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Effect of Deep Fertilizer Application with Precision Hill-Drilling Machine on Yield Formation and Fertilizer Use Efficiency in Rice (*Oryza sativa*)

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Abstract

Deep application of fertilizer with precision hill-drilling machine in super rice is a new mechanized mode with high efficiency and labor saving advantages. Field experiment was carried out with different rates of fertilizers using precision hill-drilling machine with the objective of determining super rice grain yield and NPK fertilizer use efficiency in South China area. There were five fertilizer treatments including no fertilizer, 100 kg N ha^{-1}, 100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}, 125 kg N ha^{-1}, and 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}. Super rice special fertilizer comprised 12.5% N, 6.0% P_2O_5, 10.0% K_2O, and 15% organic matter. The super rice varieties were *Yuejingsimiao 2* (inbred) and *Peizataifeng* (hybrid) which are widely grown in South China. Treatments were arranged in a split-plot design with three replications. Grain yield and accumulation of NPK and Si were affected by variety and fertilizer. The highest grain yield was obtained from 125 kg N ha^{-1} treatment. Grain yield, affected by silicon, increased at lower N rate and decreased at higher N rate. *Peizataifeng* was higher in grain yield than *Yuejinsimiao 2*. Nitrogen, P, K and Si accumulation at maturity were higher with *Yuejinsimiao 2* when 125 kg N ha^{-1} and 100 kg N ha^{-1} were applied, while concentration of N, P, K and Si was least in *Yuejinsimiao 2* with no fertilizer added. Physiological phosphorus use efficiency (PPUE) and potassium use efficiency (PKUE) were highest with *Peizataifeng* when 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1} was applied, while Physiological nitrogen use efficiency (PNUE) was highest with *Yuejinsimiao 2* when no fertilizer was added.

Keywords: Deep fertilizer application; Hill-direct-seeding; Grain yield; Nutrient use efficiency

Introduction

Nitrogen fertilizer is an important factor affecting rice production (Mikkelson, 1987). Nitrogen accounts for about 67% of the total amount of fertilizers applied to rice (Jayanthi *et al.*, 2007; Jan *et al.,* 2013). Nitrogen could be seen as a major determinant of grain yield and dry matter production in rice crop. However, it is easily lost from the lowland top soil after application due to the chemical transformations which occur in flooded lowlands, the method and timing of its placement which may give rise to de-nitrification and leaching of N (Xing and Zhu, 2002). Therefore, immense attention is given to nitrogen management in flooded lowland rice cultivation to achieve optimum yield from N fertilizer application. Highest grain yield was obtained in pot experiment when whole N was applied at sowing (Fageria *et al.*, 1997). Recovery percentages of applied nitrogen differed among soils when fertilizer was deeply placed to minimize nitrogen loss through de-nitrification. Recovery percentage correlated with grain yield and was attributed to nitrogen application. Apparently, the applied ammonia was lost through leaching, the degree of which depends on soil properties. These considerations were critical for super rice production. Rice response to fertilizer N has been shown to vary with cultivars by many researchers (Maskina *et al.*, 1992).

In rice, silicon helps to maintain leaf erectness, increase photosynthesis through improved light interception, and results in greater resistance to diseases and insect pests. Heavy N rates render rice plants more susceptible to fungal attack due to decreased silicon in the straw. Often, Si materials are applied under high fertilizer N use (Havlin *et al.*, 2005). Singh *et al.* (2006) in their study of the effect of level and time of silicon application on growth, yield and Si uptake by rice, found increasing the level of Si up to 120 kg ha^{-1} significantly increased yield and yield attributes of rice over its lower dose of 60 kg Si ha^{-1}, except test-weight which increased up to 180 kg Si ha^{-1}. Nitrogen and

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phosphorus contents in grain and straw also increased significantly due to Si application up to 180 kg Si ha^{-1}

The combination of high nitrogen rates and the absence and/or low silicon rates tend to turn leaves more decumbent as a result of greater leaf opening angles (Yoshida *et al.*, 1962). However, at the rate of 138 kg N ha^{-1}, number of sterile spikelets was decreased with increase in silicon fertilization (Ghanbari-Malidare, 2011). Silicon fertilizer application decreased sterile spikelets in rice and that caused plants not to have enough carbohydrates to fill up all spikelets produced as the silicon fertilization level increased, contributing to decrease the number of sterile spikelets and increase fertility (Ghanbari-Malidare, 2011). Fallah *et al.* (2004) indicated that silicon significantly increased percent spikelet filling, resulting in improved grain yield. Silicon deposition was reported on rice grain hulls.

