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ARTICLE

# Effects of Different Potassium (K) Fertilizer Rates on Yield Formation and Lodging of Rice

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**ABSTRACT**

As one of the most important nutrients for plants, potassium (K) has substantial effects on growth and development of crops. Present study was conducted in three different sites in South China in late season in 2019 with the objective to study the effects of different applied amounts of K fertilizer on yield formation and lodging of rice. Four K fertilizer treatments, $K_0$: 0 kg potassium oxide ($K_2O$) ha$^{-1}$ (control); $K_1$: 64.20 kg $K_2O$ ha$^{-1}$; $K_2$: 128.55 kg $K_2O$ ha$^{-1}$ and $K_3$ 153.90 kg $K_2O$ ha$^{-1}$ were applied in the field experiment. The results showed that $K_2$ and $K_3$ treatments significantly increased panicle number per unit area, grain number per panicle, seed-setting rate and the grain yield of rice compared with $K_0$ treatment. Higher net photosynthetic rates were recorded in $K_2$ and $K_3$ treatments than $K_0$ treatment at tillering stage, heading stage and maturity stage. K fertilizer treatments also increased the chlorophyll content and dry matter accumulation by 6.16–23.52% and 21.32–64.59% compared with $K_0$ treatment, respectively. Moreover, the total N and K accumulation in the aboveground tissues of rice significantly increased under $K_2$ and $K_3$ treatments compared with $K_0$ treatment. Furthermore, compared with $K_0$ treatment, K fertilizer treatments significantly enhanced the breaking-resistant strength by 40.94–144.24% and reduced the lodging index of rice by 13.14–36.72%.

**KEYWORDS**

Lodging; net photosynthetic rate; potassium; rice; SPAD value

## 1 Introduction

Rice production system is the backbone of Chinese food security system. Rice is the staple food of residents in Northeast and South China while about 60% of Chinese people eat rice as their main food [1]. As one of the most important nutrients for normal growth and development of plants, the content of potassium (K) in rice plant tissue is generally 2.0% to 5.0% [2]. As one of the essential nutrient elements for normal growth and development of plants, K is s very important to improve the metabolic function and stress resistance of rice [3]. Previous study revealed that the application of K fertilizer would not only influence the yield formation of rice, but also affect the uptake and utilization of nitrogen by rice [4,5].

Some previous studies have investigated the impacts of K on crop physiology and productivity under different environment. For example, the study of Fujimura et al. [6] demonstrated that potassium was able to enhance the heavy metal resistant of rice because exogenous potassium chloride would inhibit the absorption on Cesium-137 by rice and thus significantly reduced the concentration of Cesium in in the brown rice and in the above-ground plants of rice. The investigation of Zhao et al. [7] showed that straw return combined with K fertilization was an effective way to maintain the soil K fertility and rice productivity. An early study showed that panicle number per area, grain number per panicle and grain yield of rice increased with the increment of K fertilization rate in the upland rice system [8]. Zain et al. [9] demonstrated that application of extra K fertilizer had some positive impacts on mitigating the drought stress effect in rice. An earlier study also indicated that special symptoms could be observed on rice leaves when exposed to potassium deficiency, and these symptoms usually display differently under different potassium levels [10]. Furthermore, the research of Peng et al. [11] showed that deficiency of K in rice would lead to the decrement in net photosynthetic rate and stomatal conductance and the PSII reaction center also would be damaged.

There are a lot of studies have been done to investigate the important role of K plays in plant system, however, the study of K fertilizer application on rice production in South China was rarely reported. Hence, present study was conducted in Guangdong province (major rice producing province in South China) in three different sites to study the effect of different amounts of K fertilizer on late-season rice performance.

