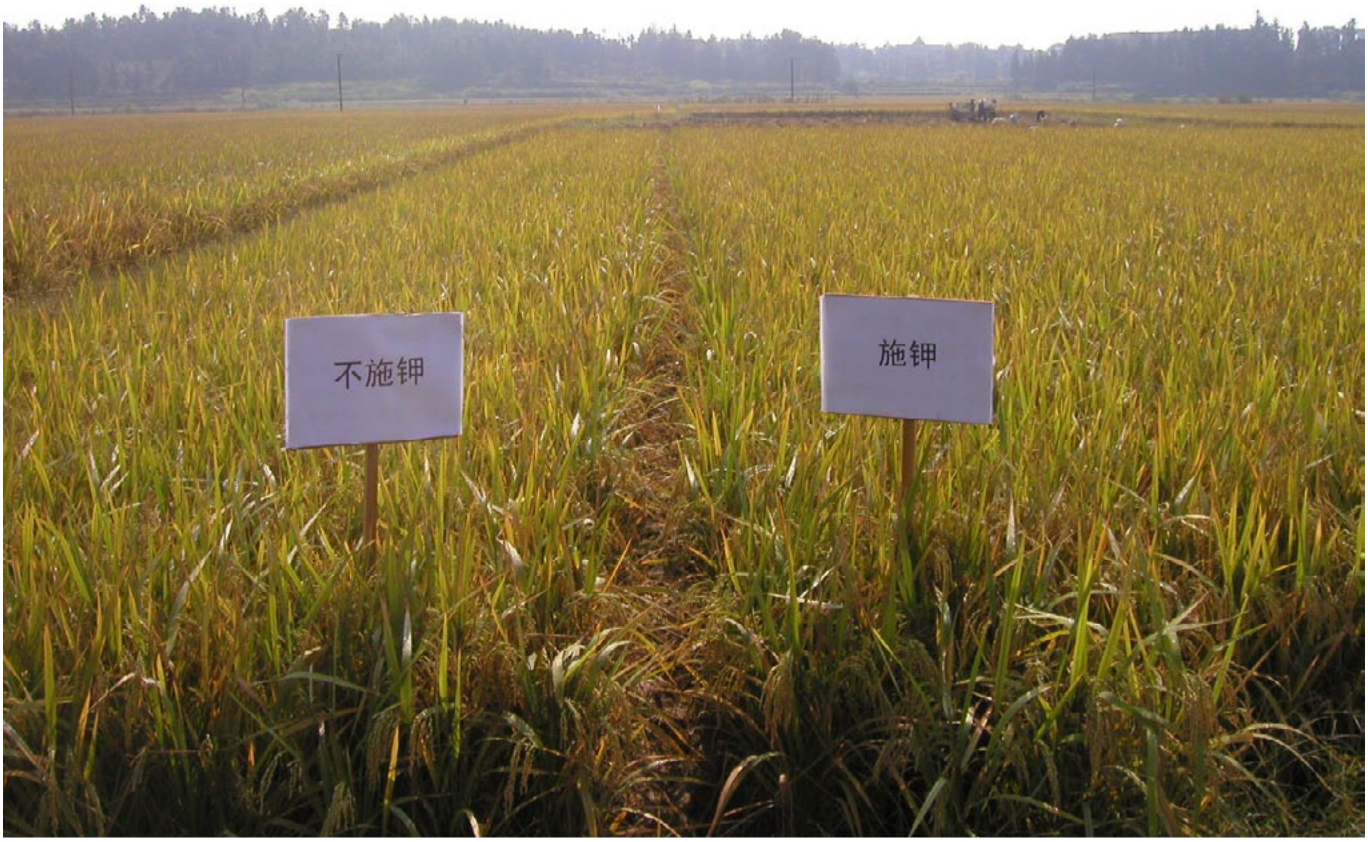
# Research Findings




Rice experiments on paddy soils of the hilly region of Hunan Province, China. Photo by authors.

## Effect of Combined K and N Application on K Use Efficiency and Balance in Rice-Rice Cropping Systems in the Hilly Regions of Hunan Province, China

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### Abstract

A field experiment under a double-rice cropping system was carried out to study the effects of altered basal potassium (K) application rates (0, 105, and 150 kg $K_2O$ ha$^{-1}$) using two nitrogen (N) rates (150 and 195 kg N ha$^{-1}$) on rice yield, K uptake, fertilizer use efficiency, agronomic efficiency, soil K balance, and economic balance. The experiment was carried out on two types of paddy soil in the hilly regions of Hunan Province, China. The early crop yield increased slightly in response to the first increase in K rate, however, further yield increase was obtained only at the higher N rate. A similar response pattern was observed for the late crop on the red-yellow soil but not on the yellow soil, where the increase in N rate did not raise the rice yield. Potassium utilization rate was generally low, and it declined with increasing K rates. Potassium agronomic efficiency did not exceed 7 kg

