Management and Dynamics of Potassium in a Humid Tropical Ultisol under a Rice-Cowpea Rotation

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ABSTRACT

Little is known about the role of K fertilization, stover management, and tillage methods on soil K availability as they affect rice (*Oryza sativa* L.) and cowpea [*Vigna unguiculata* (L.) Walp.] productivity on Ultisols of the humid tropics. The effects of five K rates (0–120 kg K ha^{-1}), returning or removing stover, and three tillage methods (no-till, strip, and conventional) were evaluated during 12 crops of rice and cowpea grown for a 4-yr period. Fertilizer K was applied to the first seven crops. The site was a recently cleared, 18-yr-old secondary forest in the Peruvian Amazon Basin. The soil was a fine-loamy, siliceous, isohyperthermic Typic Paleudult. Soils samples were collected at each crop harvest to 90 cm in 15-cm increments. Potassium fertilizer always increased grain yields when stover was removed. Conversely, responses to K additions were seldom obtained when the stover was returned. The extractable K (Modified Olsen) critical level for both upland rice and cowpeas was calculated to be 0.10 cmol L^{-1}. Returning stover with no K fertilization maintained soil K concentrations above critical levels for both species up to the last crop of the rotation. Residual effects of fertilizer K were prolonged by returning the stover. When stover was returned, subsoil exchangeable K increased with increasing rate of K fertilization. Removal of stover resulted in greater increases in subsoil exchangeable K at the 40 kg K ha^{-1} rate than at 120 kg K ha^{-1}, apparently because the higher rate resulted in K fixation. Tillage methods did not affect crop yields.

SHIFTING CULTIVATION is the most common form of agriculture practiced in the rain forest region of the Amazon basin (Sanchez, 1976), but increasing population pressure has reduced the time-span for forest regeneration between food crop production cycles. This has lowered crop productivity and thus sustainability of the system (Rhoades and Bidegaray, 1987), so other forms of crop and soil management are now being evaluated. One that has been suggested is a low-input system that includes maximum use efficiency of added and naturally present nutrients, returning residues, reduced tillage, and use of genotypes adapted to sub-optimal soil and environmental conditions (Sanchez and Salinas, 1981). Upland rice and cowpeas are crops recommended for this system on Ultisols in the Amazon Basin (Benites and Nurena, 1985).

Soils in the Amazon Basin are generally acid and have low extractable K concentrations (Sanchez and Buol, 1974). Corn yield responses to K fertilizers have been reported in these soils under high-input agriculture (Schnaar and McCollum, 1987). Upland rice grown under a high-input system in Rio Grande do Sul, Brazil also responded to K fertilization if the extractable K was less than 67 mg kg^{-1} (Fageira, 1982).

The K requirements of upland rice and cowpea under low-input systems on Ultisols in the Amazon basin have not been investigated in detail. However, responses to K fertilizers have been obtained for rice and cowpea in a low-input crop rotation on a Typic Haplorthox in the rain forest of Indonesia (Gill and Kamprath, 1990).

The role of returning crop residues on the maintenance of soil K levels and subsequent productivity of these cropping systems on Ultisols in the Amazon basin has not been investigated. Returning crop residues was found to be essential for prolonging the residual effects from K applications under high-input systems in acid, low-cation exchange capacity (CEC) Oxisols (Da Silva and Ritchey, 1982). The same authors reported that one application of 150 kg K ha^{-1} provided enough K for five crops when stover was returned. In another study established after clearing a virgin forest from a clayey Oxisol in the Brazilian Amazon Basin, a seven-crop rotation was adequately supplied with K when crop stover was returned (Smyth et al., 1987).

We suspect that tillage practices may also affect the utilization of K. In traditional shifting agriculture, the K in the ash from the burn remains at the soil surface. Incorporation of this ash by conventional tillage may affect the availability of K and the need for additional fertilization.

