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Potassium Efficiency and Potassium Balance of the Rice-Rice Cropping System Under Two Different Agro-Ecosystems

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One of the experimental plots. Photo by Yulin Liao.

Abstract

The paper considers the effect of potassium (K) together with nitrogen (N) and phosphorus (P) fertilizer supply on grain yield, and K use efficiency and K balance of the rice-rice cropping system in a hilly agro-ecosystem region and lake agro-ecosystem region in south China. Comparing various levels of K supply, highest grain yields were obtained at 150 kg K_2O ha^{-1}, for both early and late rice in the reddish-yellow clayey soil of the hilly agro-ecosystem. For the Dongting lake agro-ecosystem, the purple calcareous clayey soil was much less responsive; K fertilizer efficiency being lower because of the higher soil available K and slowly available K contents. Grain yield increase resulting from N fertilizer was much greater than that from K fertilizer in both agro-ecosystems. The recovery by rice crop of fertilizer K was determined by measuring total of straw and grain K contents compared to the total K applied to the soil. For all three treatments of applied K, recovery rates were higher in the reddish-yellow paddy soil than in the purple calcareous clayey soil. The average value of K recovery efficiency for the three K fertilizer treatments in the reddish-yellow paddy soil was 35.0 percent for early rice and 51.8 percent for late rice; while the comparative figures for the purple calcareous clayey soil were 27.1 percent for early rice and 42.6 percent for late rice. N fertilizer recovery efficiency increased with K fertilizer application. This trend was more obvious in late rice. All three K application rates of 112.5, 150 and 187.5 kg K_2O ha^{-1} resulted in a deficit in K balance. N surpluses with early rice occurred with applications of 165 kg N ha^{-1} on the reddish-yellow paddy soil and with 150 kg N ha^{-1} on the purple calcareous clayey soil. With late rice, application of 180 kg N ha^{-1} resulted in N surpluses on the soils of both agro-ecosystems. The surplus amounts of N decreased with increasing K fertilizer application.

Keywords: Rice-rice cropping system; potassium fertilizer; potassium efficiency; potassium balance.

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Introduction

The rice-rice production system is an important one in south China, contributing most of the food for the country. There are, however, signs of productivity decline and deterioration in soil fertility of the system because of a lack of K. Over recent years, increase in rice production has been achieved by the use of improved germplasm, associated with increased application of N and P fertilizers, but without a corresponding increase in the use of K fertilizers. This lack of K has been exacerbated by the practice of resource poor farmers who remove nutrients from their fields, especially K, in the form of straw for fuel and cattle feed (Wihardjaka *et al*., 1999; Yadav, 1998). Burning straw, to allow ease of tillage, also reduces soil fertility by consequent loss of organic matter (OM). For similar reasons the same problem of K depletion and deterioration in soil fertility has been observed under cropping systems in India (Römheld and Kirkby, 2010). Under the current fertilizer application regime of the rice-rice cropping system in south China, K is usually is inadequate in terms of the N, P to K nutritional balance, and may even be highly K deficient. The need to increase soil K fertility as well as take into account the K balance in soils in order to stabilize high yields was highlighted by Wang *et al*. (2005).

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Understanding K supply capacity of soils in different rice-rice planting areas, as well as the requirement to increase K-supplying potential capacity of paddy soils by adequate potassium application, is one of the important measures to increase rice crop yields and sustain K fertility of paddy soils. K fertilizer management in paddy soil is the key to high yield rice crops and the maintenance of soil K balance. According to Zheng *et al.* (1989), K fertilizer application is a traditional agricultural measure to sustain rice crop yield in the rice-rice cropping system.

In order to apply K at a rate to meet the needs of the rice crop during growth, and to obtain a rationale for K fertilizer use with optimal economic benefit, it is necessary to study K efficiency, K recovery efficiency and K balance of the rice-rice cropping system. The aim of the present study was thus to provide a scientific rationale for K fertilizer application for paddy soil in two contrasting agro-ecosystems in two different regions in Hunan province. The effect of K fertilizer on grain yield, potassium efficiency and potassium balance of the rice-rice cropping system were investigated over the 2005-2006 crop season.

Table 1. Some chemical properties of soils at the sites used in experiments.