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grain kg$^{-1}$ $K_2O$, it declined with increasing K rates but rose in response to an increase in N. Soil soluble K at harvest increased with K rates, however, no significant change was observed in soil exchangeable K. Economic analyses show that the combination of higher K and N rates was the most profitable choice for the early crop, while medium K and lower N rates were the best combination for the late crop. Altogether, these results show that K nutrition is still a focal problem of rice-rice production on paddy soils. They also indicate that the maintenance of soil K balance during the cropping season is the most critical challenge. One recommendation is to examine an alternative approach of splitting the K application rate along the season, to minimize K seepage. In addition, fertilizer management should be adjusted to local soil characteristics, and a suitable balance among soil macro- and microelements must be preserved.

## Introduction

Hunan Province is located in the tropical region of Central Asia. Its climate is characterized as humid monsoon with abundant sunshine, heat and rainfall. The hilly region, comprising 29% of the total province area (Yang, 1989), is the main food production hub in Hunan Province. It possesses superior natural conditions for rice cultivation, usually as a double season crop grown on paddy soils.

Paddy soils are defined through their production environment; typically irrigated and rain-fed lowland rice-cropping systems. Paddy soils make up the largest anthropogenic wetlands on earth. They may originate from any type of soil in pedological terms, but are highly modified by anthropogenic activities. The formation of these Anthrosols is induced by tilling wet soil (puddling), and the flooding and drainage regime associated with the development of a plough pan and specific redoximorphic features. Redox potential oscillations due to paddy management control, microbial community structure and function, and thus short-term biogeochemical processes (Kögel-Knabner *et al.*, 2010).

The increasing intensification of rice production in the region – involving improved varieties, high crop indices and yields, greater use of inorganic (mainly nitrogen [N] and phosphorus [P]) and organic fertilizers, and the growing tendency to remove straw for fuel, forage or just for the convenience of land cultivation – has put significant pressure on the potassium (K) resources of local paddy soils (Yadav, 1998; Wihardjaka *et al.*, 1999). During the last 30 years, farmland soil fertility has been significantly degraded; imbalanced mineral nutrition under intensified rice production, augmented by high temperatures and intense precipitation regimes have led to severe soil K depletion. Therefore, most rice-rice production systems experience a negative K balance (Dai *et al.*, 2000). Local farmers' practices still focus on heavy N application and tend to ignore crop K requirements, which leads to poor crop performance. Therefore, demonstrating the importance of K fertilization to obtain reasonable rice yields is still necessary, particularly in the rice-rice production system (Yadav, 1998).

In the present study, the effect of K application on yields and soil K status was examined in the hilly areas of Hunan Province using two N application levels in order to provide a scientific basis for a rational N and K management on paddy soils.

## Materials and Methods

### Experimental site and basic soil traits

The experiments were conducted in Changsha and Hengshan Counties, Hunan Province.

Changsha County is characterized by red-yellow paddy soils developed from a quaternary red soil, while Hengshan County has yellow paddy soils developed from plate shale. Soil characteristics are shown in Table 1.

### Experiment design

The experiment was conducted in 2012 and was comprised of successive early and late rice. There were six treatments: $N_1K_0$, $N_1K_1$, $N_1K_2$, $N_1K_3$, $N_2K_0$, and $N_2K_3$, as detailed in Table 2.

Most of the N fertilizer was applied at pre-planting for both the early (70%) and the late (60%) rice crops, and the rest was applied


**Map. 1.** Changsha and Hengshan Counties, Hunan Province, China.
*Source:* https://en.wikipedia.org/wiki/Xinning_County,_Hunan.

**Table 1.** The physical and chemical properties of the two paddy soils in the experiment.

| Paddy soil type | pH | Organic matter | Total N | Alkaline N | Available P | Total K | Soluble K | Exchangeable K |
|---|---|---|---|---|---|---|---|---|
| | *water* | ---------------*g kg$^{-1}$*--------------- | | -------------*mg kg$^{-1}$*------------- | | *g kg$^{-1}$* | --------------*mg kg$^{-1}$*------------- | |
| Red-yellow | 5.3 | 32.9 | 12.5 | 298.1 | 6.4 | 9.2 | 54.2 | 103.5 |
| Yellow | 5.8 | 38.3 | 13.4 | 191.2 | 4.9 | 9.9 | 74.3 | 94.4 |

**Table 2.** A detailed description of fertilizer treatments.

| Treatment | Early rice | | | Late rice | | |
|---|---|---|---|---|---|---|
| | N | K | P | N | K | P |
| | Urea | KCl | $P_2O_5$ | Urea | KCl | $P_2O_5$ |
| | *kg ha$^{-1}$* | *kg $K_2O$ ha$^{-1}$* | ---------*kg ha$^{-1}$*--------- | | *kg $K_2O$ ha$^{-1}$* | *kg ha$^{-1}$* |
| $N_1K_0$ | 150 | 0 | 75 | 180 | 0 | 45 |
| $N_1K_1$ | 150 | 105 | 75 | 180 | 136.5 | 45 |
| $N_1K_2$ | 150 | 150 | 75 | 180 | 195 | 45 |
| $N_1K_3$ | 150 | 195 | 75 | 180 | 253.5 | 45 |
| $N_2K_0$ | 195 | 0 | 75 | 234 | 0 | 45 |
| $N_2K_3$ | 195 | 195 | 75 | 234 | 253.5 | 45 |

at tillering. Phosphorus and K fertilizers were applied at pre-planting.