Potassium disappearance from the exchangeable pool in soils in the Amazon basin has often been attributed to leaching (Villachica, 1978; Seubert, 1975). Mineralogical analysis of the clay fraction of soils from the Peruvian and Brazilian Amazon basin has revealed the presence of 2:1 clay minerals (Ayarza, 1988; Tyler et al., 1978; Kitagawa and Freire, 1979), suggesting the possibility of selective K sorption at the surfaces of tetrahedral layers. An example of this was shown by Ayarza (1988) who found that 30% of the K applied to Ultisols in the Amazon basin was retained against $Mg(OAc)_2$ extraction, but not against NH_4OAc. With increasing K concentration, further sorption occurs at wedge sites, until finally the silicate lattice tends to collapse, entrapping K ions inside the crystal in a non-exchangeable form (Sparks and Huang, 1985). In some preliminary incubation studies involving the clay fraction separated from Ultisols from Yurimaguas, it was found that between 40 and 70% of the applied K was fixed (Uribe and Cox, 1989). Furthermore, clays from surface horizons retained more K in this form than those from subsoils.

The objectives of the current study were to (i) assess the K fertilizer requirements for a low-input rice-cowpea rotation grown on an Ultisol in the Amazon Basin, (ii) determine the K use efficiency and critical levels for these crops, (iii) evaluate the role of stover management on soil K levels and on the sustainability of a low-input rotation, (iv) compare the effects of no-till, minimum tillage and conventional tillage systems on grain yields, and (v) determine the effect of K additions from fertilizer and stover on the forms of K in the soil profile and on K uptake by rice and cowpeas.

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Abbreviations: CEC, cation exchange capacity; and Δ K, change in exchangeable K.

Table 1. Effect of stover management and K fertilization on yields of 12 cowpea (*c*) and rice (*r*) crops grown on an Ultisol in the humid tropics.

K‡ rate	Crop									
	c 1	*r* 2	*r* 3	*r* 5	*r* 6	*c* 7	*r* 8	*c* 9	*r* 11	*c* 12
	kg ha^{-1}									
	Stover removed									
0	1720	3930	2760	2250	1830	480	580	840	1080	200
20	1040	3800	2810	2830	1890	540	560	640	990	230
40	1930	4060	2960	3000	2250	710	690	880	1090	410
80	1760	4190	3150	3200	2330	800	860	770	1390	150
120	1860	4650	3040	3290	2730	710	710	1200	1460	290
Mean	1662	4126	2944	2914	2206	648	680	866	1202	256
K effect	+	*	+	**	**	*	+	*	NS	NS
	Stover returned									
0	1790	3740	2560	3000	2270	920	770	1110	1790	1270
20	1640	3790	2730	3320	2630	900	780	1390	2010	1120
40	1720	4050	2590	3040	2610	810	890	1480	2060	1110
80	1740	4270	2720	3060	2450	910	770	1600	1930	1140
120	1750	4270	2450	3390	2410	860	830	1450	1970	960
Mean	1728	4024	2610	3162	2474	880	808	1406	1952	1120
K effect	NS	*	NS	NS	NS	NS	+	NS	NS	NS
Stover effect	NS	NS	**	*	*	**	*	**	**	**
SE stover	33	68	54	78	57	30	40	47	65	47
K × Stover	**	**	**	**	**	**	**	**	NS	NS
SE K × stover	75	153	120	176	128	66	90	105	146	105

+,*,** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

‡ Half of the indicated rate was applied to the first crop and no K was applied to Crops 8 through 12.

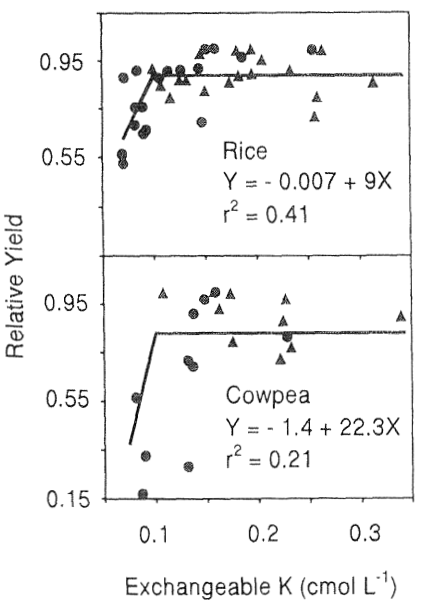

Fig. 1. Effect of exchangeable K concentration on the relative grain yield of six crops of rice and four crops of cowpea under two stover treatments. Circles are stover removed and triangles are stover returned.