Low fertilizer use efficiency resulted in resource-wasting and environment pollution (Zhang *et al.,* 2008). There may still be some limitations of mechanical deep placement of fertilizer while adapting to rice fields (Bautista *et al.*, 2001). But deep placement of fertilizer has proven effective in rice production (Wang, 2004).

Deep fertilizer application has been explored by many researchers as a cost-effective means of nitrogen management in flooded lowland rice cultivation – often as a basal application (Fageria *et al.*, 1997). Precision rice hill-drop drilling machine was developed by Luo *et al*. (2005; 2007) which showed higher rice yield (Luo *et al*. 2008; Tang *et al*., 2009). The technology of precision rice hill-direct-seeding synchronous with fertilizer application can save fertilizer by over 30% and improve rice yield by 10% than manual fertilizing (Wang *et al*., 2010). Balanced nutrition from fertilizer use in paddy rice has been studied (Yang, 2011). A combination of nitrogen, phosphorus and potash has greater effect than nitrogen alone (Yang, 2011). In this experiment silicon was added to the NPK fertilizer to benefit the fertilizer N. Therefore, the research focused on the objectives of finding the grain yield and the physiological use efficiency of nitrogen, phosphorus and potassium in the availability of silicon in direct seeded super rice. Of interest, fertilizer was one-time deeply placed synchronous with sowing by precision hill-drilling machine. This direction was considered necessary where resource management and environmental protection were sought.

Materials and Methods

Rice Materials

Yuejinsimiao 2 and *Peizataifeng*, widely grown in the Guangdong Province, South China, are the rice materials used. *Yuejinsimiao 2*, which is an inbred, was developed by Rice Research Institute, Guangdong Academy of Agriculture Science. Whole growth period in Guangdong province is about 130 days for early season. *Peizataifeng*, which is two-line hybrid rice, was developed by College of Agriculture, South China Agricultural University (SCAU). Its whole growth stage is about 125 days for early season. The two rice varieties have good attributes in terms of grain yield and quality.

Experimental Site and Conditions

The field experiment was carried out in the early season (March-July) in 2012, at the College of Agriculture's experimental farm, South China Agricultural University, Guangzhou, China (113.18' E, 23.10'N, elevation 18 m). Guangzhou has a humid subtropical climate influenced by the Asian monsoon, with an annual average temperature of 21.8°C, rainfall of 1,694 mm, and a frost-free period of 345 days. The properties of soil collected from the upper 20 cm were 19.65 g kg^{-1} organic C, available N 106.55 mg kg^{-1}, available P 31.74 mg kg^{-1}(water as extract), available K 189.48 mg kg^{-1}(ammonium acetate (1 mol L^{-1}) as extract), SiO_2 52.60 mg kg^{-1}.

Experimental Method

The land was ploughed by machine and puddled well by oxen. Seeds were mechanically hill-drop drilled by precision synchronous with deep fertilizer application by rice hill-drop drilling machine developed by Luo *et al*. (2005, 2007). The two varieties, *Yuejinsimiao 2* and *Peizataifeng*, were grown under five fertilizer rates, viz: no fertilizer, 100 kg N ha^{-1}, 100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}, 125 kg N ha^{-1}, 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}. Super rice special fertilizer comprised 12.5% N, 6.0% P_2O_5, 10.0% K_2O, and 15% organic matter. Treatments were arranged in split-plot design with three replications. Fertilizer rates were in main plots and cultivar treatments in the sub plots. The area of plot was 20.0 m^2.