Seedlings of the early crop were transplanted in late April, at a row spacing of 13.3 x 20 cm, using the cultivars Zhejiang 7 and Weiyou 402, in Changsha and Hengshan, respectively, and harvested in early July. For the late crop, seedlings of the cultivars, Fengyuan Excellent 272 and Jade Incense 88, were transplanted at 20 x 20 cm spacing in late July in Changsha and Hengshan, respectively, and harvested in mid to late October. Each treatment included four repetitions of 20 m$^2$ in a random block design.

### Sample collection and analyses

Soil samples were collected from the 0-20 cm layer before the experiment ($t_0$), and at the end of each early and late crop cycle. Soil total, soluble, and exchangeable K contents were determined using conventional analytical methods (Lu, 1999). At harvest, grain yield and aboveground biomass were determined. Samples of aboveground plant biomass were weighed, dried, and weighed again, ground to a fine powder and used for determination of K content (Lu, 1999).

### Calculation and statistical analysis

Agricultural performance was evaluated using the following parameters:

*K uptake:* defined as the amount of K absorbed by the aboveground rice biomass (kg $K_2O$ ha$^{-1}$).

*K residue:* calculated as the difference between K uptake and K application rate (kg $K_2O$ ha$^{-1}$).

*K utilization rate:* calculated as: 100 · ($K_{Treatment}$ uptake - $K_0$ uptake)/$K_{Treatment}$ dose (%).

*Agronomic efficiency:* calculated as: ($K_{Treatment}$ grain yield - $K_0$ grain yield)/ $K_{Treatment}$ uptake (kg grain kg$^{-1}$ $K_2O$).

Statistical analyses were carried out using IBM SPSS 21.0 software.

## Results and analysis

### Effects of combined N and K application on rice yields

In both soil types, the highest cumulative grain yields were obtained under the highest combination of N and K application rates (Fig. 1). On the red-yellow soil, in the early crop, the increasing K rates hardly affected the yield under the lower N rate (yield increase ranging from 2.4 to 5.1%), while under the higher N rate, the yield increase was much greater (13.7%) and about 900 kg ha$^{-1}$ more than the control. A similar pattern occurred for the late crop, although yield response to the K application under the lower N rate was more pronounced and ranged from 9.0 to 13.9%. In the late crop, yield response to the aggravated N rate was significant even when no K fertilizer was added, while the higher K rate made no further difference (Fig. 1).

Rice yields on the yellow soil were generally higher than on the red-yellow soil, by 600 kg ha$^{-1}$ per season, on average. Under the lower N rate, yield responded to the first grade of K rate, increasing by 10.3-12.4% and 12.9-17.7%, for the early and the late crop, respectively, but no further significant response could be observed when K rate was increased (Fig. 1). Upgraded N rate had a much smaller and not always significant influence on the yield.

### Effects of combined N and K application on K balance on two paddy soils

The total K uptake of both early and late rice crops increased with the rising K application rates (Table 3). Furthermore, K uptake consistently increased in