Location	Soil name	Physiographic pattern	pH*	OM	Total N	Avail. N	Avail. P	Slowly avail. K	Avail. K
				---$g\ kg^{-1}$---		-------------$mg\ kg^{-1}$------------			
Changsha county	Reddish yellow clayey soil	Hilly agro-ecosystem	5.7	38.7	12.2	196.5	19.9	115.0	106.6
Yuanjiang city	Purple calcareous clayey soil	Dongting lake agro-ecosystem	7.3	46.0	24.4	216.0	17.9	349.0	131.0

* At soil to water ratio of 1:2.5(w/w).

Materials and methods

Site description

The experiments were carried out at two sites in Hunan province, one in Changsha County and the other in Yuanjiang city. The physiographic patterns of Changsha County and Yuanjiang city are a hilly ecosystem and the Dongting lake ecosystem, respectively. In the hilly ecosystem in Changsha County, the soil is a reddish-yellow paddy soil derived from Quaternary red clay, whereas the soil derived from lake sediment in Yuanjiang city is a purple calcareous clayey soil. The chemical properties of the soils at the two experimental sites are shown as Table 1.

Experiment design

The experiment treatments as shown and described in Table 2 included NP, PK2, NPK1, NPK2 and NPK3 for both early and late rice planting seasons. A detailed description of the experimental design is presented in Fig. 1. As shown in the figure the NPK2 plots in the early rice season was divided into NP, PK2 and NPK2 plots in the late rice season. The N application rates for early rice were 165 kg N ha^{-1} in the hilly agro-ecosystem region and 150 kg N ha^{-1} in the Dongting lake region, except where N was omitted in the PK2 treatments, respectively. The N application rate for late rice was 180 kg N ha^{-1} for both experimental sites. Two thirds of the N fertilizer was applied as basal fertilizer before transplanting both the early and late rice and the other third was applied as topdressing at an early tillering stage. The application rates of P fertilizer were 90 kg P_2O_5 ha^{-1} in early rice and 45 kg P_2O_5 ha^{-1} in late rice applied as basal fertilizer. K fertilizer was also applied as basal fertilizer. Each treatment had three replications arranged in a randomized block design with a plot size of 20 m^2. The rice varieties used, or their combinations, in the experiments were "Baliangyou100" in early rice and "Weiyou64" in late rice in Changsha, and "Baliangyou100" in early rice and "Iyou198" in late rice in Yuanjiang, respectively. In each year, early rice transplanting took place in late April and late rice was transplanted about late July, with 16.7 cm × 20 cm spacing for early conventional rice and 20 cm × 20 cm spacing for late hybrid rice. Early rice was harvested around the middle of July in the early planting season and late rice was harvested around late October in the late planting season.

Table 2. Nutrient application treatments of the experiment.

Treatments	Early rice			Late rice		
	N(*)	P_2O_5	K_2O	N	P_2O_5	K_2O
	----------------------$kg\ ha^{-1}$----------------------					
NP	165/150	90	0	180	45	0
PK2	0	90	150	0	45	150
NPK1	165/150	90	112.5	180	45	112.5
NPK2	165/150	90	150	180	45	150
NPK3	165/150	90	187.5	180	45	187.5

Note: (*)165 and 150 kg N ha^{-1} in Changsha County and Yuanjiang city, respectively.

Analysis method and data analysis

The concentration of OM, total N, available N, available P, available K

Early rice in first season

NPK2			NPK1	NPK3	NP	PK2
NPK1	NP	PK2	NPK3	NPK2		
NPK3	NPK2			PK2	NPK1	NP

Late rice in second season

NPK2	NP	PK2	NPK1	NPK3		
NPK1			NPK3	NPK2	PK2	NP
NPK3	NPK2	NP	PK2		NPK1	

Fig. 1. Experimental design used in the field studies.

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Table 3. The response of grain yield to K application in different types of agro-ecosystems region.

Treatment	Grain yield		Agronomic efficiency	
	Early rice	Late rice	Early rice	Late rice
	----------kg ha^{-1}-----------		----kg grain kg^{-1} K_2O----	
Changsha County; Hilly agro-ecosystem				
NP	7,283.3 c	7,983.3 c	-	-
NPK1	7,483.3 b	8,150.0 b	1.78	1.48
NPK2	7,700.0 a	8,333.3 a	2.78	2.33
NPK3	7,683.3 a	8,433.3 a	2.13	2.40
Yuanjiang city; Dongting lake agro-ecosystem				
NP	7,666.7 a	8,316.7 a	-	-
NPK1	7,800.0 a	8,366.7 a	1.18	0.44
NPK2	7,866.0 a	8,516.6 a	1.33	1.33
NPK3	7,783.3 a	8,517.3 a	0.62	1.07

