Potassium Uptake and Recovery by an Upland Rice-Soybean Rotation on an Oxisol

D. W. Gill and E. J. Kamprath*

ABSTRACT

A major limitation to improved crop growth on many acid Oxisols is low K availability. A field experiment was conducted in West Sumatra to study the effects of K fertilization of an Oxisol under three levels of lime (0.375, 2.25 an 5 t ha^{-1}) on K accumulation of a yearly upland rice (*Oryza sativa* L.)-soybean (*Glycine max* L. Merr.) rotation where all above-ground residue was removed. Six K treatments supplied 0 to 240 kg K ha^{-1} to each crop and lime treatment. Potassium fertilization increased grain yields of rice and soybean and K content of grain and stover of both crops. With both crops a large proportion of the K was present in the stover. Liming had no effect on K accumulation of rice grain; an inconsistent effect on K accumulation in rice straw; and significantly increased the K content of soybean grain and stover. Upland rice was very efficient in utilizing K applied to that crop as well as residual soil K from previous fertilization. When K rate was greater than 100 kg ha^{-1} per crop appreciable amounts of K could not be accounted for indicating that the K was lost by leaching. Increases in exchangeable K with K fertilization only occurred in the 0- to 30-cm depth.

One of the areas in Indonesia being developed for increased agricultural production is the central Sumatran piedmont, a region dominated by acidic, low base status, Ultisols and Oxisols. Although research was recently initiated in West Sumatra and Jambi provinces on lime and P management of upland crops (Wade et al., 1986; Rumawas, 1987), little research has been conducted on K management of crops grown on these soils.

Good crop management of soils with relatively low buffering capacity requires judicious K fertilization, ensuring sufficient K levels in the soil to meet crop demands while not contributing to excessive K leaching below the root zone. Liming acid soils not only decreases soil Al, thus improving crop growth, but it can also increase retention of applied K and thereby decrease K leaching (Pearson, 1958). Liming increases K retention in soils by replacing Al on the exchange sites with Ca, allowing K to compete better for exchange sites and increasing the effective CEC (Goedert et al., 1975). However, even after liming an acid Oxisol in Brazil, Souza et al. (1979) reported that significant amounts of K leached into the subsoil during the growth of one maize crop with rates of 250 kg of K ha^{-1} or greater.

Most of the K taken up by a cereal crop remains in the stover. DeDatta (1981) reported that nearly 80% of total K accumulation by paddy rice was in the straw, while Gichuru (1986) found over 90% of the total K taken up by an upland rice crop grown in Peru to be in the straw. DeDatta (1985) reported 30% recovery of fertilizer K to be common for paddy rice grown on high base status soils in the Philippines. In a 5-yr study of K management of a millet (*Pennisetum* sp.)-peanut (*Arachis hypogaea* L.) rotation in Senegal, Pieri (1982) found that the millet took up more K than was applied to the crop. However, little information is available concerning uptake of K by rice or soybean on upland soils of West Sumatra. One study in that area found that both rice and soybean gave high yield responses to K fertilization on a limed Ultisol (Gill and Sri Adiningsih, 1986).

An experiment was initiated in West Sumatra to determine the effect of K fertilization of an Oxisol at three Al saturation levels on K accumulation in both grain and straw of an upland rice-soybean rotation, on apparent fertilizer K recovery of the two crops, and on exchangeable K levels at several soil depths.

D.W. Gill, Casilla 274, Santa Cruz, Bolivia, and E.J. Kamprath, Soil Sci. Dep., North Carolina State Univ., Box 7619, Raleigh, NC 27695-7619. Paper no. 12205 of the Journal Series of the North Carolina ARS, Raleigh, NC 27695-7601. Supported in part by the US AID and in cooperation with Centre for Soils Research, AARD, Bogor, Indonesia. Received 12 June 1989. *Corresponding author.

