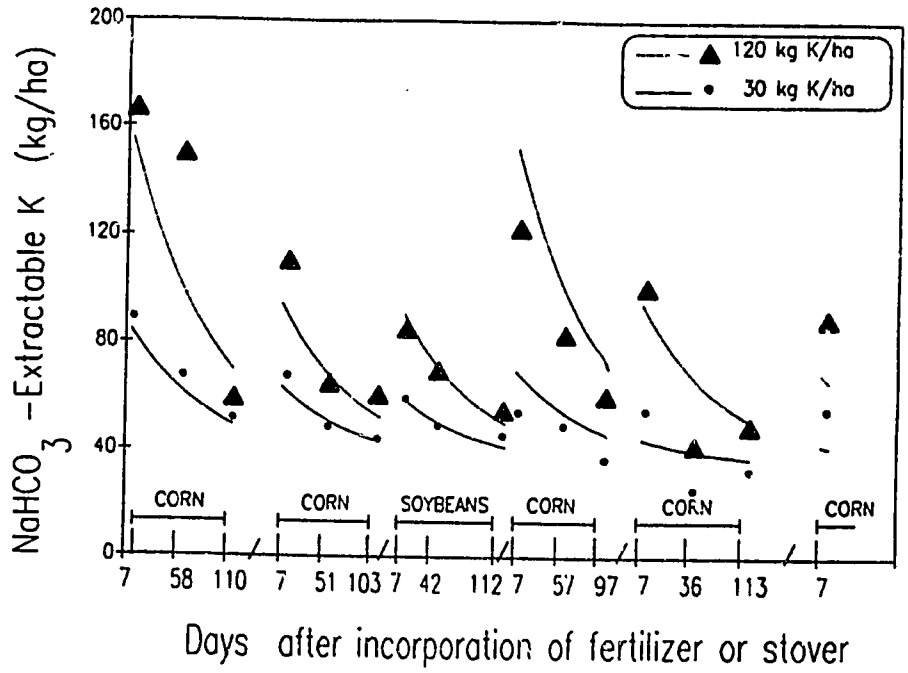

Fig. 1. Observed (points) and predicted (lines) $NaHCO_3$ extractable K in the topsoil at the highest and lowest fertilization rates for six crops sampled at germination, flowering, and harvest on the loam at Site 1.

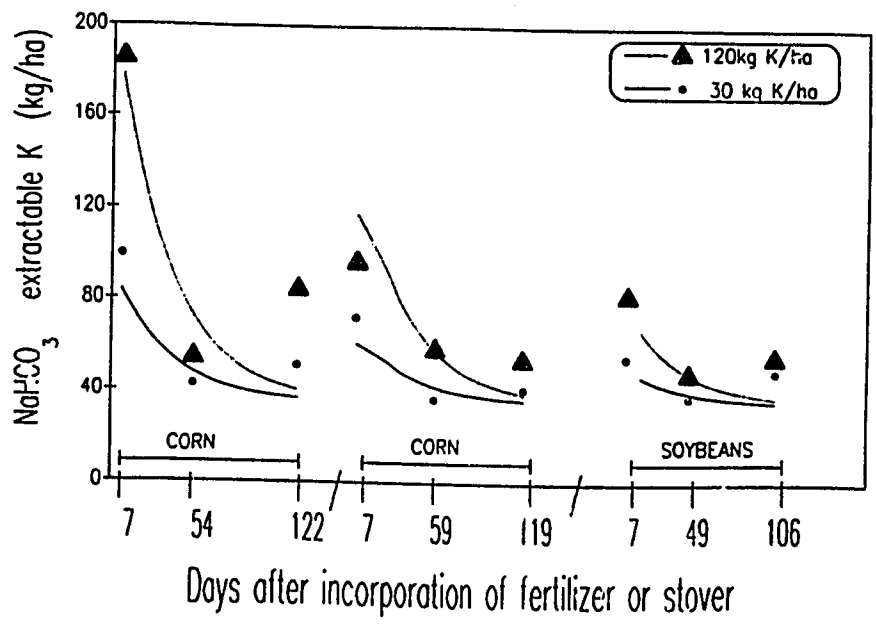

Fig. 2. Observed (points) and predicted (lines) $NaHCO_3$ extractable K in the topsoil at the highest and lowest fertilization rates for three crops sampled at germination, flowering, and harvest on the sandy loam at Site 2.

