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Comparison of partial and complete soil K budgets under intensive rice cropping in the Mekong Delta, Vietnam

Nguyen My Hoa [a,b,*], Bert H. Janssen [b,1], Oene Oenema [b], Achim Dobermann [c]

[a] Soil Science and Land Management Department, College of Agriculture, Can Tho University, 3/2 Street, Can Tho City, Vietnam
[b] Department of Soil Quality, Wageningen University, P.O. Box 8005, 6700 EC Wageningen, The Netherlands
[c] Department of Agronomy and Horticulture, P.O. Box 830915. University of Nebraska, Lincoln, NE 68583-0915, USA

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Abstract

Crop response to added fertilizer K was often found to be small in trials conducted on favorable soils of tropical rice ecosystems. Hence, applications of only fertilizer N and P were recommended. This has resulted in soil K mining in intensive cropping systems in China, India and other Asian countries. Prediction of possible K deficiency in the future requires knowledge of K budgets and an understanding of the mechanisms of K supply to crops in soils and sediments. This paper presents the results of a case study in the Mekong Delta, Vietnam. Detailed K budgets of cropping systems with two and three rice crops per year were made, and compared with partial K budgets with fertilizer K as input, and K removed with harvested grain and straw as outputs. The results of the budgets were combined with data on soil K pools in model calculations. A simple model comprising two soil K pools, labile K (LK) and recalcitrant K (RK) and applying first-order equations for the relative rates of transformation was used to predict various K management scenarios. Potassium balances were always positive for recalcitrant K, and negative for labile K unless about 80 kg ha^{-1} yr^{-1} of fertilizer K was applied. Partial K budgets resulted in K balance estimates that were too negative because of neglected K inputs via rain, irrigation water and sediments. Complete K budgets are needed for a realistic judgment. The differentiation between labile and recalcitrant K and their incorporation in the model made it possible to show the effects of various K management options on future K uptake in rice cropping systems.

Keywords: Potassium budget; Potassium fertilizer; Potassium uptake; Rice production; Sediments; Soil potassium kinetics

1. Introduction

The human population in the world is still rapidly increasing and will be about 8.3 billion by 2025. For increasing food output, crop intensification is the main vehicle in densely populated Asia because expansion of arable land is hardly realistic (Cassman et al., 2003). Intensification of crop production, in combination with unbalanced fertilization, has already resulted in depletion of potassium (K) in soils over large areas in China (Jiyun et al., 1999), India (Hasan, 2002) and other countries in Southeast Asia (Dobermann et al., 1996a, 1998; Ladha et al., 2003).

In the Mekong Delta in Vietnam, rice (*Oryza sativa*) cropping becomes more and more intensive while little K fertilizer has been applied in the past. Indigenous supplies of K were found to be low in plots where K additions were withheld (zero K plots) (Dobermann et al., 2003; Tan et al., 2004) and K concentrations in straw were as low as 10 g kg^{-1} in some places (unpublished data). Deficiency of K in rice is not yet widespread, but the K deficiency problems encountered by farmers in China and India, concern researchers and policy makers in the area. Appropriate measures should be taken before K deficiency occurs everywhere. Scientists should forecast when K deficiency is to be expected and should show the effects of various K management options. To be able to do so, soil K

* Corresponding author. Tel.: +84 71 831005; fax: +84 71 830814.
E-mail address: nmhoa@ctu.edu.vn (N.M. Hoa).
[1] Present address: Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands.

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Table 1
Abbreviations of inputs and outputs of a complete K budget for rice cropping systems

Inputs		Outputs	
Chemical fertilizer	IN1	Harvested products	OUT1
Rain water	IN2	Removed crop residues	OUT2
Irrigation water	IN3	Leaching	OUT3
Sedimentation via annual floods	IN4	Sediment removal	OUT4
		Run-off water	OUT5

dynamics must be understood, which requires knowledge of detailed K budgets and of size and conversion rates of various K-pools in the soil.