The trial was done in the early season of 2012 (from March 17th to July 12th) in a field that was fallowed after the previous year's late season rice. The density was 35 x 15 x 14cm. Irrigation was by alternate wetting and drying and plant protection measures were followed uniformly in all the plots as per requirement.

Rice Management, Sampling and Measurements

Full dose of fertilizer was applied at sowing. Ten cells were established as growing units and were bonded with raised mud wrapped with polythene sheet to avoid flow of irrigation from one plot to another, thus containing fertilizers within their plots of application. At maturity treatments were sampled for measurement of plant (stem + leaf + panicle) weight, nutrient accumulation and distribution, and grain yield. Plants were selected from 2 border rows away into the plot. Three representative hills, leaving two boarder rows at least, were then randomly uprooted from each plot following standard sampling process, washed clean of soil and other surface contaminants and taken to the laboratory for further preparation and measurements. At laboratory the plants were separated into leaves, stems and panicles for dry matter determination and nutrient (N, P, K and Si) absorption, accumulation and distribution analysis. The plant parts were dried to constant weight in oven at 80^{o}C.

For grain yield determination, plants were harvested manually at ground level at the yellow-ripe stage from three representative unit area (1 m^2) in each plot with at least 2 boarder rows away. Threshing was mechanically done immediately after harvest and grain yield was measured at about 14% moisture content.

For nutrient measurement in plant tissues, oven dried leaves, stems and panicles were grinded to powder by stainless steel grinder in the laboratory to obtain homogeneous samples from each treatment. A sample weight of 0.3g x 3 from each treatment of grinded leaves, stem and panicles were digested and analyzed for N, P, and K by Kjeldahl method as described by Lu (1999). N content in plant tissues were determined by the Kjeldahl method with a 2300 Kjeltec Analyzer Unit. The diluted solution obtained after the digestion was also used to determine the P content in plant tissues using the UV-VIS Spectrophotometer UV-2550 (SHIMADZU Corporation) machine; and to determine the K content in plant tissues using the Atomic Absorption Spectrophotometer AA-6300C (SHIMADZU Corporation), Auto Sampler ASC-6100 (SHIMADZU corporation) and Graphite Furnance Atomizer GFA-EX7i (SHIMADZU Corporation). For silicon content determination, 0.1g x 3 of grinded tissue from each treatment was digested and assayed, and the process was as described by Dai *et al*. (2005). Si content was detected by use of the UV-VIS Spectrophotometer UV-2550 (SHIMADZU Corporation). Values of OD were converted to actual as given by Dai *et al*. (2005), and were expressed in kg ha^{-1}. Physiological N, P and K use efficiency of fertilizer NPK were determined according to Jiang *et al*. (2004) and Tayefe *et al*. (2011).

Statistical Method

All data were made using Excel 2003 program and the data were analysed using with Statistix 9.0 software using ANOVA and comparison were made by Duncan's Test at the 5% level of significance.

Results

Yield and Yield Components in Super Rice

Variety and treatments were significantly different in yield. At 100 kg N + 60 kg SiO_2 ha^{-1} grain yield increased by 13.24% with *Yuejinsimiao 2*, while it increased by 13.51% with *Peizataifeng*. In contrast, at 125 kg N + 60 kg SiO_2 ha^{-1} grain yield decreased by 10.96% with *Yuejinsimiao 2*, while it decreased by 9.96% with *peizataifeng*. The addition of 125 kg N ha^{-1} to *Peizataifeng* produced the highest yield. With the addition of 60 kg ha^{-1} SiO_2 it was observed that grain yield increased by about 13% in *Yuejinsimiao 2*, and decreased by about 10% in *Peizataifeng*. The interactions between *Yuejinsimiao 2* and fertilizer were higher in productive tillers per square meter than the interactions between *Peizataifeng* and fertilizer. Number of spikelets per panicles was highest with *Peizataifeng* on application of 125 kg N ha^{-1}. Percent filled spikelets was highest with *Yuejinsimiao 2* when no fertilizer was added and least with 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1} applied to *Yuejinsimiao 2*. The highest 1000-grain weight was obtained from *Yuejinsimiao 2* fertilized with 100 kg N ha^{-1} and least from *Peizataifeng* with 125 kg N ha^{-1} (Table 1).