MATERIALS AND METHODS

The study was conducted at the Yurimaguas Experiment Station located in the Peruvian Amazon Basin. An 18-yr-old secondary forest was cleared by traditional slash and burn methods in November 1981. The soil was mapped as a fine-loamy, siliceous, isohyperthermic Typic Paleudult (Tyler et al., 1978). Samples of the topsoil (0–15 cm) taken 8 wk after the burn showed 20% clay and exchangeable K and effective CEC levels of 0.18 and 4.50 cmol L^{-1}, respectively. A crop of rice was established in February 1982 to evaluate soil variability and to produce stover. The next 12 crops, which received fertilizer and management treatments, were cowpea, rice, rice, cowpea, rice, rice, cowpea, rice, cowpea, cowpea, rice, and cowpea. The final harvest was August 1986. Of these 12 crops, No. 4 and 10 (both cowpea) failed to yield grain due to climatic adversities.

Three tillage treatments were assigned to main plots in a randomized complete block design: (i) no-tillage, where the seeds were sown with a planting stick as traditionally practiced by local farmers; (ii) strip tillage, where approximately 30% of the area was tilled with a hoe; and (iii) conventional tillage, where the entire area was cultivated with a small tractor and rotovator. Sub-plot treatments were a factorial arrangement of two stover management methods (returned and removed) and five K rates. Herbicides were used if the stover was returned; hand-weeding was practiced when the stover was removed. The treatments were replicated four times.

Potassium rates applied to the first cowpea crop were 0, 10, 20, 40, and 60 kg K ha^{-1} as KCl. For the six succeeding crops, K rates were doubled to 0, 20, 40, 80, and 120 kg K ha^{-1}, making a total of seven applications. The K was applied by dribbling on the soil surface next to the row after planting. Potassium was not applied to the five subsequent crops so that the effect of previous K additions could be measured.

All nutrients except K were broadcast. Magnesium (20 kg ha^{-1} as the sulfate) was applied to all crops, N (45 kg ha^{-1} as urea) was applied only to each rice crop, and P (as ordinary superphosphate) and micronutrients (as sulfates) were applied annually as needed according to soil analysis.

Soil samples were collected to a depth of 15 cm 8 wk after burning the forest and before any fertilizer had been applied. Subsequently, soil samples were taken after harvesting each crop. Exchangeable K and other nutrients were extracted with a mixture of 0.5 *M* $NaHCO_3$, 0.01 *M* EDTA, and 25 mg L^{-1} Superfloc 127 (American Cyanamid Co., Wayne, NJ), a modification of the Olsen extractant (Hunter, 1979). Cations were determined by atomic absorption. Aluminum was extracted with 1 *M* KCl and determined by titration. Particle size distribution was determined with a hydrometer.

Grain and stover samples were taken at each harvest. Tissues samples were digested with concentrated H_2SO_4 and 30% H_2O_2 before analysis for K by atomic absorption.

Analysis of variance and regression were performed with procedures from SAS (SAS Institute Inc, 1987). To assist in indicating the significance of the response to K within each stover treatment, analysis of variance also was conducted separately for the two stover treatments. Critical levels were determined with Model III of the linear plateau models as presented by Anderson and Nelson (1987). Relative yields were calculated by using the highest yielding treatment of each crop as a reference. Increases in soil exchangeable K (Δ K) at any given depth and time for each stover treatment receiving fertilizer were calculated by subtracting the value of the 0 kg K ha^{-1} treatment within the same stover management. One-tailed *t*-tests were used to detect significant increases.

