Potassium Budgets in Rice Cropping Systems with Annual Flooding in the Mekong River Delta

By Nguyen My Hoa, B.H. Janssen, O. Oenema, and
A. Dobermann

Potassium (K) balances provide crucial information for assessment of fertilizer needs and sustainability of rice cropping systems.

Potassium input-output balances constructed for wetland rice in Asia often include only a few, selected aspects of a full K budget such as fertilizer K as input and the amount of K removed by the crop as output (e.g. Patnaik, 1978; Bajwa, 1994; Dobermann, et al., 1996). In this study, we use a complete K budgeting approach to assess K inputs from sedimentation by annual flooding in double- and triple-crop systems of the Mekong River Delta in South Vietnam (**Figure 1**), which supplies about 50% of Vietnam's rice (Maclean et al., 2002). Rice is grown on alluvial soil concentrated along the banks of the Mekong and Bassac rivers (30% of the area), acid sulfate soils (45%), and coastal saline soils (20%). About 70% of the rice is grown with irrigation, the rest under rainfed conditions. The area with two rice crops per year is about 1.3 million hectares (M ha), and three crops are grown on about 0.4 M ha. The water depth of annual floods is greatest in the north of the river delta, while the south is less affected (**Figure 1**). The sediment load largely depends on the source of flood water and is greatest if the flood is caused by an overload of the two branches of the Mekong River. Sedimentation is also influenced by distance from the river.

The Nutrient Budgeting Approach

Potassium budgets were quantified for a soil-plant system at the field scale. The most relevant inputs (IN) and outputs (OUT) for K in rice cropping systems of the region are listed in **Table 1**. Particular emphasis is given to available and non-available K fractions when constructing K balances with inputs from fertilizer, rain, irrigation water, sediments, and outputs or removal via harvested products, residues, leaching, erosion, and water runoff.

It was assumed that K inputs from chemical fertilizers, rain water, and irrigation water were soluble. For simplicity, OUT 1-3 and 5 were also considered 'soluble'. Sediment-K of IN 4 and OUT 4 was characterized

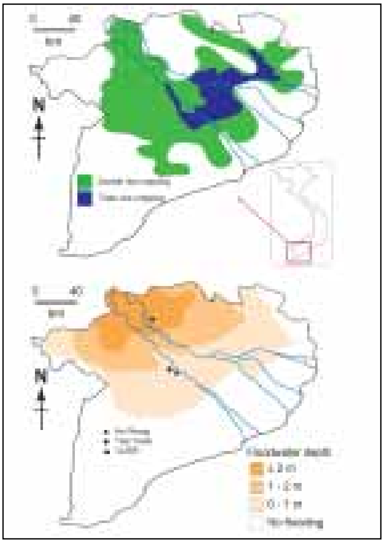

Figure 1. Water depth during annual flooding (bottom) and distribution of double- and triple-rice cropping systems (top) in the Mekong River Delta, South Vietnam. Redrawn with permission from Cantho Univeristy and the Cuu Long Rice Research Institute.

according to the three extraction methods used in this study: 1) K(NH_4OAc) extracted by 1 M NH_4OAc at pH 7 and at a soil to water ratio of 1:20 at one hour shaking time, 2) K(NaTPB) extracted by 0.2 M sodium tetraphenyl borate (NaTPB) during 5 min incubation (Cox et al., 1999), and 3) K(total) determined by a mixture of concentrated HF and $HClO_4$. This resulted in four K balances:

- KBAL(soluble) = (IN1 +IN2 + IN3) – (OUT 1 + OUT 2 + OUT 3 + OUT 5)
- KBAL(NH_4OAc) = KBAL(soluble) + IN 4 K(NH_4OAc) – OUT 4 K(NH_4OAc)
- KBAL(NaTPB) = KBAL(soluble) + IN 4 K(NaTPB) – OUT 4 K(NaTPB)
- KBAL(total) = KBAL(soluble) + IN 4 K(total) – OUT 4 K(total)

Experimental Fields and Research Methodology

The experimental sites differed in cropping intensity, sedimentation inputs, crop residue management, and fertilizer K rates (**Table 2**).

The input by chemical fertilizer (IN 1) is the amount of fertilizer K applied per hectare to each crop. Rainwater samples (IN 2) were collected and soluble K in rain water was measured. The amount of rainfall was obtained from weather stations. Irrigation water samples (IN 3) were taken from the canal feeding the fields and the quantity of irrigation water brought into the experimental area was derived from the change in water level before and after each irrigation event. Inputs via sediment in irrigation and floodwater (IN 4) were measured as suspended sediment in irrigation water samples, and sedimentation during the flooding period from mid-July to December was determined using sediment traps. The outputs or removal of K with rice grain, straw, and stubble (OUT 1 and 2) were determined from crop cuts and K concentrations in plant materials. Leaching (OUT 3) was assessed by determination of K in soil solution and in situ measurements of the vertical percolation under flooded conditions.

Table 1. Inputs and outputs of K for rice cropping systems in the Mekong Delta, as considered in this study.