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MATERIALS AND METHODS

The experiment was conducted at Sitiung in southeastern West Sumatra on a clayey, kaolinitic, isohyperthermic Typic Haplorthox. Annual rainfall at this location is 2500 mm fairly well distributed with only a weak dry season in August. The soil moisture regime is udic. The initial chemical properties of the 0 to 100-cm depth were quite uniform with 80% clay, pH 4.2, 92% Al saturation, 0.10 cmol$_c$ Ca L^{-1}, 0.06 cmol$_c$ Mg L^{-1}, and 0.06 cmol$_c$ K L^{-1} (Gill, 1988). From October 1984 through May 1986, a rotation of upland rice-soybean was grown each year during the two cropping seasons. The upland rice cultivar Sentani and the soybean cultivar Willis, which are local adapted varieties, were used.

The experimental design was a randomized complete block with three replications. Treatments were a complete factorial of three lime rates 0.375, 1.5 and 5 t ha^{-1} (low, medium, and high, respectively) applied initially and six KCl rates (0, 20, 40, 80, 120 and 240 kg of K ha^{-1}) applied prior to planting each crop. Lime rates applied before beginning the experiment sought to establish Al saturation levels of 10, 40 and 70%. An extra 0.75 t ha^{-1} of lime was applied to the medium lime treatment after the first rice crop to decrease Al levels closer to those desired. A total of 160 kg of P ha^{-1} applied as triple superphosphate and 92 kg of Mg ha^{-1} applied as $MgSO_4$ were broadcast to all plots over the 2 yr. The first rice crop received 60 kg N ha^{-1} and the second crop 30 kg N ha^{-1}. Each crop received 15 kg $MnSO_4$ ha^{-1}, both rice crops and the second soybean crop received 10 kg $CuSO_4$ ha^{-1} and 10 kg $ZnSO_4$ ha^{-1}. The second soybean crop also received 10 kg borax ha^{-1}.

Grain and stover yields were taken from a 10-m^2 area within each plot. Grain yields were corrected to 14% and 13% moisture for rice and soybean, respectively, while stover subsamples were air dried. All above-ground residue for each crop in the rotation was removed at harvest which is the standard practice of the local farmers. The 1st yr, the nutrient content of plant samples was determined by x-ray fluorescent quantometer after pulverizing the sample to a phase powder and forming 1-mm thick briquettes at a pressure of 3.8 × 10^8 Pa. Samples from crops the 2nd yr were analyzed by atomic absorption after dry-ashing overnight at 500 °C and digesting for 1 h in concentrated HCl.

Soil samples were taken prior to fertilization and planting of each crop in the rotation. The 0 to 15-cm depth of all treatments was sampled, as well as the 15 to 30, 30 to 50 and 50 to 75 cm of the 0-, 40-, 120-, and 240-kg K ha^{-1}

Table 1. Selected soil chemical parameters of the 0 to 15-cm depth as affected by lime rates (K levels averaged across all KCl rates).

Rice crop	Lime level	pH	Al	K	Ca	Mg	ECEC	Al saturation
	t ha⁻¹		cmol$_c$ L⁻¹					%
1984-1985	0.375	4.3	2.48	0.14	0.59	0.15	3.36	74
	1.5	4.4	1.90	0.15	1.07	0.16	3.28	58
	5.0	5.5	0.54	0.16	2.97	0.20	3.87	14
1985-1986	0.375	4.1	2.40	0.14	0.50	0.24	3.28	73
	2.25†	4.3	1.90	0.13	1.28	0.25	3.26	49
	5.0	4.8	0.36	0.15	3.15	0.29	3.95	9

† Includes an additional 0.75 t ha⁻¹ applied prior to the second crop.