RESULTS AND DISCUSSION

Tillage Effects on Grain Yields

Differences in grain yields among tillage treatments were not significant throughout the study. Thus, no-till is the most appropriate of these for a low-input system. This form of land preparation only requires

the use of a planting stick for sowing the seed and is therefore the least costly.

Stover Management Effects on Grain Yields

Stover management did not affect grain yields for the first two crops (Table 1). Lower yields were obtained for the third crop when stover was returned. We have no plausible explanation for this unexpected difference in yield.

After the third crop, higher yields were always associated with the return of crop stover. Also, the detrimental effect of stover removal became more pronounced with time. Cowpeas were more adversely affected than rice by stover removal, as indicated by the sharp decline in cowpea yields with stover removal.

Potassium Treatment Effects on Grain Yields

When the crop stover was removed, significant yield responses to K applied to the first seven crops were always obtained (Table 1). Residual fertilizer K effects were observed in the yields of the two succeeding crops, No. 8 and 9, following the final K application. For the last two crops, No. 11 and 12, a response to residual K was not obtained. This suggests that stover removal reduced soil K at all rates of fertilization to such low levels that yield differences could not be detected.

When stover from previous crops was returned, response to K treatments was seldom obtained, suggesting that returning stover alone was sufficient to maintain soil K levels near or above the critical levels for the two crops under study.

The differential effect of K application on grain yields between the two stover treatments has the following implications for K management of this low-input rotation on soils of this type: (i) the probability of obtaining a yield response to K fertilization whenever stover is removed is high; (ii) the probability of obtaining a yield response when stover is returned is low; and (iii) removal of stover reduces the residual effect of K fertilization.

Potassium and Stover Management Effects on Soil K

The extractable soil K critical level was 0.10 cmol L^{-1} for upland rice and cowpea (Fig. 1). This point was calculated by the linear plateau method, but the coefficients of determination were rather low. The critical level we found is considerably less than that of 0.15 cmol L^{-1} proposed by Sanchez and Benites (1976).

Returning stover resulted in exchangeable K concentrations scattered around the plateau (Fig. 1). With stover removal, some soil K levels were in the yield responsive range. This is in accordance with data presented in Table 1 which indicates that a response to K fertilizer application was seldom obtained when the stover was returned. On the other hand, significant yield responses to fertilizer K (Crops 1 through 7) occurred whenever the crop stover was removed, indicating that the amounts of K removed by stover were large enough to reduce the soil K below the critical level for these crops.

The changes in soil K levels throughout the experiment for the 0 kg K ha^{-1} rate and for the 40 kg K ha^{-1} rate are presented in Fig. 2. The higher K levels found initially were the result of K incorporation from the ash after slashing and burning the secondary forest vegetation.

When K fertilizer was not added, returning stover was sufficient to maintain soil K levels above the rice and cowpea critical level throughout the 12-crop rotation (Fig. 2). In contrast, stover removal at this 0 K rate resulted in soil K levels that were below critical levels for both crops after the first crop of the experiment.

When K was added at 40 kg ha^{-1} and the stover removed, soil K levels were maintained above the critical levels for both crops (Fig. 2). However, once the K fertilizer applications were terminated, soil K levels dropped rapidly to levels similar to that of no K fertilizer with stover removal. Thus, removal of the crop residue accelerated the rate of depletion of residual K by subsequent crops. When the stover was returned, soil K was also reduced upon interruption of K fertilization, but it remained above the critical level for all succeeding crops.

Potassium Use Efficiency of Rice and Cowpea

Yields of rice were reduced less than those of cowpea by K deficiency at 0.07 cmol L^{-1} extractable K; the predicted relative yield of rice was 0.62, while that of cowpea was only 0.16 (Fig. 1). This observation, plus the fact that cowpea was more severely affected than rice by stover removal (Table 1), suggests that upland rice is better adapted than cowpea to low K soils. Lambert and Linck (1964) studied the competition between legumes and grasses for K and found the grass took up much more K than the leg-