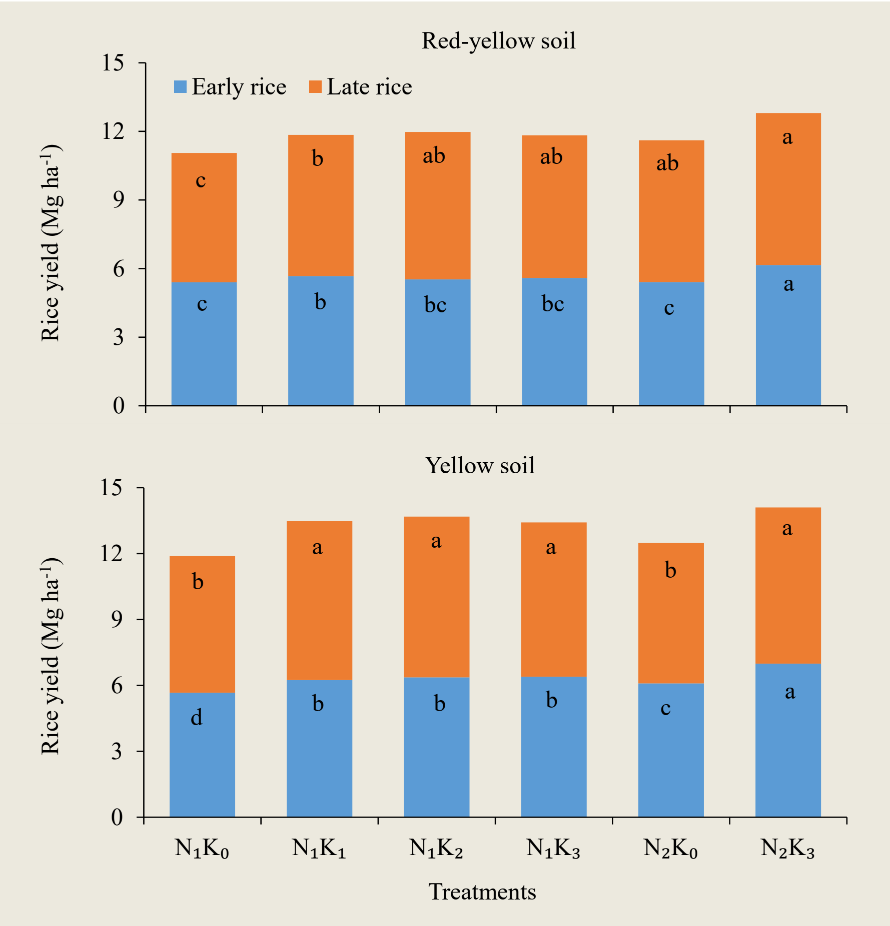



**Fig. 1.** Effect of combined N and K treatments on early and late rice yields on two paddy soil types. Same letters indicate no significant differences at $P < 0.05$.

response to rising N rates. Thus, K uptake was greater in treatments $N_2K_0$ and $N_2K_3$ than in the corresponding $N_1K_0$ and $N_1K_3$ treatments (Table 3).

Potassium uptake occurred under no K application, indicating considerable levels of soil available K, which seemed greater in the yellow than in the red-yellow soil (Table 3). The apparent K residue was negative under the lower K rates, especially for the later crops. Consequently, the K utilization rate was low, particularly in the early crop, ranging from 22 to 32% (Table 3). In the late crop, K utilization rate was considerably higher on the red-yellow soil, where it ranged from 36 to 65%, in comparison to the lower range of 10 to 25% on the yellow soil. The effect of N rate on K utilization rate differed between the early and late crops. While it had insignificant influence in the early crop, increased N rate brought about an increase in K utilization rate in the late crop (Table 3).

Potassium agronomic efficiency (KAE) was significantly higher on the yellow soil, compared with the red-yellow soil (Table 3). Under the lower N rate, KAE declined steeply with the rising K rate.

**Table 3.** K uptake, balance, and agronomic efficiency in double-crop rice grown under combined K and N application on two paddy soils in the hilly region of Hunan Province, China.

| Soil type | Treatment | Early rice | | | | Late rice | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | K uptake | Apparent K residue | K utilization rate | Agronomic efficiency | K uptake | Apparent K residue | K utilization rate | Agronomic efficiency |
| | | -------*kg $K_2O$ ha$^{-1}$*------- | | *%* | *kg grain kg$^{-1}$ $K_2O$* | -------*kg $K_2O$ ha$^{-1}$*------- | | *%* | *kg grain kg$^{-1}$ $K_2O$* |
| Red-yellow | $N_1K_0$ | 87.3 | -87.3 | - | - | 108.2 | -108.2 | - | - |
| | $N_1K_1$ | 120.4 | -15.4 | 31.5 | 2.00 | 197.6 | -61.1 | 65.5 | 3.75 |
| | $N_1K_2$ | 131.1 | 18.9 | 29.2 | 0.67 | 214.0 | -19.0 | 54.3 | 4.04 |
| | $N_1K_3$ | 149.6 | 45.4 | 31.9 | 0.77 | 199.2 | 54.3 | 35.9 | 2.27 |
| | $N_2K_0$ | 113.5 | -113.5 | - | - | 113.6 | -113.6 | - | - |
| | $N_2K_3$ | 161.7 | 33.3 | 24.7 | 2.89 | 259.8 | -6.3 | 57.7 | 1.78 |
| Yellow | $N_1K_0$ | 105.3 | -105.3 | - | - | 175.8 | -175.8 | - | - |
| | $N_1K_1$ | 136.0 | -31.0 | 29.2 | 5.53 | 190.6 | -54.1 | 10.8 | 7.41 |
| | $N_1K_2$ | 139.4 | 10.6 | 22.7 | 4.67 | 201.7 | -6.72 | 13.3 | 5.64 |
| | $N_1K_3$ | 154.3 | 40.7 | 25.1 | 3.75 | 228.0 | 25.5 | 20.6 | 3.16 |
| | $N_2K_0$ | 128.4 | -128.4 | - | - | 181.5 | -181.5 | - | - |
| | $N_2K_3$ | 171.6 | 23.4 | 22.2 | 4.65 | 246.1 | 7.4 | 25.5 | 5.18 |

Excluding the late crop on the red-yellow soil, KAE significantly rose in response to a higher N rate, as indicated by the KAE of $N_2K_3$, which was higher than that of $N_1K_3$ (Table 3).