## 2 Materials and Methods

### *2.1 Plant Material and Growing Conditions*

A three-site field experiment was conducted between July and November in 2018 with rice cultivar, "*Guangfengxiang-8*," a temperature sensitive conventional rice variety which bred by Guangzhou Institute of Agricultural Science and widely planted in South China, provided by College of agriculture, South China Agricultural University. Site.1 was located in Longtan Village, Aotou Town, Conghua City, Guangdong Province, China (23°66′N, 113°41′E, 56 m altitude) and the experiment soil was sandy loam containing 21.66 g $kg^{-1}$ organic matter, 1.34 g $kg^{-1}$ total N, 0.65 g $kg^{-1}$ total P, 20.83 g $kg^{-1}$ total K. Site.2 was located in Doumen town new village, Zhuhai City, Guangdong Province, China (22°22′N, 113°29′E, 5m altitude) and the experiment soil was sandy loam containing 21.24 g $kg^{-1}$ organic matter, 1.75 g $kg^{-1}$ total N, 0.89 g $kg^{-1}$ total P, 20.99 g $kg^{-1}$ total K. Site.3 was located in Dong Wan Cun, Doumen Town, Zhuhai City, Guangdong Province, China (22°33′N, 113°24′E, 10 m altitude) and the experiment soil was sandy loam containing 20.57 g $kg^{-1}$ organic matter, 1.39 g $kg^{-1}$ total N, 0.68 g $kg^{-1}$ total P, 20.57 g $kg^{-1}$ total K. Three experimental sites enjoyed a subtropical monsoon climate and the temperature during the experiment was shown in Fig. 1.

### *2.2 Experimental Designs and Treatments*

Four K treatments were arranged in in a randomized complete block design (RCBD) with three replicates, i.e., $K_0$: 0.00 kg potassium oxide ($K_2O$) $ha^{-1}$ (control); $K^1$: 64.20 kg $K_2O$ $ha^{-1}$; $K_2$: 128.55 kg $K_2O$ $ha^{-1}$ and $K_3$ 153.90 kg $K_2O$ $ha^{-1}$. 47.25kg $P_2O_5$ $ha^{-1}$ and 162.00kg N $ha^{-1}$ were also applied with the K fertilizer. All the fertilizers were applied with 70% as basal dose and 30% at tillering. The rice seeds were soaked in water for 24 h and germinated in manual climatic boxes for another 24 h. The germinated seeds were sown in polyvinyl chloride trays for nursery raising. Then rice seedlings were transplanted to the field at the planting distance of 30 × 15 cm. The transplanting was carried out in August and the harvest was in November.