Plant Dry Weight in Super Rice at Maturity

At maturity, leaf and stem dry weights were highest with the application of 100 kg N ha^{-1} to *Peizataifeng*. Except for the application of 125 kg ha^{-1} N + 60 kg ha^{-1} SiO_2 to *Yuejinsimiao 2, Yuejinsimiao 2* - fertilizer interactions had lower stem dry weights. Highest panicle dry weight was obtained when 125 kg ha^{-1} N was applied to *Peizataifeng*. It can be clearly seen (Table 2) that *Peizataifeng* - fertilizer interactions comparatively produced higher dry panicle weights. At maturity, *Peizataifeng* on application of 125 kg ha^{-1} N had the highest plant above-ground dry weight. Except for the application of 125 kg ha^{-1} N + 60 kg ha^{-1} SiO_2 to *Yuejinsimiao 2,* all the *Yuejinsimiao 2*–fertilizer interactions produced lower plant above-ground dry weights. Stem weight was over 95% higher than leaf weight, while panicle weight was 38% higher than stem weight. Panicle weight contributed more to whole plant weight than stem and leaf weights (Table 2).

Nitrogen, Phosphate, Potassium (N P K) and Si Accumulation of Above-Ground Plant Matter in Super Rice at Maturity

There was some difference in N, P, K and Si accumulation under deep application of fertilizer by precision hill-drilling machine (Table 3). Accumulation of N, P, K and Si at maturity was greatest with *Yuejinsimiao 2* when 125 and 100 kg N ha^{-1} were applied. The treatment had higher N and K contents in Peizataifeng than *Yuejingsimiao 2*. The application of 100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1} to *Yuejinsimiao 2* decreased N, K and Si concentration by 3.07%, 7.50% and 16.73%, respectively, and increased P concentration by 2.93%, compared with 100 kg N ha^{-1} only. Further, the application of 125 kg N ha^{-1} + 60 kg ha^{-1} SiO_2 to *Yuejinsimiao 2*, resulted in increased concentration of N, P, K and Si by 23.36%, 18.29%, 12.21% and 67.05%, respectively, compared with only 125 kg N ha^{-1}. In *Peizataifeng*, when 100 kg N ha^{-1} + 60 kg ha^{-1} SiO_2 was applied, N, P, K and Si concentration decreased by 16.81%,

Table 1: Effect of fertilizer application on yield and yield components in super rice

Hybrids	Treatments	Productive tillers m^{-2}	Spikelets/ panicle	Filled spikelets (%)	1000-grain wt (g)	Yield (t ha^{-1})
Yuejinsimiao 2	No fertilizer applied	256.00 a	171.41 ab	78.53 a	20.93 ab	6.82 e
	100 kg N ha^{-1}	266.44 a	141.34 b	68.18 abc	21.60 a	7.55 de
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	264.44 a	150.20 b	72.63 a	21.18 ab	8.31 bcd
	125 kg N ha^{-1}	246.89 a	172.52 ab	71.72 ab	20.94 ab	8.62 abc
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	241.11 a	221.46 a	56.01 d	20.37 bc	7.58 de
Peizataifeng	No fertilizer applied	251.33 a	178.55 ab	66.92 abcd	21.16 ab	6.85 e
	100 kg N ha^{-1}	226.22 a	185.04 ab	72.93 a	20.08 bc	7.99 cd
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	253.33 a	221.19 a	75.05 a	20.98 ab	9.07 ab
	125 kg N ha^{-1}	234.66 a	232.51a	59.89 bcd	19.78 c	9.53 a
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	240.22 a	182.44 ab	57.23 cd	20.34 bc	8.58 bc

Different letters in the same column mean significantly different at <0.05 levels, the same below

Table 2: Effect of fertilizer application on plant dry weight at maturity of super rice

