Crop Straw Can Optimize Potassium Fertilization Strategies in Rice Cropping Systems

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Generalized fertilizer recommendations for K in China exist partly because of a lack of local evidence disproving their use, and partly to address limited fertilizer K resources. This research demonstrates how making good use of the nutrient value of crop straw can help optimize fertilizer K application and reduce the reliance on strategies that promote generalized fertilizer recommendation systems across large areas.

Paddy-upland rotations, located mainly in the Yangtze River basin, arguably form the most important cropping systems in China. However, rice and subsequent crops like wheat, rice, or oilseed rape remove large amounts of K annually, from 210 to 360 kg K_2O/ha/yr, in part because of the removal of crop straw from fields. As a result, soil K deficiency has become a key limiting factor for sustained high yields due to relatively low rates of K input in the region. However, besides K fertilizer, it is always important to consider all potential K resources available to farmers within a region.

The K in crop straw left in the field is a readily available source that is released quickly for plant use, especially under flooded conditions. Changes towards large-scale mechanization in Chinese agricultural production are providing favorable conditions to expand the practice of returning crop straw to fields. This article examines a 2011-2012 study (IPNI China, 2012) that measured the impact of crop straw on the K nutrition of rice, its yield, and optimal fertilizer K application rates.

According to China's second national soil survey, trial sites with available K content (1 N NH_4OAc extractable K) of >150 mg/kg (Zhongxiang and Yicheng sites) were classified as high K soils; those with available K content between 100 and 150 mg/kg (Tuanfeng, Xiantao, Honghu, and Zhijiang sites) were classified as medium K soils; and those with available K content <100 mg/kg (Macheng, Guangshui, Ezhou, and Qichun sites) were classified as low K soils. Earlier on-site investigation revealed that crop straws are always removed from the farmland for rice transplanting. Field experiments were carried out in a randomized block design with six treatments including: 1) zero-K check, 2) the generalized K recommendation of 75 kg K_2O/ha, 3) 4.5 t/ha wheat straw/winter rape straw (with ~2.1% K content), and 4) straw combined with two lower rates of K fertilizer (i.e., 25 and 50 kg K_2O/ha). The crop straw was mechanically chopped to a length of 10 cm and then incorporated into the soil with the fertilizer.

Linear and plateau K fertilization models (Cerrato and Blackmer, 1990) were used to determine the optimum levels of K fertilization:

$$y = a + bx \ (x \leq C)$$
$$y = P \ (x > C)$$

where, y is the grain yield (kg/ha), x is fertilizer K rate (kg/ha), a is the intercept, b is the regression coefficient, C represents the intersection of the straight line and the plateau, and P is the plateau yield (kg/ha). Px and Py are the prices of K_2O (4.5 Yuan/kg) and of rice (2.5 Yuan/kg) during 2011-2012 in China. When b > Px/Py, C is the recommended amount of K; when b < Px/Py, the recommended amount of K is 0.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; NH_4Oac = ammonium acetate.

Comparisons at a low soil K site showing the general K fertilizer recommendation (top left), the zero K check (top right), K plus Straw (bottom left), and K minus Straw (bottom right).

Results

Potassium fertilization and K input from crop straw residue both contributed to better rice yields, but their impact depended on soil K status (**Table 1**). Yield responses to the generalized K or straw treatments alone were similar in size, but not significantly greater than the check across soil fertility levels. Only the fertilizer and straw K treatment generated better yields, which were significantly higher than the check treatment in low and medium K soils.

Table 1. Effect of straw incorporation and K fertilization on rice yield and K uptake, Yangtze River Basin.

Soil K levels	Treatment	Yield, kg/ha	Yield increase, kg/ha	Yield increase, %	K uptake, kg/ha	K uptake increase, kg/ha	K uptake increase, %
High K	Check	8,372 a	-	-	253 b	-	-
	K†	8,635 a	263	3.1	285 a	32	12.6
	Straw‡	8,852 a	480	5.7	278 a	25	9.9
	Straw + K	9,005 a	633	7.6	293 a	40	15.8
Medium K	Check	8,710 b	-	-	265 b	-	-
	K	9,460 ab	750	8.6	305 a	40	15.1
	Straw	9,023 ab	313	3.6	279 b	14	5.3
	Straw + K	9,808 a	1,098	12.6	322 a	57	21.5
Low K	Check	7,767 b	-	-	170 c	-	-
	K	8,376 ab	609	7.8	194 b	24	14.1
	Straw	8,019 ab	252	3.2	185 b	15	8.8
	Straw + K	8,503 a	736	9.5	212 a	42	24.7

†General recommendation of 75 kg K_2O/ha. All treatments received 165 kg N/ha and 45 kg P_2O_5/ha.
‡Straw applied at 4.5 t/ha. Means in the same column followed by the same letter are not significantly different at p = 0.05.

As with the yield responses, K fertilization also led to an increase in K uptake in rice biomass in high, medium and low K soils (**Table 1**). Straw input most affected crop K uptake in low and high K soils and was less effective in medium K soils. The fertilizer and straw K treatment produced the highest K uptake values across all soils.

Impact of Straw on Potassium Uptake and Yield

With straw incorporation, the yield increases in different soils varied with K fertilizer rates (**Figure 1a**). Linear equations were significant for the plots of yield increase and K application rate for both medium and low K soils, but the correlation was non-linear in high K soils. In medium K soils, while the K fertilizer rate increased by 30% (i.e., 50 to 75 kg/ha) the yield only increased from 7.6 to 8.8%. This indicates that surplus K^+ ions were absorbed by the rice crop grown on medium K soils. For low K soils, the present generalized recommendation for K fertilizer was found to be inadequate.