This paper presents an approach to study complete K budgets of soils at field scale, using various rice cropping systems in the Mekong Delta in Vietnam as examples. A nutrient budget is an ''account'' of nutrient flows to (inputs) and out of (outputs) a certain, clearly defined, agroecosystem (e.g. soil, field, farm). A nutrient balance is the difference between the sums of nutrient inputs and nutrient outputs (Janssen, 1999). Table 1 lists the inputs (INs) and outputs (OUTs) of a complete K budget.

Many studies on K input–output balances for wetland rice and other crops in Asia were based only on the amounts of fertilizer applied as input and the amount of K removed by the crop as output, and represent partial K balances (Nambiar and Ghosh, 1987; Dobermann et al., 1996b). Some studies included assumptions on K in irrigation water (e.g. Bajwa, 1994) or on rice straw management (e.g. Patnaik, 1978; Dobermann et al., 1996b) using simplified budgets. Inputs of K from rainfall and irrigation water were often assumed to be comparable to or smaller than nutrient losses due to leaching and thus not to represent a net input of nutrients (Dobermann et al., 1996b, 1998).

According to Janssen (1999), a differentiation between 'available' and 'not-immediately available' nutrients is useful in nutrient balance studies, but for K-balance studies such a differentiation has not yet been made. So far K balance estimates were mostly based on soluble K for all inputs and outputs. Less available K from inputs such as sedimentation was neglected. During a growing season, however, substantial amounts of K are released from less available pools. If there is no erosion, balances of less available K are expected to be less negative than balances of soluble K.

For a correct interpretation, K budgets must be compared with the K stock in the soil. Also, the processes going on in the soil itself should be considered. There is no guarantee that K added in an available form is taken up by the crop; it may partly get lost by leaching or be adsorbed onto clay and soil organic matter, or be captured in soil minerals. A neutral balance indicates that the total stock in the soil does not change, but the 'quality' of the stock, and hence soil fertility, may still alter. Therefore, one must also include the dynamics of the K pools in the soil and the transformations of added K to be able to interpret K budgets in a sensible way. The many processes involved make the use of models imperative (Selim et al., 1976; Bertsch and Thomas, 1985; Hoa, 2003). It is not feasible to discuss all these issues in one article. In this paper, we shall apply only a simplified model just to show how different is the meaning of budgets of various K forms in determining K supply to plant.

The general objective of this study was to develop a simple yet suitable tool to explore the future of K supply in rice cropping systems. Specific objectives were to (i) establish complete K budgets of different rice cropping systems, (ii) examine whether partial K budgets would suffice, and (iii) evaluate the consequences of various K management options for future K uptake in rice cropping systems, by using a model with two K pools relevant for soil K dynamics.

2. Materials and methods

2.1. Site selection

Four monoculture rice cropping systems in the Mekong Delta were compared, representing different methods of residue management, and various levels of cropping intensity, sedimentation and fertilization (Table 2). Two systems were in fields of ongoing experiments, and two in farmers' fields. Details of fields and crop husbandry are given by Hoa (2003).

In 1994, a long-term fertilizer experiment was established at the Cuu Long Rice Research Institute (CLRRI) in Can Tho province, Vietnam. The NP and NPK plots of that experiment, each 25 m^2 in size, were used in this study. Twelve crops had been grown without K fertilization in the NP plot until the sampling period (March 2000). An Phong (Table 2) refers to a field of 0.5 ha, belonging to the Rice Variety Screening Center of Dong Thap province. For more than 10 years, two rice crops per year were grown. The farmer's field in Thoi Thanh (Can Tho province) was

Table 2
Cropping systems considered in the K balance studies

Code/location	Cropping intensity	Sedimentation	Residue management	K fertilizer application
CLRRI-NP	Double	Little	Removal	None
CLRRI-NPK	Double	Little	Removal	High
An Phong	Double	Much	Incorporation[a]	Moderate
Thoi Thanh	Triple	Much	Incorporation[a]	Low

[a] Incorporation after dry season crop, partially removed in other crops.