Hybrids	Treatments	Leaf weight (g $hill^{-1}$)	Stem weight (g $hill^{-1}$)	Panicle weight (g $hill^{-1}$)	Above-ground plant weight (g $hill^{-1}$)
Yuejinsimiao 2	No fertilizer applied	9.41 cd	21.64 g	48.50 cd	79.29 ef
	100 kg N ha^{-1}	12.91 ab	26.80 f	36.34 e	76.04 f
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	11.93 bc	21.75 g	40.58 e	76.59 f
	125 kg N ha^{-1}	12.91 ab	27.52 ef	43.49 de	81.92 def
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	11.89 bc	33.83 cd	54.00 bc	100.65 cde
Peizataifeng	No fertilizer applied	7.77 d	32.33 de	60.31 b	102.74 cd
	100 kg N ha^{-1}	15.86 a	42.67 a	69.59 a	127.73 ab
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	12.64 b	37.28 bc	54.00 bc	99.91 cde
	125 kg N ha^{-1}	13.91 ab	39.03 ab	73.13 a	132.08 a
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	9.18 cd	40.04 ab	59.26 b	108.14 bc

24.08%, 8.97% and 35.38%, respectively, compared with when only 100 kg N ha^{-1}. Further, application of 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1} to *Peizataifeng* resulted in decreased N, P, K and Si concentration by 13.87%, 24.41%, 24.84% and 7.77%, respectively, compared with only 125 kg N ha^{-1} (Table3).

N, P, K and Si Accumulation of Different Plant Organs in Super Rice at Maturity

At maturity, N was higher in panicles than stems and leaves. In all treatments panicle N accounted for about 50 or more percent of plant N. *Peizataifeng* – fertilizer interactions had higher N contents in panicles over *Yuejinsimiao 2*. Application of 125 kg N ha^{-1} to *Peizataifeng* produced the highest N content in panicles and stems. In all fertilized treatments phosphorus distribution was in descending order of panicle, stem, and leaf. Phosphorus content of panicles was over 75% of above-ground plant P.

K concentration was higher in stems than panicles and leaves. Over 60% of above-ground K was contained in stem tissues. Except for the application of 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1} to *Peizataifeng*, the *Peizataifeng* – fertilizer interactions had higher stem K content over *Yuejinsimiao 2*. In above-ground plant K content, *Peizataifeng* – fertilizer interactions outwitted *Yuejinsimiao 2*. In *Peizataifeng* descending order of K distribution was: stem, panicle, leaf. In *Yuejinsimiao 2* leaf K was higher than panicle K with the application of 100 kg ha^{-1} N and 100 kg ha^{-1} N + 60 kg SiO_2. *Peizataifeng* maintained higher K contents in stems, leaves and panicles on application of 100 kg ha^{-1} N and 125 kg ha^{-1} N.

In all fertilized treatments silicon was highest in stems. Over 46% of above-ground plant Si content was contained in the stem. Except with the application of 125 kg N ha^{-1} to *Yuejinsimiao 2*, Si distribution was in the descending order: stem, panicle, leaf. Highest stem and panicle Si content was noticed with the application of 125 kg N ha^{-1} + 60 kg ha^{-1} SiO_2 to *Peizataifeng*. *Peizataifeng* – fertilizer interactions were higher in stem Si content than *Yuejinsimiao 2*. In stems, panicles and above-ground plants, Si content was shown to be lower when Si was applied than no application, especially in *Peizataifeng* (Table 4).

N, P and K Use Efficiency in Super Rice

Physiological N use efficiency (PNUE) was highest when no fertilizer was applied to *Yuejinsimiao 2*, while physiological phosphorus use efficiency (PPUE) and potassium use efficiency (PKUE) were highest with the application of 125 kg N ha^{-1} + 60 kg ha^{-1} SiO_2 to *Peizataifeng*. It was noticed that when silicon was applied PNUE decreased. Among the four fertilizer combinations 125 kg ha^{-1} N gave the highest PNUE (Table 5).