Similarly, **Figure 1b** shows the linear equations fit to plots of the increase in shoot K versus K fertilizer application rate across soil fertility levels. Although the linear correlation was not significant for high K soils, K accumulation tended to increase linearly with K fertilizer application rate in medium and low K soils. There are risks of luxury K absorption, such as the change in the K:Mg ratio if the straw is used for fodder (Römheld and Kirkby, 2010), due to excess K application in medium K soils, while in low K soils the need for additional K input via fertilizer to meet rice production goals is apparent.

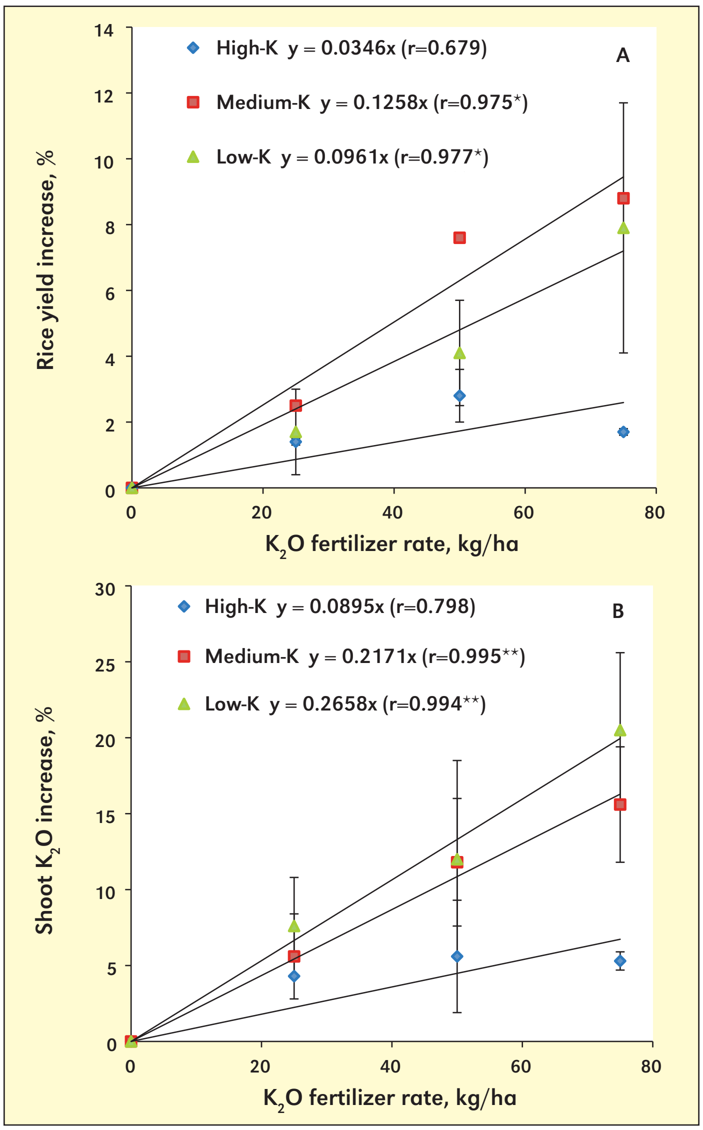

Figure 1. Relationships between yield increase (A), K uptake (B) and K fertilizer rate with crop straw incorporation, Yangtze River Basin. * and ** denote significance at p = 0.05 and p = 0.01, respectively.

Optimal Fertilizer Potassium Rates in Rice with Straw Incorporation

Two 15-year field experiments carried out in the Sichuan Basin indicated that soil K reserves could be used to predict the application rates of K fertilizer (IPNI China, 2012). The yield response data in **Figure 1** suggests that the current K fertilizer recommendation of 75 kg K_2O/ha is excessive for high and medium K soils supplied with 4.5 t/ha of incorporated wheat or oilseed rape straw. Yet, on low K soils, the general fertilizer recommendation plus straw is still not adequate to meet the demands of high yielding rice crops. The optimal amount of fertilizer K to be combined with straw is presented according to the linear and plateau models (**Table 2**). For example, in high K sites at Zhongxiang and Yicheng, the corresponding optimal rates of K fertilizer were 36 kg/ha and 40 kg/ha, or about half of the generalized recommendation. For medium K soils, the optimal K fertilizer rate averaged 60 kg/ha or 80% of the generalized recommendation.

Entire Yangtze River Basin area within China.

Summary

The K nutritional needs of paddy rice can be effectively met through the combination of K fertilizer and recycled crop straw. Although K fertilization had better effects on yield and K uptake than straw return alone in medium and low K soils, the opposite was true in high K soils. Using a linear and plateau fertilization model, the optimal K fertilizer rates for high and medium K soils averaged 38 and 60 kg/ha, respectively. But for low K soils, the current generalized recommendation of 75 kg K_2O/ha is insufficient and needs to be increased to ensure both high rice yields and soil K fertility. BC

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Table 2. Optimal fertilizer K rates for rice with straw incorporation, Yangtze River Basin.

Soil K levels	Sites	Min. yield, kg/ha	Max. yield, kg/ha	Optimum K_2O rate, kg/ha	R^2
High K	Zhongxiang	8,281	8,447	36.1	0.976*
	Yicheng	9,423	9,658	40.4	0.739
Medium K	Tuanfeng	9,798	10,375	62.7	0.961*
	Xiantao	9,682	10,604	58.6	0.955*
	Honghu	8,333	9,852	56.1	0.963*
	Zhijiang	8,101	8,400	62.6	0.961*

Based on linear and plateau K fertilization models (Cerrato and Blackmer, 1990).

References

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IPNI China. 2012. http://china.ipni.net/article/CNP-3019 (*verified June 4, 2014*).