### Effects of combined N and K application on soil soluble K

Soil soluble K content at the beginning of each crop ($t_0$) was higher than at the harvest of crops which had received the lower K treatments ($K_0$ and $K_1$). Soil soluble K displayed a linear positive response to K application rates and at rates equal to 150 kg $K_2O$ $ha^{-1}$ or above, and it was much greater at harvest than at $t_0$. This response pattern was similar for the two crops, being much clearer at the early crop (Fig. 2). Excluding the case of the late rice crop on the yellow soil, soil soluble K content at harvest was always higher at $N_2K_3$ than at the $N_1K_3$ treatment.

### Effects of combined N and K application on soil exchangeable K

On the red-yellow soil, fertilizer applications had a minor influence on soil exchangeable K (Fig. 3). Even though, at the end of the early crop, increased K rates brought about a recovery of the basal situation. In the late crop, soil exchangeable K declined, and under the lower N rate, the effect of K rates was quite poor. However, under the higher N rate soil exchangeable K recovered and even slightly increased in response to the $K_3$ treatment. On the contrary, soil exchangeable K was highly responsive to K application rates (Fig. 3). At the harvest of the early crop, soil exchangeable K increased by 32% in response to $N_1K_2/K_3$ and reached 125 mg $kg^{-1}$. Here, a higher N rate alone was sufficient for a substantial rise in exchangeable K, which further increased to 130 mg $ha^{-1}$ in response to the $K_3$ treatment. A similar response pattern occurred in the late crop under the lower N rate, nevertheless here, the rise of the exchangeable K in response to the higher N rate was not furthered by the $K_3$ treatment (Fig. 3).

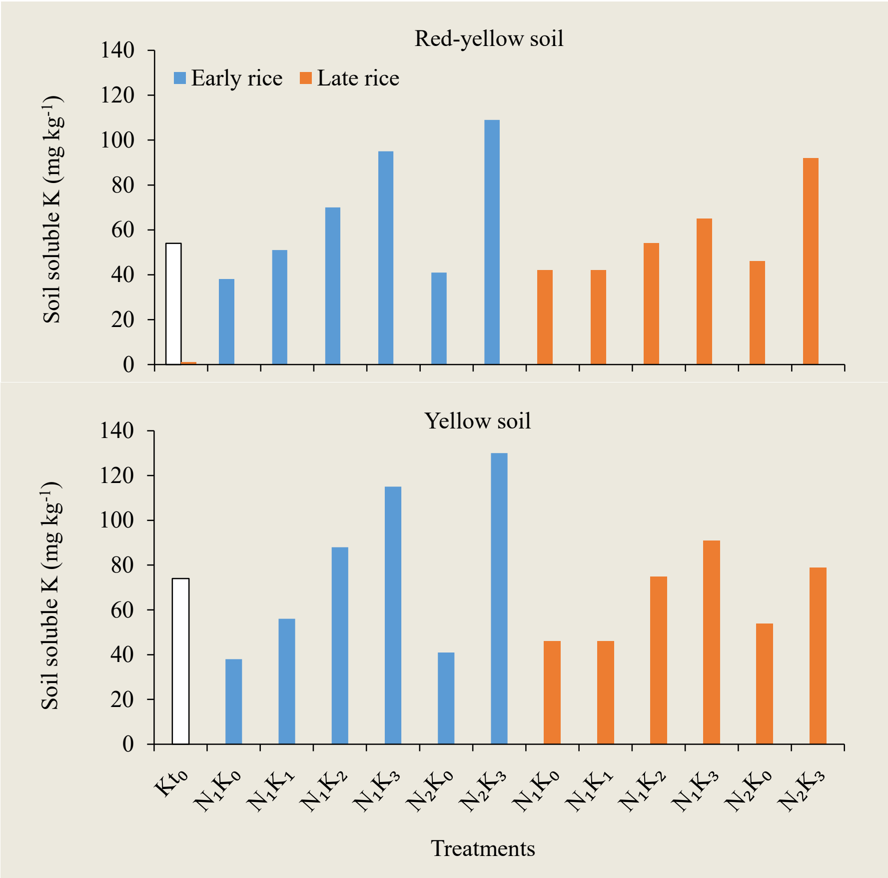



**Fig. 2.** Effects of combined N and K application on soil soluble K contents in two paddy soils in the hilly region of Hunan Province, China. Empty, blue, and orange bars represent soluble K contents at the beginning of the experiment (K $t_0$), after the early, and after the late rice crops, respectively.