treatments. Determination of exchangeable Al^{3+} was made using 1 *M* KCl as an extractant and titrating with NaOH to the phenolphthalein endpoint, while K^+, Ca^{2+} and Mg^{2+} were extracted with 1 *M* NH_4OAc and measured by atomic absorption. The soil pH, Al saturation and cation content of the 0 to 15-cm depth for the three lime treatments are given in Table 1. Statistical analyses were performed using SAS routines (SAS Institute, Inc., 1979). Lime and K effects were partitioned into linear and quadratic components. The optimum K fertilizer rate was determined using the linear-plateau method (Anderson and Nelson, 1987). Apparent fertilizer K recovery for the four crops was calculated as follows: $[(A - B)/C)100]$, where A = total crop K uptake under Treatment X, B = total crop uptake with 0 applied K, and C = K applied as KCl under Treatment X. Residual fertilizer K was estimated as follows: Residual K = Fertilizer K Treatment X − (K uptake Treatment X − K uptake of check).

RESULTS AND DISCUSSION

Potassium Accumulation and Partitioning

The accumulation and partitioning of K between grain and vegetative portions of rice and soybean are given in Tables 2 and 3, respectively. Potassium content of rice grain was increased several fold by K fertilization. This was due to a relatively large increase in rice grain yield with K fertilization (Table 4). Liming had no effect on K content of rice grain. Lower K content of grain in the first crop was a result of yields being lower due to moisture stress as compared with the second crop. The K content of the rice grain was similar to that reported by DeDatta (1981), Khumbar and Sonar (1980) and Gichuru (1986).

Table 2. Effect of lime and K on K accumulation in rice grain and straw.

Treatment	1984-1985 Grain	1984-1985 Straw	1984-1985 K in straw	1985-1986 Grain	1985-1986 Straw	1985-1986 K in straw
	— K, kg ha⁻¹ —		%	— K, kg/ha⁻¹ —		%
Lime						
Low	4.4	56.8	89	6.9	156.3	92
Medium	4.9	56.0	88	6.0	133.7	91
High	5.1	67.4	91	6.3	124.3	90
Fertilizer K kg, ha⁻¹						
0	2.0	7.3	77	1.4	4.6	76
20	3.8	28.6	88	4.3	34.3	88
40	4.9	49.1	91	6.1	83.8	93
80	4.8	73.1	94	8.7	199.9	96
120	6.4	85.6	93	8.5	254.9	97
240	6.8	116.7	94	9.3	265.7	97
Lime	NS	*	NS	NS	*	NS
Linear	NS	*	*	NS	*	*
K	**	**	**	**	**	**
Linear	**	**	**	**	**	**
Quadratic	**	**	*	**	**	**
Lime × K	NS	NS	NS	NS	NS	NS

NS,*,** Denote effects which are not significant, or significant at the 0.05 and 0.01 levels, respectively.

Table 3. Potassium uptake in soybean grain and stover and proportion of total K uptake found in the stover for the 1985 and 1986 crops.

Treatment Lime	Treatment K	1985 Grain	1985 Stover	1985 K in the stover	1986 Grain	1986 Stover	1986 K in the stover
	kg ha⁻¹	— K kg ha⁻¹ —		%	— K kg ha⁻¹ —		%
Low	0	2.9	3.0	51	2.9	2.3	44
	20	5.6	7.1	56	6.4	7.6	54
	40	6.5	8.4	56	8.9	12.5	58
	80	2.4	5.4	69	6.8	14.6	68
	120	7.7	12.7	62	10.6	24.8	70
	240	5.6	12.8	70	9.7	20.5	68
Medium	0	3.0	4.2	58	3.1	3.0	49
	20	10.2	9.6	48	10.5	11.1	51
	40	12.4	14.3	54	13.8	18.7	58
	80	10.8	17.4	62	9.2	17.3	65
	120	13.0	20.4	61	12.8	20.2	61
	240	13.4	28.1	68	16.6	41.4	71
High	0	5.9	6.0	50	4.2	4.8	53
	20	12.6	11.3	47	17.2	11.0	39
	40	15.0	12.6	46	20.9	19.1	48
	80	22.7	33.8	60	23.4	43.3	65
	120	21.2	31.3	60	25.7	47.5	65
	240	20.7	30.2	59	30.5	56.4	65
Lime		**	**	*	**	**	*
Linear		**	**	*	**	**	*
Quadratic		NS	NS	NS	*	**	NS
K		**	**	**	**	**	**
Linear		**	**	**	**	**	**
Quadratic		**	**	*	**	**	**
Lime × K		NS	**	NS	**	**	NS
CV		37.3	33.1	9.5	24.8	28.5	10.1

NS,*,** Effects which are not significant at the 0.05 and 0.01 levels, respectively.