Note: Statistical significance is indicated at a 95 percent level ($P \leq 0.05$).

and pH value in soil and total K and total N in the rice plants were analyzed by the use of conventional methods (Lu, 2000). Statistical analyses were performed with SPSS 10. Input of nitrogen included the N applied together with that returned by crop residues. Output included the N uptake by the rice crop together with gaseous losses. These losses were estimated by using data from other authors (Liu *et al*., 2002; Zheng *et al*., 2004). Input of K included the K applied as fertilizer and that returned by crop residues. The output included the K uptake by the rice crop.

Results

K fertilizer application effect on grain yield in the two agro-ecosystem regions

In the hilly agro-ecosystem, grain yield difference between the three treatments with K fertilizer application and the treatment without K fertilizer application was significant at $P<0.05$ (Table 3). The difference between yields of the NPK3 and NPK2 treatments, however, was not significant at $P<0.05$. The results indicate that the comparatively higher grain yield was obtained when 150 kg K_2O ha^{-1} was applied (NPK2 treatment) under the K fertility status and production condition of this agro-ecosystem. In the Dongting lake agro-ecosystem, the grain yields were increased in the three treatments with K applied in early rice and late rice, but the difference between them and the no K fertilizer application treatment was not significant, at $P>0.05$. This finding indicates that native soil K was adequate to sustain the higher yield in Dongting lake agro-ecosystem. The agronomic efficiency of K (i.e. kg grain per kg K_2O applied) of early rice in the hilly agro-ecosystem varied from 1.78 to 2.78 and that of late rice varied from 1.48 to 2.40. In the Dongting lake region, the comparative values for early rice ranged from 0.62 to 1.33 and late rice 0.44 to 1.33. The agronomic efficiency of K in the hilly agro-ecosystem was thus higher than in the Dongting lake region, with an average value of agronomic efficiency of K being 2.15 kg grain kg^{-1} K_2O in the hilly agro-ecosystem as compared with 1.00 kg grain kg^{-1} K_2O in the Dongting lake agro-ecosystem.

The recovery efficiency of K and N by rice plants in early rice and late rice in different agro-ecosystem regions

The average value of K recovery efficiency (i.e. the K in grain and straw as compared with the K applied) for the three K fertilizer treatments is given in Table 4. For the hilly agro-ecosystem region with the reddish-yellow paddy soil, it was 35.0 percent (33.5-36.7 percent) for early rice, and 51.8 percent (47.3-55.8 percent) for late rice. For the lake agro-ecosystem region with purple calcareous clayey soil, the comparative figures were 27.1 percent (26.1-27.8 percent), and 42.6 percent (36.9-48.7 percent), respectively. Calculating the average value of K recovery efficiency by rice plants for the two seasons, the average of three K fertilizer treatments on the reddish-yellow paddy soil (43.4 percent) was 8.5 percent higher than that on the purple calcareous clayey soil (34.9 percent). The average N recovery efficiency values of the three K fertilizer application plots in the hilly agro-ecosystem region for early rice and late rice were 32.7 percent (30.3-34.1 percent) and 34.6 percent (32.2-35.3 percent), respectively. In the Dongting lake agro-ecosystem region, the comparative figures were 34.6 percent (33.5-35.3 percent) and 35.0 (34.2-36.3 percent), respectively. Fertilizer N recovery efficiency increased with increasing K fertilizer application, this trend being more obvious in late rice.

Balance of K and N in different agro-ecosystem regions

The input of potassium included the K

Table 4. Recovery efficiency of K fertilizer and N fertilizer by rice plants (grain+straw) in rice–rice cropping system of different types of agro-ecosystem region.