### Economic considerations

Two principal parameters were used to evaluate the economic aspect of the examined fertilization practices: 1) the revenue:investment ratio (RIR); and, 2) the net increase in profit. RIR must be greater than 1, otherwise the farmer loses money. When this term is fulfilled, the profitability of each practice is compared to the alternative practices.

In the early crop on the red-yellow soil, RIR was < 1 and the net profit was negative whenever N was applied at the lower rate ($N_1$). Under those circumstances, $N_2K_3$ was the sole profitable treatment (Table 4). However, in the late crop on the same soil, the situation was different; here, a lower fertilizer combination, $N_1K_2$, yielded the highest profit. In this case, the highest yield or revenue did not necessarily indicate the highest profit.

Revenues were significantly higher on the yellow soil, especially for the late crop (Table 4). The net increase in profit was positive and RIR greater than 1 among all treatments. In the early crop, the highest net increase in profit was obtained for treatment $N_2K_3$, whereas $N_1K_1$ was the best treatment of the late crop.

## Discussion

Potassium is an important nutrient element required to achieve high and stable rice yields (Xie *et al.*, 2000; Singh *et al.*, 2002). A large number of studies have shown that K application in paddy soils can significantly increase rice yields (Liao *et al.*, 2008; Yang *et al.*, 2008). The

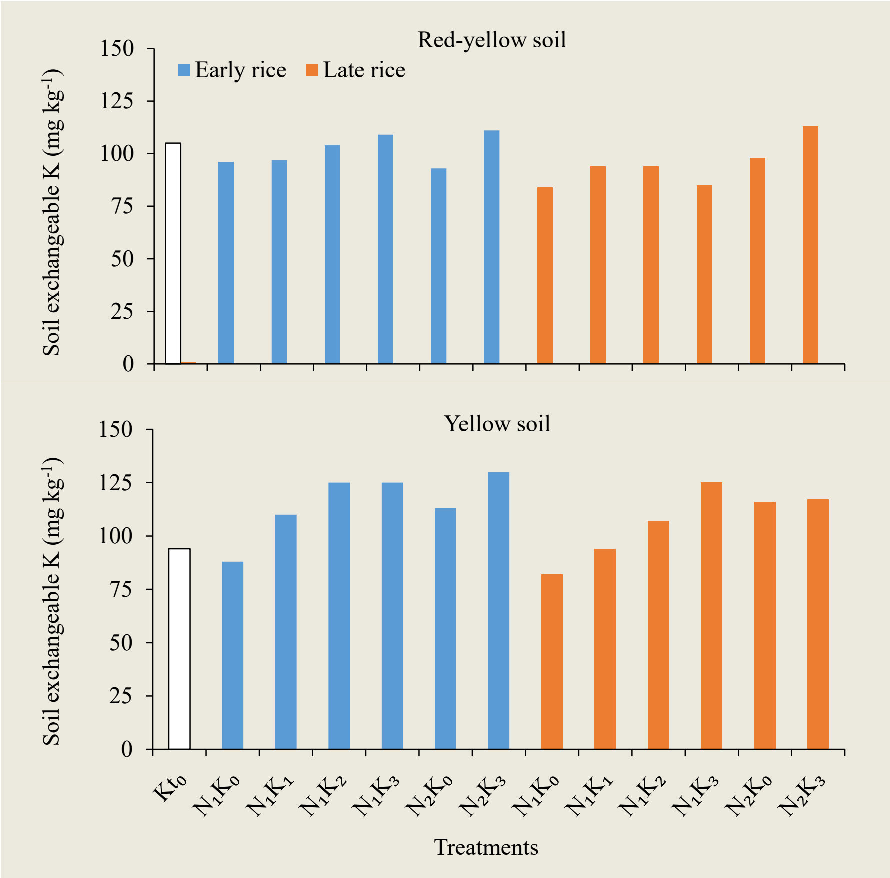



**Fig. 3.** Effects of combined N and K application on soil exchangeable K contents in two paddy soils in the hilly region of Hunan Province, China. Empty, blue, and orange bars represent exchangeable K contents at the beginning of the experiment (K $t_0$), after the early, and after the late rice crops, respectively.

present results may offer a more careful approach to K application regimes, ensuring they are suitable for the rice-rice system, and take into account differences between paddy soils and the interaction between N and K in this system.

Rice yields were consistently higher in response to the basic K application rate (105 kg $K_2O$ $ha^{-1}$), compared to the non-fertilized control ($N_1K_0$). However, as long as the N rate remained at the lower level (150 kg $ha^{-1}$), raising the K rate to 150 or 195 kg $ha^{-1}$ resulted in no further increase in yield (Fig. 1). However, an increase of the N rate to 195 kg $ha^{-1}$, accompanied with the highest K rate (195 kg $K_2O$ $ha^{-1}$), gave rise to a significant yield elevation in most cases. These results raise some questions regarding the nutrient limiting rice growth and yield at each condition. Apparently, under the lower N rate, crop K demands are fulfilled by the basic K application rate and further K input might be wasted. At this point, additional N supply allows further crop development, reestablishing crop K demand.