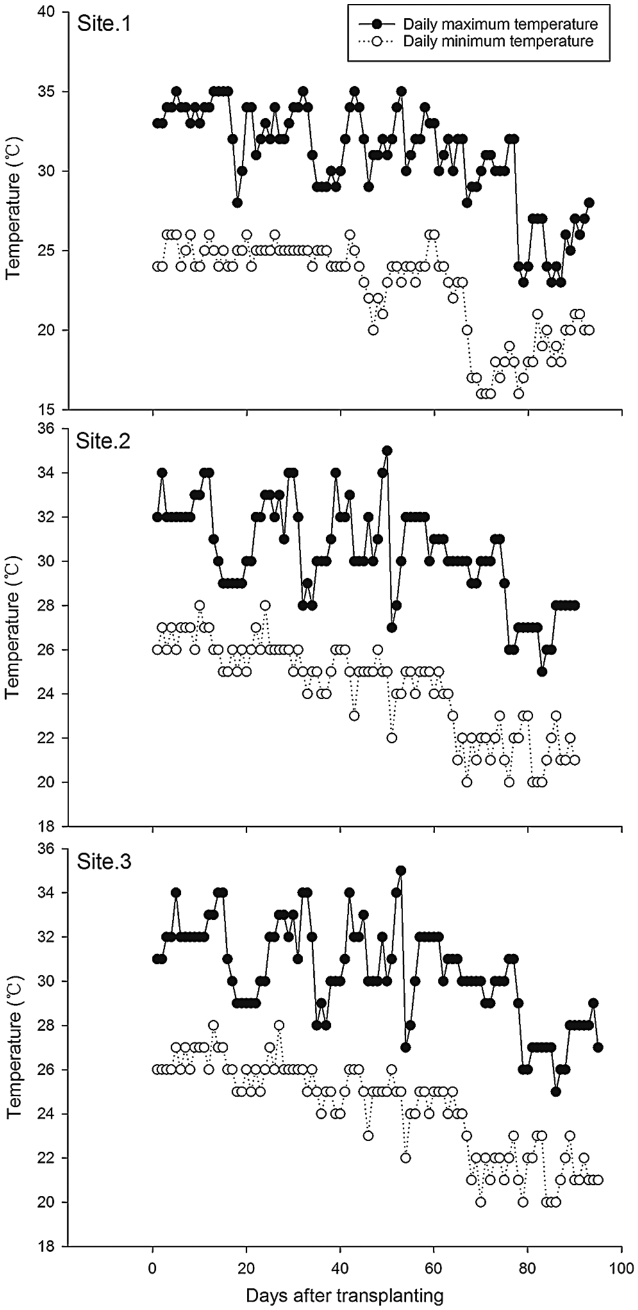

Figure 1: Daily temperature during the experiment at three sites

### *2.3 Estimation of Yield and Yield-Related Traits*

At the maturity stage, the rice grains were harvested from five-unit sampling area (1 $m^2$) in each plot and threshed by machine to measure the grain yield. Thirty random hills of rice plants in each plot were sampled for calculating the average effective panicle number per hill. Then six hills of rice plants from each plot were taken to determine the yield- related traits including grain number per panicle, seed-setting rate and 1000-grain weight.

### *2.4 Determination of Net Photosynthetic Rate, Chlorophyll Contents and Total N, P, K Accumulation in Plants*

At tillering stage, heading stage and maturity stage, net photosynthetic rate was determined with the portable photosynthesis system (LI-6400, LI-COR, USA) at 09:00–10:30 a.m. with the following adjustments: photosynthetically active radiation at leaf surface was 1100 and 1200 μmol $m^{-2}$ $s^{-1}$, ambient $CO_2$ concentration 385.5 and 399.7 μmol $mol^{-1}$. SPAD meter 'SPAD-502' (Konica Minolta, Japan) was used for precise, rapid and non-destructive estimation of leaf chlorophyll contents. At maturity stage, ten random hills of rice plants in each plot were sampled and N, P, K accumulation in the aboveground tissues were calculated according to the methods described by Pan [12].

### *2.5 Determination of Lodging Index*

The lodging index of rice plant was estimated by the methods described by Liu et al. [13]. At maturity stage, A lodging tester YYD-1A (Topyunong Science and Technology Co., Ltd. Hangzhou, Zhejiang, China) was held to the plants at a height of 20 cm above the bottom of stem and slowly pushed vertically, the breaking-resistant strength (F) force was recorded when the plants were leant at 45°. The height (H), fresh weight (W) were also measured at same time. The lodging index (LI) was calculated as below:

$$\mathrm{LI} = 0.049 \times \mathrm{G} \times \mathrm{W/F}$$

### *2.6 Statistical Analysis*

Data were analyzed on Statistix 8.1 (Analytical Software, Tallahassee, FL, USA) at the probability level of 5% ($p < 0.05$). Differences among means were separated by using least significant difference (LSD) test. Graphs were drawn with Sigma Plot 14.0 (Systat Software Inc., California, USA).

## 3 Results

### *3.1 Yield and its Related Trails*

Yield and yield related trails of rice were affected significantly by the K fertilizer application (Tab. 1). The $K_2$ and $K_3$ treatments had the highest or equally highest yield which were ranged between 6.90 and 9.39 t $ha^{-1}$ in all three sites. Compared to $K_0$ treatment, $K_2$ and $K_3$ treatments significantly increased yield by 8.63–30.06% in three sites. The increased grain yield could be explained by the higher panicle number, grain number and seed-setting rate. 17.31–34.04% higher panicle number, 7.42–11.73% higher grain number and 5.37–20.36% higher seed-setting rate were recorded in both $K_2$ and $K_3$ treatments than $K_0$ treatment in site.1, site.2 and site.3. However, there was no significant difference among all treatments in 1000-grain weight and three sites had similar trends.