Treatment	Changsha County; hilly agro-ecosystem region			Yuanjiang city; Dongting lake agro-ecosystem region		
	Early rice	Late rice	Average	Early rice	Late rice	Average
	------------------%------------------					
Potassium recovery efficiency						
NPK1	36.7	52.4	44.6	27.3	48.7	38.0
NPK2	34.7	55.8	45.3	26.1	42.3	34.2
NPK3	33.5	47.3	40.4	27.8	36.9	32.4
Nitrogen recovery efficiency						
NPK1	30.3	32.2	31.3	33.5	34.5	34.0
NPK2	33.2	35.3	34.3	34.9	36.3	35.6
NPK3	34.1	36.3	35.2	35.3	34.2	34.8
NP	25.8	23.0	24.4	25.6	20.9	23.3

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applied and that returned by crop residues. The output of K included the K uptake by the rice crop. From the results of total K balance (Table 5), the total input of K increased with increasing rate of K fertilizer application. The amount of K output increased with the increasing input rate. Comparing the soil K output rate of the two agro-ecosystem regions, the soil K output in Dongting lake agro-ecosystem was obviously higher than that in the hilly agro-ecosystem region. This may be due to the abundance of soil K in Dongting lake agro-ecosystem region. When the K fertilizer application rate increased from 112.5 kg ha^{-1} per season to 187.5 kg ha^{-1} per season, the amount of K uptake by the rice crop showed no obvious increase, but the amount of soil K deficit decreased with increasing K fertilizer application rate. The total grain yield of two season's rice crop did not increase with increasing rate of K fertilizer application. The total amount of K uptake from two seasonal rice crops in Dongting lake agro-ecosystem region was far higher than that in the hilly agro-ecosystem region. The results illustrate a most important reason for the absence of yield increase with increasing K fertilizer application in this region.

Table 5. Estimates of K balance in different fertilization treatment at different types of agro-ecosystem region (kg K_2O ha^{-1}).

Treatment	Early rice			Late rice			Total		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
	--kg ha^{-1}--								
	Changsha County; Hilly agro-ecosystem region								
NP	0	129.6	-129.6	3.5	186.8	-183.3	3.5	316.4	-312.9
NPK1	112.5	170.9	-58.4	116.2	245.8	-129.6	228.7	416.7	-188.0
NPK2	150	181.7	-31.7	153.8	270.5	-116.7	303.8	452.2	-148.4
NPK3	187.5	192.4	-4.9	191.1	275.4	-84.3	378.6	467.8	-89.2
	Yuanjiang city; Dongting lake agro-ecosystem region								
NP	0	164.7	-164.7	3.7	245.7	-242.0	3.7	410.4	-406.7
NPK1	112.5	195.4	-82.9	116.4	300.5	-184.1	228.9	495.9	-267.0
NPK2	150	203.8	-53.8	153.8	310.0	-156.2	303.8	513.8	-210.0
NPK3	187.5	216.9	-29.4	191.3	314.9	-123.6	378.8	531.8	-153.0

The results of soil N are shown in Table 6. The input of N includes the N applied and that derived from crop residues. Output of N includes N uptake by the rice crop together with gaseous losses. Gaseous losses were calculated using related data of other authors (Liu *et al.*, 2002; Zheng *et al.*, 2004). Nutrient composition of irrigated water is similar to that of leached water. A calculation of input of irrigated water and output of leached water was therefore not included in the balance (Ji *et al.*, 2006). An N surplus occurred in the balances of both agro-ecosystem regions but was greater in the hilly agro-ecosystem region. Highest surpluses were found in the NP treatments with N surpluses in the hilly agro-ecosystem and Dongting lake agro-ecosystem region being 81.8 and 43.8 kg N ha^{-1}, respectively. Increasing rate of K fertilizer application resulted simultaneously in a decrease in N surplus. The same trend could be seen in the findings for both agro-ecosystem regions.

Changes in available K values in soils induced by different fertilization treatments in the soils of the two different types of agro-ecosystem region

Change of available K in soils is correlated with level of available K and slowly available K in soil used prior to the onset of the experiment (Muneshwar *et al.*, 2002). As fertilizer treatment is known to affect the available K status of soils, measurements of available K were made after, as well as before, the experiment. In both agro-ecosystems, NP treatment caused the highest decrease of available K (Table 7). However, in the Dongting lake agro-ecosystem this decrease was smaller, presumably because of the higher amounts of available and slowly

Table 6. Estimates of N balance in different fertilization treatments at different types of agro-ecosystem region (kg N ha^{-1}).