To determine the size of the non-exchangeable K pool, the H_2SO_4 extraction method outlined by Hunter and Pratt (1957) was used with some modifications: 10 g of ground soil were placed in preweighed 50-mL centrifuge tubes and stirred for 10 min in 25 mL of 1 *M* NH_4OAc. The tubes were then centrifuged at 850 × *g* for two min. The supernatant was filtered and extractable K determined. The tubes containing the soils were weighed to determine the amount of solution left in the soil so the quantity of NH_4OAc soluble K in that solution could be calculated. Water was then added to the tubes to complete 25 mL of solution, and 10 mL of concentrated H_2SO_4 were added and stirred vigorously for 10 s with a glass rod. After 30 min the soils were centrifuged and the supernatant filtered for K analysis. The amount of NH_4OAc soluble K present in solution before the H_2SO_4 addition was subtracted from the final K determination.

To describe the dynamics of exchangeable K in the topsoil, an exponential model developed by Cox et al. (1981) was used. The model was modified to account for the effect of stover incorporation on soil K levels. After modification, the model was expressed as follows:

$$K = K_{eq} + (K_o - K_{eq} + \alpha F + \beta R) \exp(-\gamma T) \quad [1]$$

where K = extractable K, kg ha^{-1}; K_{eq} = minimum or baseline extractable K; K_o = extractable K before fertilizer application or stover incorporation; F = fertilizer K added; R = K added by crop residue; T = time, days; γ = loss constant, per day. Parameters α and β represent the effectiveness of K applications by fertilizers and stover in changing soil K levels; a value of one would indicate 100% effectiveness. Parameters α, β, and γ were estimated with the NLIN procedure in SAS (SAS Inst. Inc., 1987). A value of 35 kg ha^{-1}, which was the minimum value observed from the check plots, was used for K_{eq}.

Analysis of variance was used to determine the effects of K rate and the K rate by time interaction on subsoil K levels. Regression also was used to describe the rate effect on the patterns of K accumulation in the subsoil.

Changes in the size of the exchangeable and non-exchangeable K pools were determined by differences between the K level at any given time and the level before treatments were applied. These values are referred to as the delta values.

RESULTS AND DISCUSSION

Exchangeable Potassium

Exchangeable ($NaHCO_3$ extractable) K in the topsoil was quite dynamic. Exchangeable K increased with increasing K fertilization, then decreased during cropping, showing little difference in level between the samples taken at flowering and at harvest (Fig. 1 and 2). Leaching could also be a factor in the decrease. After returning the stover and the K in the crop, exchangeable K was again increased. This increase became smaller with each cropping cycle. Some of the increase could also be due to release from non-exchangeable sources.

The exponential model fit the topsoil exchangeable K data for both soils quite well (Fig. 1 and 2). The estimated parameters for the model differed, however, for the two sites (Table 2). A larger percentage of the K applied as fertilizer was detected at germination in the sandier soil (Site 2) as indicated by the greater value for α. Fertilizer was only applied once at this location, so the estimate of α may not have been as accurate as that estimated at Site 1 which was fertilized twice.

Table 2. Parameters and coefficients of determination for Eq [1] at the two experimental sites.

Parameters†	Site 1	Site 2
α	0.85	1.28
β	1.16	0.90
γ	0.0115	0.0285
R^2	0.95**	0.93**

†α and β indicate the effectiveness of K in fertilizer and stover in changing extractable soil K; γ is the loss constant.