**Table 1:** Yield and yield related trails under different amounts of K fertilizer application in three sites

| Site | Treatment | Panicle number per hill | Grains number per panicle | Seed-setting rate (%) | 1000-grain weight (g) | Yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| Site.1 | $K_0$ | 11.50 ± 0.96b | 123.22 ± 2.66c | 84.12 ± 1.63b | 21.76 ± 0.05a | 7.22 ± 0.22b |
| | $K_1$ | 11.75 ± 0.48b | 127.41 ± 2.87bc | 91.94 ± 1.49a | 21.43 ± 0.13a | 7.97 ± 0.37b |
| | $K_2$ | 13.75 ± 0.25a | 132.36 ± 3.10ab | 94.59 ± 0.37a | 21.53 ± 0.05a | 9.39 ± 0.51a |
| | $K_3$ | 13.50 ± 0.29a | 134.09 ± 2.59a | 91.37 ± 0.55a | 21.06 ± 0.15a | 8.94 ± 0.25a |
| Site.2 | $K_0$ | 13.00 ± 1.22b | 121.60 ± 1.86c | 73.88 ± 3.66c | 20.58 ± 0.17a | 6.84 ± 0.44b |
| | $K_1$ | 14.50 ± 1.19ab | 127.27 ± 2.42b | 79.34 ± 2.54bc | 20.63 ± 0.20a | 7.14 ± 0.25ab |
| | $K_2$ | 15.75 ± 1.11a | 135.86 ± 1.84a | 87.58 ± 1.10ab | 20.90 ± 0.41a | 7.43 ± 0.25ab |
| | $K_3$ | 15.25 ± 1.65a | 133.06 ± 2.73a | 88.92 ± 3.18a | 20.27 ± 0.21a | 7.70 ± 0.25a |

**Table 1 (continued).**

| Site | Treatment | Panicle number per hill | Grains number per panicle | Seed-setting rate (%) | 1000-grain weight (g) | Yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| Site.3 | $K_0$ | 11.75 ± 0.48c | 120.49 ± 2.37c | 77.79 ± 1.99b | 19.70 ± 0.18a | 6.00 ± 0.01d |
| | $K_1$ | 13.25 ± 1.44bc | 128.31 ± 2.71b | 83.02 ± 1.10a | 19.83 ± 0.25a | 6.34 ± 0.16c |
| | $K_2$ | 15.50 ± 1.32ab | 132.40 ± 2.35ab | 84.09 ± 1.09a | 20.01 ± 0.09a | 7.17 ± 0.33a |
| | $K_3$ | 15.75 ± 0.48a | 134.19 ± 2.44a | 81.97 ± 0.65a | 19.77 ± 0.08a | 6.90 ± 0.01a |

Note: Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference (LSD) test.

### 3.2 Biomass Accumulation

As shown in Fig. 2, different amounts of K fertilizer significantly influenced the dry matter accumulation of rice. In site.1, 21.32, 45.89, 36.39% higher dry matter weight were recorded in $K_1$, $K_2$ and $K_3$ treatments than $K_0$ treatment, respectively; In site.2, compared with $K_0$ treatment, $K_1$, $K_2$ and $K_3$ treatments significantly increased dry matter weight by 23.47, 51.55 and 47.05%, respectively; In site.3, 24.76, 64.59 and 52.76% higher dry matter weight were recorded in $K_1$, $K_2$ and $K_3$ treatments compared with $K_0$ treatment, respectively.

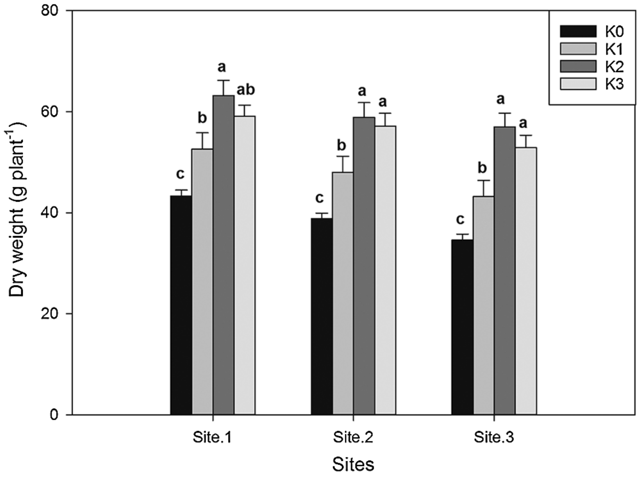

**Figure 2:** Dry matter accumulation under different amounts of K fertilizer application in three sites (Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference (LSD) test)

### 3.3 Net Photosynthetic Rate

The data of net photosynthetic rate in different stage depicted that application of K fertilizer had significant impacts on photosynthesis of rice (Fig. 3). In site.1, there was no remarkable difference between $K_0$ treatment and $K_1$ treatment. Compared with $K_0$ treatment, $K_2$ treatment significantly increased net photosynthetic rate by 30.06, 29.55 and 29.05% in tillering stage, heading stage and maturity stage, respectively while 25.41–29.36% higher net photosynthetic rates were recorded in $K_3$ treatments than $K_0$ treatment; In site.2, compared with $K_0$ treatment, $K_3$ treatment significantly increased net photosynthetic rate by 17.77, 22.93 and 26.03% in tillering stage, heading stage and maturity stage, respectively; In site.3, both $K_2$ and $K_3$ treatments had significantly higher net photosynthetic rates than $K_0$ treatment and there was no remarkable difference between $K_2$ and $K_3$ treatments in tillering stage, heading stage and maturity stage.