Code	Description
Inputs	
IN 1	Chemical fertilizer
IN 2	Rain water
IN 3	Irrigation water
IN 4	Sedimentation via annual floods
Outputs	
OUT 1	Harvested products
OUT 2	Removed crop residues
OUT 3	Leaching
OUT 4	Erosion
OUT 5	Run off water

Table 2. Cropping systems at the experiment site, including: 1) a long-term experiment at the Cuu Long Rice Research Institute, CLRRI, Omon, and 2) a farmer's field at An Phong, Omon, Cantho province, and 3) a farmer's field at Thoi Thanh, Dong Thap province. NP = treatment receiving fertilizer N and P, NPK = treatment receiving fertilizer N, P, and K.

Site	Treatment	Annual crops	Sediment inputs	Residue management	K fertilizer application
CLRRI	NP	rice-rice	Low	Removal	none
CLRRI	NPK	rice-rice	Low	Removal	high
An Phong	NPK (farmer's field)	rice-rice	High	Incorporation after dry season crop, partially removed in other crops	moderate
Thoi Thanh	NPK (farmer's field)	rice-rice-rice	High	Incorporation after dry season crop, partially removed in other crops	low

Estimates of sediment-K losses (OUT 4) via drainage or sediment removal from irrigation canals by farmers were obtained by farmer interviews. The sediment removal

Table 3. Potassium fractions and K inputs with sediments during flooding periods of 2000 and 2001 at CLRRI, An Phong, and Thoi Thanh.

Sediment characteristics	CLRRI	An Phong	Thoi Thanh
K fractions in sediments			
$K(NH_4OAC)$, mmol/kg	4.62-4.63	2.31-2.66	2.07-3.09
K (NaTPB), mmol/kg	11.67-16.00	10.81-14.25	10.83-16.79
K (total), mmol/kg	459-475	526-557	538-556
Sediment thickness, weight, and K inputs			
Thickness, mm	8.8-16.6	19.8-22.2	20.2-30.0
Sediment weight at 40°C, t/ha	17-40	76-94	90-178
Input of $K(NH_4OAc)$, kg/ha	3-7	7-10	10-21
Input of K (NaTPB), kg/ha	11-18	42-40	59-75
Input of K (total), kg/ha	320-710	1,651-1,926	1,892-3,868

was calculated based on information on canal size and depth, and the time of sedimentation.

In irrigated rice fields, water run-off (OUT 5) may occasionally occur from August to November (mainly in flood periods) due to heavy rains. It was not measured in this study.

The K concentration in rain water (IN 2) ranged from 0.3 to 3.3 mg/l. The K input from rain water ranged from 6 to 10 kg/ha/year, with rainfall averaging 1,461 to 1,911 mm. The K concentration in irrigation water (IN 3) ranged from 1.5 to 2.5 mg/l. The K input with irrigation water ranged from 4 to 12 kg/ha, depending on the amount of irrigation water, ranging from 250 to 500 mm at the three sites. The sediment content of the irrigation water was small ranging from 11 to 500 mg/l across sites so that sediment-K inputs with irrigation water (IN 4) were negligible and thus neglected. Sediment inputs during the annual flooding period, however, were substantial and K inputs with different fractions (IN 4) are provided in **Table 3**.

Removal of K with grain (OUT 1) was ≤ 10 kg/ha when yield was ≤ 5 t/ha and about 20 kg/ha when yield ranged between 6 to 7 t/ha. Straw-K content ranged from 39 to 118 kg/ha depending on yield level and K nutrition of the crop. Stubble-K ranged from 12 to 50 kg/ha. Potassium removal with crop residues (OUT 2) was calculated according to the residue management at each site. Average K concentrations in the soil solution at the three sites ranged from 0.52 to 6.4 mg/l. Water percolation rate ranged from 0.3 mm to 1.5 mm/d, which is a typical percolation rate in rice fields with a hardpan. Total K loss due to percolation (OUT 3) was small (<1 to 2 kg/ha). At Thoi Thanh, the sediment fraction in drainage water (OUT 4) after soil puddling was very small (1.8 g/l) and therefore neglected for the K balance. Calculated K loss from sediment removal in the form of $K(NH_4OAc)$, K(NaTPB) and K total were 4, 21, and 681 kg/ha/year, respectively. As in Thoi Thanh, sediment losses at An Phong were estimated with 35% of the sediment inputs.

K budgets in double- and triple-rice crop systems with annual flooding. The annual K budgets of the double and triple rice cropping systems at the experimental sites are given in **Table 4**. The analysis across sites showed K inputs with rain and irrigation water of 21 to 24 kg K/ha annually. The balance of K (soluble) ranged from +44 to -86 kg K/ha and was largely influenced by fertilizer K application and residue management, and to a lesser extent by K removal with harvested products. Removal of straw residues formed a major output of K (**Table 4**).

Table 4. Annual K budgets in double- and triple-rice cropping system in CLRRI, An Phong, and Thoi Thanh.