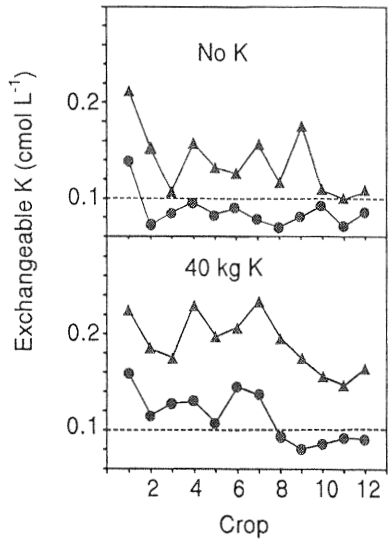

Fig. 2. Effect of stover management on extractable K throughout a 12-crop rotation of rice (R) and cowpeas (C) at the 0 kg K ha^{-1} rate and receiving 40 kg K ha^{-1} for the first seven crops. Dotted line is the critical level for rice and cowpea. Circles are stover removed and triangles are stover returned.

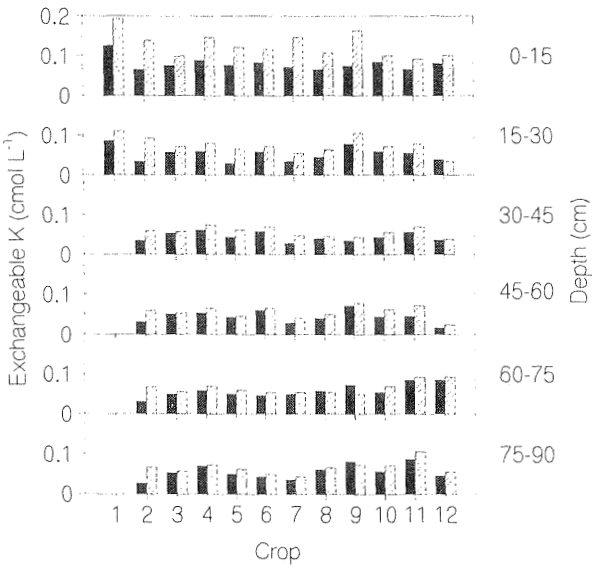

Fig. 3. Exchangeable K to a depth of 90 cm for the 0 kg K ha^{-1} rate with stover removed (solid bars) or returned (cross-hatched bars) for 12 crops (cowpea, rice, rice, cowpea, rice, rice, cowpea, rice, cowpea, cowpea, rice, and cowpea).

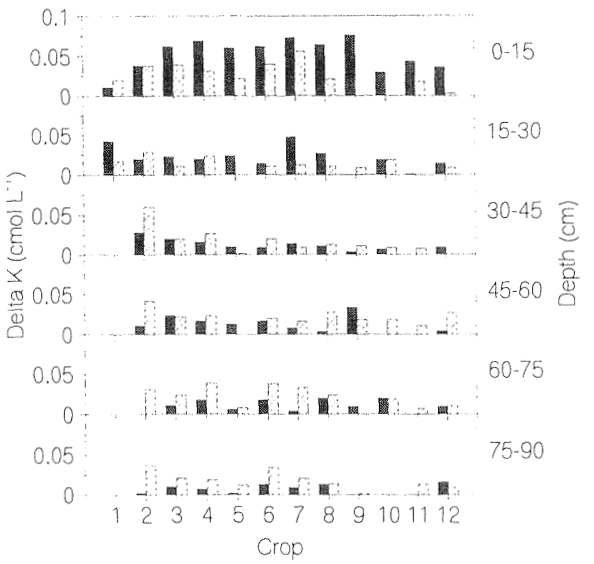

Fig. 4. Effect of 40 kg K ha^{-1} on the change in exchangeable K (Δ K) relative to that of the 0 kg K ha^{-1} rate down to 90 cm with stover remover (solid bars) or returned (cross-hatched bars) through 12 crops (cowpea, rice, rice, cowpea, rice, rice, cowpea, rice, cowpea, cowpea, rice, and cowpea).

ume. Perhaps because of differences in root morphology or K absorbing power, grasses may be able to withstand low K conditions better than legumes.