### 3.4 Chlorophyll Contents

As shown in Fig. 4, different amounts of potassium fertilizer affected the chlorophyll content of rice differently. In site.1, 6.17–17.95% higher SPAD values were recorded in $K_1$, $K_2$ and $K_3$ treatments than $K_0$ treatment in tillering stage, heading stage and maturity stage (except $K_1$ in maturity); In site.2, compared with $K_0$ treatment, $K_2$ and $K_3$ treatments significantly increased SPAD values by 16.11–20.75% while there was no remarkable difference between $K_2$ and $K_3$ treatments; In site.3, compare with $K_0$ treatment, $K_1$, $K_2$ and $K_3$ treatments significantly increased SPAD value by 16.33, 20.62, 22.29% in tillering stage, 16.88, 20.13 23.52% in heading stage and 14.65, 19.80 and 20.92% in maturity stage, respectively.

### 3.5 Total N, P and K Accumulation

As shown in Fig. 5, applications of K fertilizer significantly affected the total N and K accumulation in rice. Compared with $K_0$ treatment, $K_1$, $K_2$ and $K_3$ treatments significantly increased the total N accumulation by 15.69–41.95% but there was no remarkable difference among $K_1$, $K_2$ and $K_3$ treatments. 21.19–39.16% higher total K accumulations were recorded in both $K_2$ and $K_3$ treatments than $K_0$ treatment. On the other hand, there was no significant difference among $K_0$, $K_1$, $K_2$ and $K_3$ treatments in total P accumulation in site.1, site.2 and site.3.

### 3.6 Lodging Index

As shown in Tab. 2, the application of K fertilizer significantly affected lodging parameters of rice. Compared with $K_0$ treatment, K fertilizer treatments significantly increased the breaking-resistant strength of rice by 40.94–144.24% while the highest or equally highest strength was recorded in $K_2$ and $K_3$ treatments. Higher fresh weights were also recorded in $K_1$, $K_2$ and $K_3$ treatments than $K_0$ treatment. As far as lodging index was concerned, K fertilizer treatments remarkably decreased the lodging index of rice by 13.14–36.72% while the lowest or equally lowest lodging indexes were recorded in $K_2$ and $K_3$ treatments.

## 4 Discussion

Present study revealed the effects of K fertilization on yield formation, photosynthesis, dry matter accumulation and lodging resistant of rice. As far as grain yield was concerned, the results of our study showed that application of K fertilizer significantly affected the grain yield of rice which was coincident with the study of Jiang et al. [14] who indicated that K fertilizer inputs need to be appropriately supplied to achieve the goal to get high rice yield and maintain the soil potassium balance. In our study, the highest or equally highest grain yield was observed in $K_2$ and $K_3$ treatments in three sites. Previous study also indicated that insufficient K supply usually causes serious yield decrease and quality declining in rice and wheat production [15]. The research of Zoerb et al. [16] revealed that average soil reserves of K are generally large whilst most of K is not plant-available and thus the crops need to be supplied with soluble K fertilizers during the agricultural production.

The increment in grain yield was attributed to the higher panicle number, grain number and seed-setting rate. In 2005, Asli [17] came up with the theory of source-sink and described its manipulation and effect on potential grain yield of rice. Our results agreed with the study of Liu et al. [18] which indicated that grain yield had a significant and positive correlation with grain number as well as seed-setting rate. An earlier study also showed that there was a positive and significant relationship exited between dry matter accumulation and grain yield in super hybrid rice [19]. Present study showed that application of K fertilizer significantly promoted the dry matter accumulation of rice. The increment of dry matter accumulation could be explained by the increment in net photosynthetic rate which was attributed to the higher chlorophyll contents due to K fertilizer application. Our results agreed with the previous study which indicated that K fertilizer could increase chlorophyll contents and promote net photosynthetic rate [20]. The research of Luo et al. [21] also indicated that there exited a significant correlation between net photosynthetic rate and grain yield as well as chlorophyll contents and net photosynthetic rate. Furthermore, the study of Bottrill et al. [22] showed that chloroplasts from sulphur- and potassium-deficient plants contain lower amounts of both chlorophyll and nitrogen in spinach plants.