Potassium accumulation by rice straw increased markedly with K fertilization (Table 2) which increased straws yields to over 10 t ha⁻¹ and increased the K concentration from 2.7 to 29.7 g kg⁻¹ (Gill, 1988). The main effect of lime on the K content of straw was not consistent. Liming increased K content of rice straw the 1st yr and decreased it the 2nd yr. As K rates increased, the percentage of total K which accumulated in rice straw increased (Table 2) from a low of 76% with no K applied to 93 to 97% at the higher K rates. Pieri (1982) also found that as higher K rates were applied to millet in Senegal, a higher percentage of the K taken up was in the straw.

Accumulation of K in both grain and stover of soybean in 1985 and 1986 was significantly increased by lime applications (Table 3). Although K concentrations in grain and straw decreased slightly with lime additions, yields increased greatly (Table 4) thus causing K accumulation to increase. Fertilization with K increased K accumulation considerably in grain and stover both years. Although K accumulation in soybean stover was greater than that in the grain, the percent of the total accumulated in stover was not as large as that for rice. At maximum yield each ton of soybean grain contained 20.6 and 16.9 kg K in the first and second crop, respectively. This compares with an average of 19.4 kg K t⁻¹ grain in a North Carolina soybean study (Henderson and Kamprath, 1970) and

Table 4. Yield of rice and soybean with zero K and at K rate which maximized yields as determined by linear-plateau model.

Crop	Lime rate	K	Grain yield
		kg ha^{-1}	T ha^{-1}
Rice 1984–1985	Averaged across all lime rates	0	0.85
		100	2.15
Rice 1985–1986		0	0.63
		60	3.43
Soybean 1985	Low	0	0.25
		20	0.30
	Medium	0	0.15
		20	0.59
	High	0	0.40
		60	1.06
Soybean 1986	Low	0	0.17
		35	0.59
	Medium	0	0.28
		35	0.81
	High	0	0.54
		60	1.68

18 kg K t^{-1} grain in a soybean study on Oxisols in Brazil (Mascarenhas et al., 1980).

There was a significant lime by K interaction on K accumulation of soybean stover in the first crop and in both grain and stover the 2nd yr (Table 3). Liming increased grain yield which resulted in a decrease in the percentage of total K accumulated in the stover (Table 3).

Apparent Fertilizer Potassium Recovery

The apparent fertilizer K recovery for each of the four crops is given in Table 5. The initial rice crop was very efficient in taking up low rates of fertilizer K with efficiencies in some instances greater than 100% (Table 5). This indicates that the increased growth with K fertilization stimulated uptake of native soil K. At the high rate of K, 240 kg ha^{-1} the apparent recovery was slightly less than 50%.

The soybean crops which followed the rice crops were much less efficient in utilizing fertilizer K than was rice (Table 5). Liming increased the efficiency of K recovery. With the second soybean crop the high lime treatment increased the average percent K recovery 111% over that of the low lime rate. Liming increased yields considerably because of neutralization of exchangeable Al^{+3} which resulted in more efficient recovery of fertilizer K (Table 5).

The rice crop following soybean had apparent fertilizer K recoveries of greater than 100% of that applied (Table 5). The second rice crop utilized the large amount of residual K fertilizer from the previous soybean crop. In a 5-yr study with cereal and legume rotation, Pieri (1982) found that K recovery by millet was greater than 100% while with peanut it was considerably less.