From these results, it may be concluded that (i) traditional tillage, i.e., no-till, is adequate and comparable to conventional forms of land preparation; (ii) returning stover is crucial to the sustainability of this low-input crop rotation as it prolongs the residual effect from previous K additions, be they in the form of ash at burning or as low rates (40 kg K ha^{-1}) of K fertilizers; and (iii) higher K use efficiency of upland rice makes it better adapted than cowpea to low K soils. Returning stover with no additional K fertilization provides enough K for adequate and sustainable yields for 12 crops of rice and cowpeas on these soils following traditional slash-and-burn land clearing.

Potassium in the Soil Profile

When K was not applied, the K status of the 0 to 15 and 15 to 30 cm layers was generally lower when the stover was removed than when it was returned (Fig. 3). This trend was most noticeable at 0 to 15 cm where a significant effect of returning stover was found in nine of the 12 crops, and it was also apparent in half of the crops at 15 to 30 cm, but occurred in only one of 12 crops at any depth increment greater than 30 cm.

Increases in exchangeable K (Δ K) were detected for the 40 kg K ha^{-1} rate with and without stover removal during the first seven crops when fertilizer was applied (Fig. 4). After annual additions of K were ceased, a residual effect of previously applied K was apparent with the stover returned for one crop (eighth), but there was little residual effect of prior fertilization in the last four crops at any depth or stover treatment. One exception to this was an increase in Δ K at 0 to 15 cm in plots with stover removed. The increases in Δ K during the first seven crops were consistent only

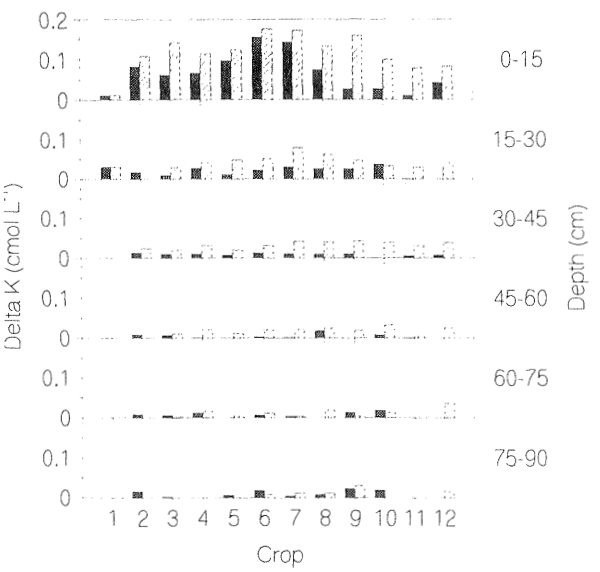

Fig. 5. Effect of 120 kg K ha^{-1} on the change in exchangeable K (Δ K) relative to that of the 0 kg K ha^{-1} rate down to 90 cm with stover removed (solid bars) or returned (cross-hatched bars) through 12 crops (cowpea, rice, rice, cowpea, rice, rice, cowpea, rice, cowpea, cowpea, rice, and cowpea).

to a depth of 30 cm when the stover was removed, whereas when it was returned, increases were noted consistently to 90 cm.

Patterns of K accumulation in the subsoil at the 120 kg K ha^{-1} rate were very different for the two stover treatments (Fig. 5). The increase in exchangeable K from 0 to 60 cm was much higher when the crop stover was returned, plus there was a substantial residual effect with this treatment. With the stover removed, increases in exchangeable K occurred only to 30 cm, and there was a small residual effect down to this depth.

Table 2. Potassium removed in the grain and removed or returned in the stover of the first seven crops grown at three K rates and two stover treatments.