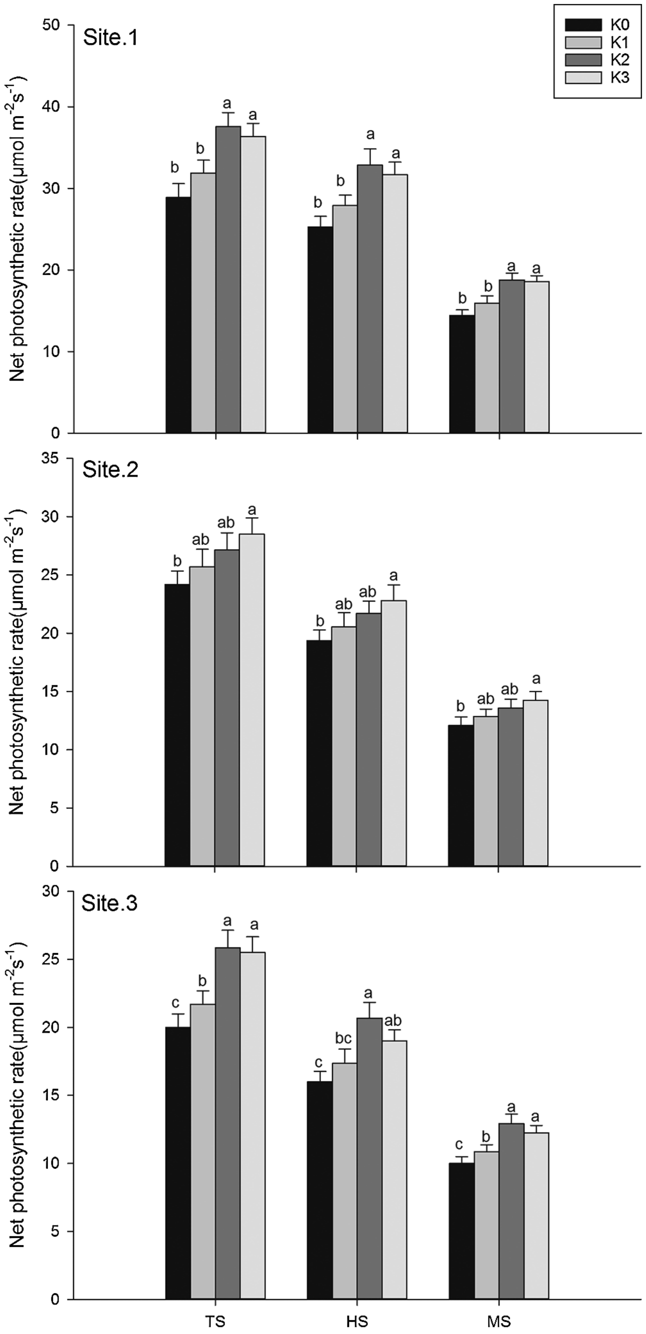

**Figure 3:** Net photosynthetic rate under different amounts of K fertilizer application in three sites (Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference (LSD) test. TS: tillering stage; HS: heading stage; MS: maturity stage)