Potassium Balance

Rates of K fertilization increased excnangeable K linearly in the 0 to 15-cm and 15- to 30-cm depth in measurements made after the first rice crop (Table 6). Potassium treatments had no effect on exchangeable K at depths below 30 cm. There were additional increases in exchangeable K of the 0 to 15-cm depth with the three highest K rates in samples taken after the harvest of the soybean crop (Table 6). Only with the 240 kg K ha^{-1} rate was there an additional increase in exchangeable K at the 15- to 30-cm depth.

Liming had no significant effect on the exchangeable K retained in the soil as suggested by previous studies (Goedert et al., 1975). The lack of an effect could be due to several factors. Liming only increased the effective CEC 0.5 to 0.6 cmol$_c$ kg^{-1} an increase of less than 20%. Since soil samples were taken after K uptake by the crops had been completed, this could have removed any differences in K retention due to liming.

Table 5. Apparent fertilizer K recovery (AKR†) for rice and soybean crops during a 2-yr period.

Treatment		1984–1985		1985–1986	
		Rice	Soybean	Rice	Soybean
Lime	K	AKR	AKR	AKR	AKR
	kg ha^{-1}	%	%	%	%
Low	0	–	–	–	–
	20	160	34	235	46
	40	84	22	178	41
	80	84	2	305	21
	120	68	12	269	26
	240	48	5	124	8
Medium	0	–	–	–	–
	20	120	64	132	77
	40	100	50	217	66
	80	72	26	247	25
	120	57	22	194	22
	240	49	14	107	22
High	0	–	–	–	–
	20	66	60	122	96
	40	125	39	235	78
	80	102	56	208	72
	120	82	34	181	22
	240	46	16	105	32
Lime		NS	**	NS	**
Linear		NS	**	NS	**
Quadratic		NS	NS	NS	NS
K		**	**	**	**
Linear		**	**	*	**
Quadratic		NS	**	**	**
Lime × K		**	NS	NS	NS
CV		47.8	56.2	39.2	36.9

† AKR = [(total K uptake at treatment X − total K uptake at the 0 K treatment)100]/(K applied at that treatment).

‡ NS denotes not significant, while * and ** denote significant effects at the 0.05 and 0.1 levels, respectively.

Table 6. The effect of K applications on exchangeable K levels at four depths after the first rice and soybean crops.

	After first rice crop				After first soybean crop			
	Sampling depth, cm							
Applied K	1–15	15–30	30–50	50–75	0–15	15–30	30–50	50–75
kg ha^{-1}	Exchangeable K, cmol$_c$ L^{-1}							
0	0.06	0.05	0.06	0.06	0.05	0.06	0.06	0.07
20	0.08	–	–	–	0.06	–	–	–
40	0.08	0.06	0.06	0.06	0.08	0.07	0.08	0.06
80	0.09	–	–	–	0.18	–	–	–
120	0.13	0.07	0.06	0.04	0.16	0.07	0.07	0.07
240	0.23	0.10	0.09	0.06	0.31	0.16	0.09	0.06
Lime	NS†	NS	NS	NS	NS	NS	NS	NS
Linear	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS
K	**	**	NS	NS	**	**	NS	NS
Linear	**	**	NS	NS	**	**	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS
Lime × K	NS	NS	NS	NS	NS	NS	NS	NS
CV	23.6	31.4	44.7	26.8	34.4	45.3	47.1	49.5

† NS denotes not significant, while * and ** denote effects which are significant at the 0.05 and 0.01 levels, respectively.

Table 7. Potassium balance sheet on an Oxisol after one crop of rice as influenced by K rates at three lime levels.

Lime treatment	K, kg ha⁻¹				
	Fertilizer	Residual fertilizer	Soil test	Increases in soil test	Unaccounted fertilizer
Low	0	–	64	–	0
	20	−12	76	12	0
	40	6	76	12	0
	80	13	79	15	0
	120	38	111	47	0
	240	125	193	129	0
Medium	0	–	70	–	0
	20	−4	85	15	0
	40	−10	88	18	0
	80	23	94	24	0
	120	52	105	35	17
	240	122	170	100	22
High	0	–	64	–	0
	20	7	82	18	0
	40	−10	70	6	0
	80	−1	99	35	0
	120	22	123	59	0
	240	125	211	147	0

Table 8. Potassium balance sheet on an Oxisol after growth one cycle of rice and soybean as influenced by K rates at three lime levels.