Treatment		Crop							
K rate	Stover returned	1 cowpea	2 rice	3 rice	4 cowpea	5 rice	6 rice	7 cowpea	Sum
kg ha^{-1}		kg K ha^{-1}							
					Grain				
0	no	22.9	22.0	14.8		13.3	10.8	6.9	90.7
0	yes	22.5	20.8	14.0		15.4	12.7	12.3	97.7
40	no	25.1	22.8	14.9		15.4	13.3	8.3	99.8
40	yes	22.2	22.5	14.2		15.9	13.9	9.5	98.2
120	no	24.4	25.2	16.4		17.2	14.5	10.0	107.7
120	yes	21.9	23.1	13.2		17.7	12.6	11.1	99.6
Mean		23.2	22.7	14.6		15.8	13.0	9.7	99.0
					Stover				
0	no	52.1	58.3	40.8	21.5	40.1	34.5	16.5	263.8
0	yes	42.5	55.3	38.6	43.3	38.6	44.4	38.0	300.7
40	no	48.5	60.5	39.8	30.2	39.8	41.4	28.6	288.8
40	yes	48.3	59.8	38.3	29.5	38.3	44.2	37.8	296.2
120	no	49.9	67.9	44.0	29.6	44.0	40.6	37.0	313.0
120	yes	47.1	61.4	34.6	32.2	34.6	44.0	39.1	293.0
Mean		47.9	60.5	39.4	31.1	39.2	41.5	32.8	292.5

Potassium in the Grain and Stover

Potassium concentration in cowpea grain was similar among treatments and years. It averaged 13 g kg^{-1} although the soil K ranged from 0.07 to 0.47 cmol L^{-1}. Therefore, the amount of K removed by cowpea grain was mainly dependent on grain yield. For the first cowpea crop, there was little yield difference among treatments and K removal averaged 23.2 kg K ha^{-1} (Table 2). For Crop 7, yields were lower and more variable, so the amount of K removed ranged between 6.9 and 12.3 kg K ha^{-1}.

The K concentration in rice grain was also independent of soil K and averaged 5.4 g kg^{-1} over years. Therefore, K removal in grain was dependent on yield and ranged between 13.0 and 22.7 kg K ha^{-1}.

Percent K in cowpea stover was closely related to soil K and could be predicted by

$$Y = 3.09 - 5.46 \exp(-21.85X), \qquad [1]$$

where X = soil K (cmol L^{-1}). The K content of cowpea stover across treatments ranged between 47.9 and 31.1 kg K ha^{-1} for Crop 1 and Crop 4, respectively (Table 2).

Potassium concentration in rice stover was independent of soil K with a mean value of 14.1 g kg^{-1} across a range in soil K between 0.06 and 0.30 cmol L^{-1}. Crop 2 removed the largest amount of K with a mean of 60.5 kg ha^{-1} across treatments. The lowest amount of K was removed by Crop 5 (39.2 kg ha^{-1}).

The very small increase in exchangeable K at depths greater than 60 cm with the 120 kg K ha^{-1} rate and with the stover returned was unexpected (Fig. 5). Substantial downward movement occurred at 40 kg ha^{-1} with the stover returned (Fig. 4). The fact that the increase in subsoil exchangeable K was very small may be related to K fixation. We postulate that, as the K in solution from this treatment leached to lower depths, its concentration was sufficiently great to cause K ions to diffuse to interlayer positions and induce collapse of the 2:1 clays which are present in these soils (Tyler et al., 1978). The trapped K ions would no longer be exchangeable, so exchangeable K levels were lower. This concept has been reviewed in some detail by Sparks and Huang (1985).

There was a significant increase in exchangeable K at depths less than 60 cm with 120 kg ha^{-1} and stover returned. We also postulate that once fixation sites are saturated, large increases in exchangeable K may take place with continued fertilization at this high rate. This appears to have been the case as there was a tendency for the Δ K to increase with cropping during the first seven crops, the ones receiving fertilizer.

When the highest rates of K were applied, small amounts of K might have leached beyond the 90-cm depth, in which case K fixation would not be as high as estimated. Also, some K may not be accounted for due to removal in weeds. When hand-weeding the stover removal treatment, weeds were removed from the plots, and since they would contain some K, this would magnify the amount of K that could not be accounted for with stover removal. Weeds are not a problem immediately after clearing, but the problem becomes more severe with continued cropping.

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