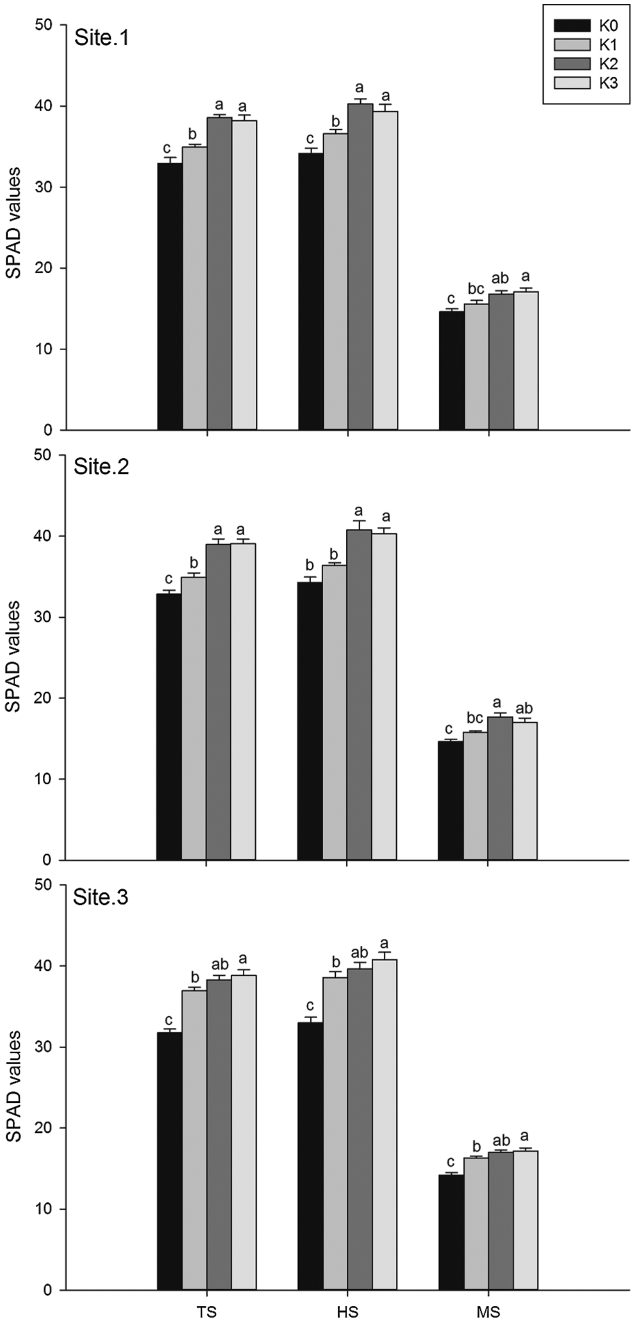

**Figure 4:** SPAD values under different amounts of K fertilizer application in three sites (Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference (LSD) test. TS: tillering stage; HS: heading stage; MS: maturity stage)