The positive influence of the interaction between N and K on crop growth and development is well documented (Doberman, 2007; Buresh *et al.*, 2010; Wang *et al.*, 2011). The approach of 'high N with high K' may increase rice yield, as occurred for the early crop, nevertheless it might also lead to a significant waste of nutrients, as occurred in the late crop, with the obvious economic as well as environmental consequences. Optimizing nutrient application would, however, require a better understanding of the applied nutrient fate in the soil and the estimated nutrient use efficiency.

Total soil K is roughly comprised of three fractions: soluble, exchangeable, and mineral K (Zörb *et al.*, 2014). The soluble K fraction is comprised of $K^+$ ions and is the one most available to plant roots. Exchangeable K represents the interphase between the liquid and solid phases of the soil. The $K^+$ ions are adsorbed to the negatively charged surface of the soil particles, but can be quite rapidly released to the soluble fraction. Thus, exchangeable K acts as a reserve for soil available K, and the quantity stored is largely dependent on the cation exchange capacity (CEC) of local soil particles. The mineral K fraction is considered as a long-term reserve, which usually does not take part in the immediate soil K balance. Most K fertilizers enrich the soil with soluble K, which might be allocated between the liquid and the exchangeable fractions according to the chemical balance between the two at the temporary soil moisture content. Paddy soils display a unique type of rhizosphere, interchanging between wet and dry field conditions, when soils are continuously flooded during most of the rice-growing season and then drained during the non-cropping season (Yang, 1989; Doberman *et al.*, 1996; Kögel-Knabner *et al.*, 2010). In addition to the significant consequences of this pattern on soil structural, and chemical (Yang *et al.*, 2004; Magahud *et al.*, 2015) and microbial characteristics (Dong *et al.*, 2014), soil K balance is especially affected (Doberman *et al.*, 1996; Xie *et al.*, 2000). Under flooding conditions, K fertilizer supplied at the beginning of the cropping season is predestined to four possible termini: soluble K; exchangeable K; crop uptake; and, seepage away from the field. In the early crop presented, the soluble K at harvest increased on both soil types with the rising K application rate, while the exchangeable K increased considerably only on the yellow soil (Fig. 2 and 3). Early crop K utilization rates were relatively

**Table 4.** Economic evaluation of combined N and K application on double rice cropping system in two paddy soils in the hilly region of Hunan Province, China.

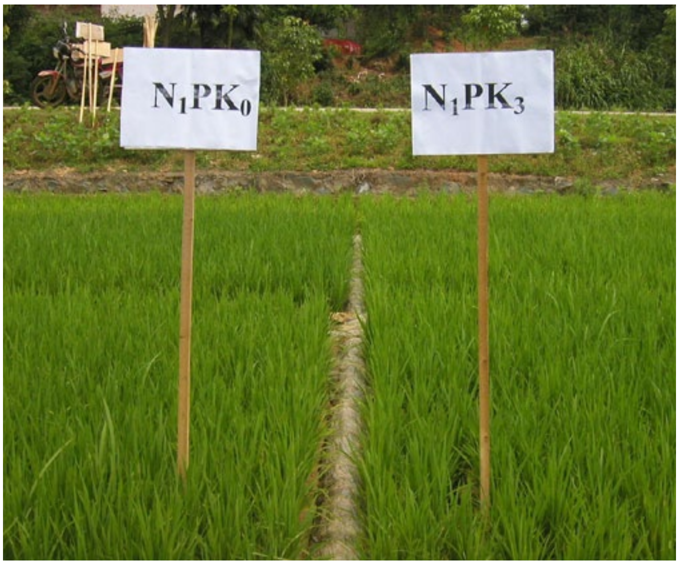
| Soil type | Treatment | Early rice | | | | | Late rice | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Revenue | Revenue increase | Fertilizer cost | Net increase in profit | RIR | Revenue | Revenue increase | Fertilizer cost | Net increase in profit | RIR |
| | | Yuan $ha^{-1}$ | | | | | Yuan $ha^{-1}$ | | | | |
| Red-yellow | $N_1K_0$ | 14,893 | - | 1,308 | - | - | 16,196 | - | 1,255 | - | - |
| | $N_1K_1$ | 15,666 | 773 | 2,115 | -34 | 0.96 | 17,661 | 1,464 | 2,210 | 509 | 1.53 |
| | $N_1K_2$ | 15,257 | 364 | 2,358 | -686 | 0.35 | 18,447 | 2,251 | 2,620 | **886** | 1.65 |
| | $N_1K_3$ | 15,439 | 546 | 2,673 | -819 | 0.40 | 17,841 | 1,645 | 3,029 | -130 | 0.93 |
| | $N_2K_0$ | 14,937 | - | 1,543 | - | - | 17,732 | - | 1,536 | - | - |
| | $N_2K_3$ | 16,988 | 2,051 | 2,908 | **686** | 1.50 | 19,019 | 1,287 | 3,311 | -488 | 0.73 |
| Yellow | $N_1K_0$ | 15,630 | - | 1,308 | - | - | 17,783 | - | 1,255 | - | - |
| | $N_1K_1$ | 17,233 | 1,604 | 2,115 | 797 | 1.99 | 20,675 | 2,891 | 2,210 | **1,936** | 3.03 |
| | $N_1K_2$ | 17,562 | 1,932 | 2,358 | 882 | 1.84 | 20,929 | 3,146 | 2,620 | 1,781 | 2.30 |
| | $N_1K_3$ | 17,647 | 2,018 | 2,673 | 653 | 1.48 | 20,077 | 2,294 | 3,029 | 519 | 1.29 |
| | $N_2K_0$ | 16,803 | - | 1,543 | - | - | 18,275 | - | 1,536 | - | - |
| | $N_2K_3$ | 19,303 | 2,501 | 2,908 | **1,136** | 1.83 | 20,315 | 2,039 | 3,311 | 265 | 1.15 |