Potassium returned in stover had a greater impact on the exchangeable pool at Site 1 than at Site 2 as indicated by the greater value of parameter β. Its value is even greater than 1.0, which means that more K was applied than was measured in the stover. Since only aboveground biomass was measured, K added through root decomposition and that washed out of the plants before harvest could explain the finding that $\beta > 1.0$. We know of no reason, however, why this effect should differ between the two sites.

The higher value of the γ parameter for Site 2 indicates a faster rate of decline in exchangeable K after K addition and during crop growth. This may be related to the lower cation exchange capacity or it could be associated with greater leaching in the coarser-textured soil at that site.

There was an effect of K rate on subsoil exchangeable K at 20 to 40 cm and 20 to 60 cm for Sites 1 and 2, respectively (Table 3.) However, there was never a time-by-K-rate interaction, indicating that time had a similar effect on subsoil exchangeable K regardless of K rate. Moreover, the slopes of the regression equations to predict subsoil exchangeable K as a function of time were never significant, indicating no change in subsoil exchangeable K with time.

Potassium rate did not have a significant effect on subsoil exchangeable K below 40 cm at Site 1 (Table 3), indicating no evidence of leaching below that depth. The effect of K rate on exchangeable K at 20-40 cm showed that leaching was of minor importance. The increase in exchangeable K across the three crops was only 3.9 kg ha^{-1} at the highest rate of K applied. What is more evident is that decreases in exchangeable K, rather than increases, took place for the low K rates in the subsoil. This suggests K uptake from this depth. Uptake would not really be expected, however, because the extremely high Al saturation of this horizon should severly restrict root development (Table 1).

At Site 2, there was an effect of K rate on subsoil exchangeable K not only in the 20- to 40-cm horizon, but also at 40 to 60 cm (Table 3). In addition, the increase in exchangeable K at the highest K rate was larger than occurred at Site 1, suggesting greater leaching. According to the results of a previous study (Uribe and Cox, 1988), the soil at Site 2 has a lower K buffering capacity and would maintain a greater portion of the exchangeable K in the soil solution, making that K more prone to leaching. This concurs with the field observations.

Non-exchangeable Potassium

Potassium extracted with concentrated H_2SO_4 after removal of exchangeable K by NH_4OAc was used to

Table 3. Mean delta K values (soil K at a given time minus original soil K) for two forms of K at the two sites by depth and K rate, plus tests of significance on rate and time.

Depth	K Rate	Site 1 Exch. K	Site 1 Non-exch. K	Site 2 Exch. K	Site 2 Non-exch. K
cm		kg ha^{-1}			
20–40	0	−9.7	14.6	−9.7	3.7
	30	−4.9	13.8	2.1	3.4
	60	−1.4	17.4	−0.5	3.3
	90	−4.0	24.3	5.5	2.2
	120	[illegible]	18.2	7.2	−0.4
	K effect	**	NS	**	NS
	K*Time	NS	NS	NS	NS
	Slope	NS	**(b=0.13)†	NS	NS
40–60	0	−1.9	17.6	−2.3	9.3
	30	−2.0	20.0	2.5	5.6
	60	2.5	24.7	6.9	13.6
	90	0.1	25.9	7.0	10.6
	120	6.4	19.1	9.5	9.4
	K effect	NS	NS	**	NS
	K*Time	NS	NS	NS	NS
	Slope	NS	**(b=0.12)	NS	NS
60–80	0			0.6	−9.1
	30			−4.2	−2.3
	60			−1.7	3.4
	90			−1.6	−1.1
	120			0.8	8.2
	K effect			NS	NS
	K*Time			NS	NS
	Slope			NS	NS

** Significant at the 0.01 probability level.
† b = slope of the regression equation averaged over K rates; Delta K = a + b*Time, where Time is in days.

characterize the dynamics of non-exchangeable K. In the topsoil (0–20 cm) of Site 1, there were sampling time and K treatment effects, but there was not a time by treatment interaction. Thus, although there was an effect of time and of K rate on non-exchangeable K, those changes followed the same trend for all treatments (Fig. 3). At Site 2, however, neither time nor K rate had any effect upon non-exchangeable K.