		CLRRI			
Parameter	K input, output, balance	NP	NPK	An Phong	Thoi Thanh
		---------- kg/ha/year ----------			
K(soluble)	IN 1: Chemical fertilizer	0	150	70	40
	IN 2: Rain water	6	6	10	6
	IN 3: Irrigation water	18	18	14	15
	Σ IN 1-3: Total input	24	174	94	61
	OUT 1: Harvested product	13	15	31	45
	OUT 2: Removed residues	79	113	68	100
	OUT 3: Leaching	1	2	2	2
	Σ OUT 1-3: Total output	93	130	101	147
	KBAL(soluble)	-69	44	-7	-86
K(NH$_4$OAc)	IN 4: Flood water sediments	3	3	7	10
	Σ IN 1-4: Total inputs	27	177	101	71
	OUT 4: Sediment loss	0	0	3	4
	Σ OUT 1-4: Total output	93	130	104	151
	KBAL(NH$_4$OAc)	-66	47	-3	-80
K(NaTPB)	Sediment in flood water	11	11	42	59
	Total input (Σ INs 1-4)	35	185	136	120
	Sediment loss	0	0	15	21
	Total output (Σ OUT 1-4)	93	130	116	168
	KBAL(NaTPB)	-58	55	20	-48
K(total)	Sediment in flood water	320	320	1,651	1,892
	Total input (Σ IN 1-4)	344	494	1,745	1,953
	Sediment loss	0	0	594	681
	Total output (Σ OUT 1-4)	93	130	695	828
	KBAL(Total)	251	364	1,050	1,125

Other outputs were relatively small, except when farmers remove sediment to allow gravity irrigation. Percolation loss in these clay soils was small, because of the presence of hardpans and the puddling practice. Losses via leaching may be negligible for clay soils.

Annual flooding supplied substantial amounts of K through sedimentation, but there were large differences in K inputs among K fractions. Newly deposited sediments from annual flooding supplied small amounts under 10 kg K(NH$_4$OAc)/ha, small to moderate amounts of 11 to 59 kg K(NaTPB)/ha, and very large amounts of 320 to 1,890 kg mineral K(total)/ha depending on the rate of sedimentation. It can be assumed that K(NH$_4$OAc) is more readily available to the rice crop, while K(NaTPB) and K(total) would largely effect the long-term supply of indigenous K supply. Sediment K inputs clearly need to be considered in the calculation of K budgets and long-term K fertilizer requirements, where annual flooding occurs in the Mekong River Delta of Vietnam.

Balances of K(soluble) were strongly influenced by K fertilizer application. In treatments without K application at CLRRI, where sediment deposition was less than 50 t per ha and year, balances were negative for K(soluble), K(NH$_4$OAc), and K(NaTPB), but positive for K(total). The negative balance of K(soluble) was reversed with the application of 150 kg K/ha in NPK treatments, hence balances of K(NH$_4$OAc), and K(NaTPB) were reversed accordingly. At An Phong, fertilizer K inputs of 70 kg/ha resulted in neutral or slightly positive K balances for the above mentioned fractions, while the application of 40 kg fertilizer K/ha in the triple-rice cropping system at Thoi Thanh was insufficient to prevent negative soluble K. There was a net input of 3-7 kg K(NH$_4$OAc)/ha and 11 to 38 kg K(NaTPB)/ha with sediments. Evidently, the differentiation between available and non-available K is important, especially when the inputs of initially non-available forms supply substantial amounts of K to the plants. Sediment-K inputs of the K (total) fraction were substantial and by far exceeded K inputs from all other fractions.

Conclusion

We conclude that the partial budgeting approach is inadequate for an accurate estimation of K balances in rice cropping systems with substantial annual flooding in the Mekong Delta of Vietnam. The annual K input with rain and irrigation water supplies about 20 to 25 kg K/ha or 10% of the plant K uptake requirements in a double-rice cropping system (i.e. 200 kg plant K/ha for two rice crops each yielding 6 to 7 t/ha), while crop residue removal after harvest is about 70 to 90% of plant K at harvest. Less negative K balances are expected where crop residues are fully recycled. Sedimentation in areas with annual flooding provides substantial amounts of not-immediately-available mineral K and plays an important role in the maintenance of long-term supply of K in the system. Long-term fertilizer K requirements in areas with long periods of flooding and sedimentation should not be based on partial nutrient budgets. Constructing adequate K budgets under such conditions should include the measurement of available and non-available K. Potassium omission or addition plots should be used to verify fertilizer K requirements in cases of uncertainties. Negative K balances and larger yield responses to fertilizer K application can be particularly expected in regions of the Mekong River Delta where cropping intensity is high, and annual flooding is absent or restricted to short periods with little sedimentation.

Dr. Nguyen is Deputy Head, Soil Science & Land Management Dept., College of Agriculture, Cantho University, Vietnam; e-mail: nmhoa@ctu.edu.vn. Dr. Janssen is Assistant Professor, Department of Soil Quality, Wageningen University, The Netherlands; e-mail: bert.janssen@wur.nl. Dr. Oenema is Professor, Department of Soil Quality, Wageningen University, The Netherlands; e-mail: O.Oenema@wur.nl. Dr. Dobermann is Professor, University of Nebraska, Lincoln; e-mail: adobermann2@unl.edu.

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