*Note:* Rice prices used for calculations were: early rice - 2.76 yuan $kg^{-1}$; late rice - 2.86 yuan $kg^{-1}$; fertilizer prices: N - 5.22 yuan $kg^{-1}$ urea; $P_2O_5$ - 7.00 yuan $kg^{-1}$; $K_2O$ - 7.00 yuan $kg^{-1}$.

poor, at less than 35% in both soil types. Although significantly higher on the yellow soil, K agronomic efficiency of the early crop was generally low (Table 3), compared to published reports on paddy soils (Doberman *et al.*, 1998; Ali *et al.*, 2005; Buresh *et al.*, 2010). This pattern was principally similar for the late crop, although K utilization rates were much higher for the red-yellow soil, and K agronomic efficiency was higher for the yellow soil (Table 3). These results suggest that large proportions of applied K were lost to seepage.

There is no doubt that significant rates of K application are a must for rice-rice cropping systems on paddy soils. The severe soil K deficiency caused by long-term non-application of K fertilizer in southern paddy soil has become one of the main limiting factors of high-yielding rice production (Xie and Zhou, 1995; Li *et al.*, 1998). In recent years, soil fertility monitoring results revealed that soil available K content in southern paddy soil regions showed a decreasing trend, with an annual decline rate ranging from 0.58 to 3.32 mg K $kg^{-1}$ $year^{-1}$ (Xie and Zhou, 1995). At present fertilization levels, in spite of the prevailing ‘balanced NPK approach’, K status is generally in deficit, and in some areas the deficit is serious (Liao *et al.*, 2007; Liao *et al.*, 2009; Wang *et al.*, 2010). In order to restore and maintain soil K fertility, soil K balance must be closely monitored. It is generally believed that the lower the soil K status, the more obvious the effect of K application is, and the higher the K utilization rate is (Wang, 2010). In the present study, however, yield response was highest for the lower K application rate but it did not increase further with rising K rates, unless N rate was also raised (Fig. 1). This, together with the evidence of significant K waste to seepage, highlights the need for significant improvement of K fertilization management.

Custom basal K application provides a short opportunity for K uptake by the crop, because plants are small, their root system has not fully developed yet, and soil soluble K is diminishing rapidly due to seepage. Alternatively, K application doses should be split during the cropping season, thus broadening the crop’s opportunity windows for K uptake. Also, rice K demand changes according to biomass and stage of development; maximum rice yields were obtained where K had been applied from 25 to 50 days after planting (Ali *et al.*, 2005). Potassium application regimes should therefore be adjusted to local soil characteristics, as shown previously (Zheng *et al.*, 1989; Dai *et al.*, 2000; Doberman, 2007; Buresh *et al.*, 2010; Wang *et al.*, 2010; He *et al.*, 2015; Shivanna and Sheelarani. 2015), and demonstrated in the present study. Differences between cultivars in the rate of K uptake must also be considered (Fageria, 2015). While designing a new fertilization approach, a careful balance must be kept between K and the other macro- and microelements (Li *et al.*, 1998; Doberman, 2007; Wang *et al.*, 2011).





Experimental sites. Photos by authors.

Economic evaluations in the present study show that a farmer's maximum profit from the early rice crop is obtained with high N and K application rates, while a lower N and K combination was sufficient for the late crop (Table 4). Nevertheless, the suggested alteration in K application regime is expected to change K utilization rate, K agronomic efficiency, and consequently the farmer's inputs and revenue. Hence, the economic aspect should be reconsidered after the new approach is established.

### Acknowledgement

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