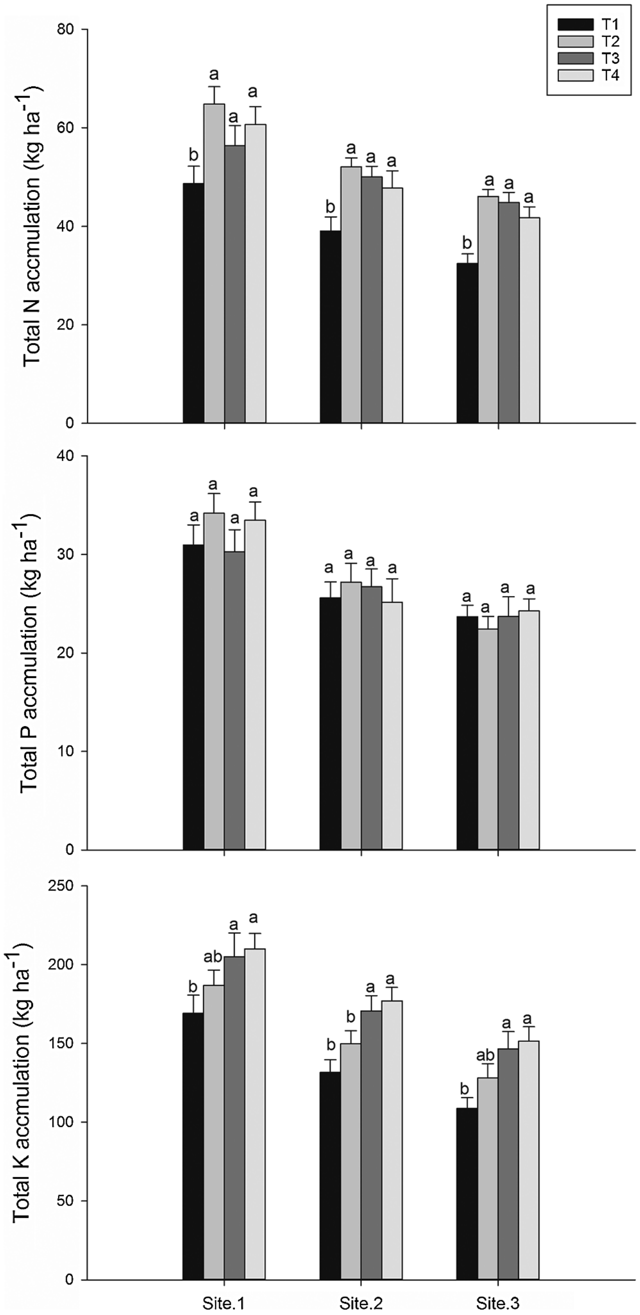

**Figure 5:** Total N, P and K accumulation in the aboveground tissues under different amounts of K fertilizer application in three sites (Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference [LSD] test)

Rice lodging refers to the irrecoverable dislocation phenomenon that the rice plant inclines or even adheres to the ground or breaks the stem caused by its own factors or environmental factors (bad weather, diseases and pests, etc.) in the process of growth and development. Many studies have revealed the harm of lodging to crop production. For example, Shar et al. [23] demonstrated that lodging near the harvest is one of the most chronic constraints the grain yield of rice. Zhao et al. [24] demonstrated that lodging would reduce the mechanical harvesting efficiency and thereby causes economic loss. The study of Xie et al. [25] also revealed that lodging would induce the change in contribution proportion of stem, leaf and panicle in the canopy of rice in paddy field. In our study, K application remarkably reduced the lodging index of rice in three sites and it was attributed to the substantial increment in breaking-resistant strength. Previous study revealed that the mechanical force of rice stem which mainly affected the lodging resistance of rice was closely related to lignin content as well as thickness of cell walls [26]. Thus, we deduced that application of K fertilizer might increase the stem lignin content or cell wall thickness. But more studies have to be done in order to reveal the mechanism lied behind the regulation in lodging of rice due to K fertilizer. Our results indicated that K fertilizer inputs need to be appropriately supplied to strength the lodging resistant of rice and prevent the yield loss from the lodging stress.

**Table 2:** Lodging parameters of rice under different amounts of K fertilizer application in three sites

| Site | Treatment | Plant height (cm) | Breaking-resistant strength (N) | Fresh weight (g) | Lodging index |
|---|---|---|---|---|---|
| Site.1 | | | | | |
| | $K_0$ | 104.03a | 8.76c | 219.46c | 127.91a |
| | $K_1$ | 104.67a | 12.35b | 266.49b | 111.10b |
| | $K_2$ | 104.11a | 16.83a | 312.52a | 94.87c |
| | $K_3$ | 104.00a | 17.04a | 314.27a | 94.07c |
| Site.2 | | | | | |
| | $K_0$ | 105.21a | 7.34c | 194.46c | 136.91a |
| | $K_1$ | 104.27a | 10.91b | 241.49b | 113.99b |
| | $K_2$ | 105.25a | 15.26a | 287.52a | 97.31c |
| | $K_3$ | 104.97a | 15.37a | 289.27a | 96.97c |
| Site.3 | | | | | |
| | $K_0$ | 103.87a | 5.72c | 169.46c | 152.06a |
| | $K_1$ | 105.14a | 9.55b | 216.49b | 118.26b |
| | $K_2$ | 105.40a | 13.65a | 262.52a | 99.41c |
| | $K_3$ | 103.67a | 13.96a | 264.27a | 96.22c |

Note: Different letters indicate significant difference at $p < 0.05$ among different K application rates according to least significant difference (LSD) test.

## 5 Conclusion

Application of K fertilizer resulted in higher panicle number per hill, grain number per panicle, seed-setting rate and consequently the increased grain yield. The rice under higher amounts of K fertilizer treatments had higher chlorophyll content, net photosynthetic rate and higher dry matter accumulation in the aboveground tissues of rice. K fertilizer application also significantly enhanced the breaking-resistant strength and reduced the lodging index of rice. The best or equally best amounts of K fertilizer were 128.55 kg $ha^{-1}$ and 153.90 kg $ha^{-1}$ in present study.

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**Conflicts of Interest:** The authors declare that they have no conflicts of interest to report regarding the present study.

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