The means across K rates throughout the experiment illustrate the differential effect of topsoil texture upon the changes in non-exchangeable K between the two experiments (Fig. 3). The size of the non-exchangeable K pool at Site 1 (higher clay content) peaked at germination of each crop (Fig. 3). Thus, a fraction of the applied K, either as fertilizer or as stover, was fixed. The non-exchangeable K pool declined as the crop developed, indicating that fixed K was released as the crop depleted exchangeable K. This mechanism would actually prevent loss by leaching and provide a reserve of K for periods of high demand. On the other hand, the size of the topsoil non-exchangeable K pool in Site 2 remained nearly constant throughout the experiment (Fig. 3). This variation in non-exchangeable K between the two soils also could con-

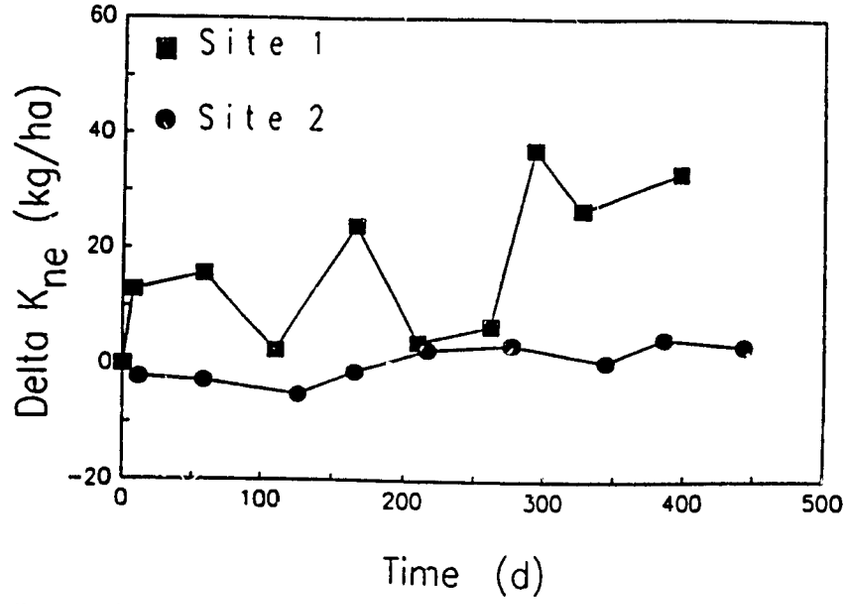

Fig. 3. Changes in topsoil non-exchangeable K (K_{ne}) averaged over K rates at Sites 1 and 2 throughout a corn, corn, soybean rotation. Except for the point at the origin, the sequence of samples is germination, flowering, and harvest for each crop.

tribute to the difference in the value of parameter α given in Table 2.

The rate of K applied had no effect upon the size of the non-exchangeable K pool at either site below 20 cm (Table 3). The time by K rate interaction also was not significant. However, at Site 1, non-exchangeable K below 20 cm tended to increase with time independently of K rate. This is evidenced by the significant and positive slopes of the regression lines between delta non-exchangeable K and time at the 20– to 40– and 40– to 60–cm depths. Fixation of added K cannot be used to explain these increasing trends because they were independent of K rate and occurred even when K was not added. Weathering of primary minerals is the only other flux that could increase the size of this pool and, as indicated previously, there are micas in the clay fraction. After ignoring the peaks at germination due to fixation of applied K, the same trend seemed to have taken place at the surface (Fig. 3). This increase may be associated with low solution concentrations from leaching, cropping, or both. Cropping can accelerate the weathering of primary minerals as it lowers the K concentration in solution and generates a driving force for K release. (Martin and Sparks, 1983).

Although Site 2 has a lower clay content, the mineralogical composition of the two soils is similar, and some fixation and weathering should also be expected in Site 2. Considering the very low clay content of this soil and the low concentration of 2:1 clay minerals, however, it is possible that small amounts of K fixation and release were not detectable under field experimental conditions.

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