Lime treatment	K, kg ha⁻¹				
	Fertilizer	Residual fertilizer	Soil test	Increases in soil test	Unaccounted fertilizer
Low	0	–	58	–	0
	40	1	73	15	0
	80	37	76	18	19
	160	90	164	106	0
	240	144	194	136	8
	480	333	251	193	140
Medium	0	–	58	–	0
	40	3	58	0	3
	80	10	64	6	4
	120	82	128	70	12
	240	149	105	47	102
	480	327	298	240	87
High	0	–	58	–	0
	40	15	82	24	0
	80	14	134	76	0
	120	34	146	88	0
	240	102	105	47	55
	480	332	275	217	115

In order to determine whether there was appreciable loss of fertilizer K by leaching, the amount of fertilizer K not taken up by the plant was estimated (Tables 7 and 8). The residual fertilizer K not used would either be held on exchange sites or could be removed by leaching. Where there were appreciable amounts of residual fertilizer K with the first crop it could be accounted for in the increase of exchangeable K (Table 7). This indicates that with the first application there was very little K lost by leaching.

At the end of the growth of the first two crops there was a significant correlation ($r = 0.92$) between the estimated residual fertilizer K and the increase in exchangeable K. For the first three K rates the estimated residual fertilizer K could be accounted for by the increase of exchangeable K (Table 8). At the highest K rate per crop, 240 kg K ha^{-1}, there was an appreciable amount of K presumably lost by leaching (Table 8). Similar results were obtained on an Oxisol in Brazil where estimates of residual fertilizer K corresponded to increases in exchangeable K, but with a rate of 250 kg K ha^{-1} appreciable leaching occurred (Souza et al., 1979).

Table 9. Total K removed and apparent fertilizer K recovery by a rice-soybean rotation over a 2-yr period.

Lime treatment	K, kg ha⁻¹			
	Total fertilizer	Total removed	Apparent fertilizer recovery	Apparent recovery, %
Low	0	24	–	–
	80	119	95	120
	160	154	130	81
	320	353	329	103
	480	472	448	93
	960	474	450	47
Medium	0	27	–	–
	80	107	80	100
	160	211	184	115
	320	324	297	93
	480	381	354	74
	960	489	462	48
High	0	40	–	–
	80	108	68	85
	160	231	191	119
	320	390	350	109
	480	460	420	88
	960	519	479	50

The apparent fertilizer K recovery was determined after the second cycle of the rice-soybean rotation (Table 9). Recoveries were quite good for rates as high as 120 kg ha^{-1} crop^{-1} indicating very little loss of K by leaching. There was, however, a relatively low recovery at the 240 kg K ha^{-1} crop^{-1} which indicates that significant losses due to leaching could occur. This seems to be substantiated by the fact that after the first cycle of the rotation there was a large amount of K which could not be accounted for and was assumed to be lost by leaching (Table 8). Unfortunately contamination of some of the soil samples at the end of the second cycle prevented making accurate measurements of changes in exchangeable K.

CONCLUSIONS

A rice-soybean rotation was very efficient in the recovery of fertilizer K when rates of as much as 120 kg ha^{-1} per crop were applied to a clayey Oxisol. In this cropping system of rice and soybean in which all of the plant material is removed relatively low amounts of K were lost by leaching with rates of 120 kg K ha^{-1} or less. Only with a rate of 240 kg K ha^{-1} crop^{-1} was there an appreciable amount of fertilizer K which could not be accounted for and was presumably lost by leaching. Where rice straw is removed from the field a large amount of K is exported from the system.

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