Treatment	Early rice			Late rice			Total		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
	--kg ha^{-1}--								
	Changsha County; hilly agro-ecosystem region								
NP	165	115.1	49.9	186.4	154.5	31.9	351.4	269.6	81.8
NPK1	165	118.5	46.5	189.1	166.6	22.5	354.1	285.1	69.0
NPK2	165	123.3	41.7	189.2	172.2	17.0	354.2	295.5	58.7
NPK3	165	124.7	40.3	189.3	173.9	15.4	354.3	298.6	55.7
	Yuanjiang city; Dongting lake agro-ecosystem region								
NP	150	128.9	21.1	187.0	164.3	22.7	337.0	293.2	43.8
NPK1	150	137.9	12.1	189.7	178.5	11.2	339.7	316.4	23.3
NPK2	150	139.9	10.1	189.6	181.7	7.9	339.6	321.6	18.0
NPK3	150	140.5	9.5	189.7	178.0	11.7	339.7	318.5	21.2

Note: Gaseous loss of N from the NP treatment was calculated as 20.9 percent of the fertilizer N applied in early rice and late rice of the hilly agro-ecosystem region while that of NPK1, NPK2 and NPK3 treatment was calculated as 18.5 percent of the fertilizer N applied in early rice and late rice of the hilly agro-ecosystem region. Gaseous loss of N from the NP treatment was calculated 25.3 percent of the fertilizer N applied in early rice and late rice of Dongting lake agro-ecosystem region, while that of NPK1, NPK2 and NPK3 treatment was calculated as 23.5 percent of the fertilizer N applied in early rice and late rice of Dongting lake agro-ecosystem region.

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available soil K. Application of K fertilizer lessened the decrease in available K levels, in both agro-ecosystems, but not to the initial level of K before the onset of the experiment. While this may point to a net depletion of K, it can also be attributed to rather slow release of K to its available form.

Table 7. Status of available K in soils of different fertilization treatment in rice-rice cropping system of different types of agro-ecosystem region (K mg kg^{-1}).

Treatment	Changsha County; Hilly agro-ecosystem region		Yuanjiang city; Dongting lake agro-ecosystem region	
	Early rice	Late rice	Early rice	Late rice
	-------------------------*mg kg^{-1}*-------------------------			
Initial K status(†)	106.6; 115.0		131.0; 349	
NP	59.7c	53.4d	95.5d	95.5b
PK2	86.1a	83.3a	128.3a	128.3a
NPK1	63.5b	57.6c	108.4bc	98.2b
NPK2	66.3b	66.5b	97.7d	99.7b
NPK3	64.8b	67.3b	114.2b	100.3b

(†) Available K; slowly available K.

Note: Statistical significance is indicated at a 95 percent level ($P \leq 0.05$).

Discussion

The efficiency of K fertilizer application in a rice-rice cropping system is higher in the hilly agro-ecosystem region compared to that in Dongting lake agro-ecosystem region, the main reason for this difference being the K-supplying capacity level of soil. The content of slowly available K and available K in reddish-yellow paddy soil derived from Quaternary red clay in hilly agro-ecosystem region is obviously lower than that of purple calcareous clayey soil derived from lake sediment in the Dongting lake agro-ecosystem region. The high K supplying capacity of this soil is able to meet the K requirement to produce a high grain yield of rice in the Dongting lake agro-ecosystem region. This finding is in accord with the lower agronomic efficiency K values measured in this agro-ecosystem.

Under continuous K fertilizer application from 112.5 to 187.5 kg K_2O ha^{-1}, the associated trend in increasing yield was smaller for late rice than for early rice in both agro-ecosystem regions. The results showed a residual effect of K fertilizer to the soil (Bao and Xu, 1993). The yield increase effect and agronomic efficiency, resulting from N fertilizer application, was much bigger than that from K fertilizer in both types of agro-ecosystem regions. Reasonable N fertilizer application is thus a key to obtaining high yield in rice production, and the most important measure to ensure the benefit of K fertilizer application to paddy soil which are deficient in K.

The recovery efficiency of N fertilizer increased with increasing rate of K fertilizer application, the trend being more significant in late rice. This result indicates that K fertilizer application induces the rice crop to take up more nitrogen from N applied fertilizer, the effect being consistent in both types of agro-ecosystem regions.

The K balance was negative under 112.5, 150 and 187.5 kg K_2O ha^{-1} fertilizer application rate in each planting season. N surpluses occurred under early rice at rates of 165 kg N ha^{-1} in reddish-yellow paddy soil, and 150 kg N ha^{-1} in purple calcareous clayey soil. With late rice with application of 180 kg N ha^{-1}, surpluses of N were also present in both agro-ecosystems. The amount of surplus N decreased with increasing K fertilizer application regardless of the agro-ecosystem.

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