Discussion

Crop plants grown on soils with sufficient amounts of available nitrogen develop and thrive with a healthy green color. Nitrogen deficiency results in poor plant growth and

Table 3: Effect of fertilizer application on nutrient accumulation in above ground plant matters at maturity of super rice

Hybrids	Treatments	Nitrogen (N) (kg ha^{-1})	Phosphorus (P) (kg ha^{-1})	Potassium (K) (kg ha^{-1})	Silicon (Si) (kg ha^{-1})
Yuejinsimiao 2	No fertilizer applied	41.43 d	50.49 bc	187.42 e	280.01 bc
	100 kg N ha^{-1}	65.40 bcd	44.01 cd	219.16 cde	319.52 b
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	63.85 bcd	45.30 c	202.73 de	266.06 bc
	125 kg N ha^{-1}	57.88 cd	50.89 bc	230.93 cde	256.27 c
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	66.62 bcd	60.20 a	255.64 bc	428.12 a
Peizataifeng	No fertilizer applied	65.72 bcd	44.71 c	233.56 cde	400.77 a
	100 kg N ha^{-1}	95.33 a	60.17 a	320.17 a	420.09 a
	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	79.91 abc	45.68 cd	291.42 ab	271.43 bc
	125 kg N ha^{-1}	99.89 a	59.75 a	319.08 a	461.09 a
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	86.04 ab	43.37 d	239.81 cd	425.27 a

Table 4: Effects of fertilizer on distribution of N, P, K and Si in super rice plants at maturity

Hybrids/		Nitrogen (kg ha^{-1})			Phosphorus (kg ha^{-1})			Potassium (kg ha^{-1})			Silicon (kg ha^{-1})		
Treatments		stem	leaf	panicle	stem	leaf	panicle	stem	leaf	panicle	stem	leaf	panicle
	N1	6.79 d	7.18 cd	27.45 c	0.00 f	2.36 abcd	48.14 abcd	120.80 d	25.48 c	41.143 cd	130.77 d	57.14 bcde	92.10 c
	N2	12.19 bcd	17.88 ab	35.33 bc	2.86 e	1.63 bcd	39.52 cde	142.28 cd	48.17 a	28.717 f	149.94 cd	70.10 ab	99.48 c
V1	N3	11.76 bcd	12.57 bcd	39.52 bc	4.13 cd	3.97 a	37.19 de	123.31 d	45.10 a	34.317 ef	120.69 d	67.26 abc	78.11 cd
	N4	15.90 abc	13.33 abc	28.65 c	8.95 a	3.11 ab	38.83 cde	166.41 bc	28.74 ab	35.777 def	133.46 d	63.76 abcd	59.06 d
	N5	19.10 ab	12.35 bcd	35.18 bc	7.68 ab	2.81 abc	49.71 abc	185.10 ab	26.45 c	44.083 cd	207.50 ab	69.80 ab	150.82 b
	N1	7.91 cd	6.38 d	51.42 abc	0.00 f	0.66 d	44.04 abcde	166.93 bc	21.85 c	44.773 cd	172.10 c	40.68 e	187.99 a
	N2	21.43 a	12.98 bc	60.93 ab	7.05 bc	1.06 cd	52.05 ab	221.55 a	44.67 a	53.940 ab	180.37 bc	67.52 abc	172.20 ab
V2	N3	18.68 ab	19.40 a	41.84 abc	3.96 d	1.92 bcd	39.81 bcde	204.30 ab	41.73 ab	45.397 bc	140.83 d	48.55 de	82.06 cd
	N4	15.42 abc	17.66 ab	66.81 a	8.95 a	3.18 ab	55.19 a	215.54 a	45.99 a	57.550 a	212.59 a	75.65 a	172.85 ab
	N5	17.92 ab	10.90 cd	57.22 ab	7.68 ab	2.45 abcd	35.06 e	165.39 bc	26.79 bc	47.637 bc	215.53 a	52.11 cde	157.60 b

V1=Yuejinsimiao 2; *V2=Peizataifeng*; N1=no fertilizer; N2=100 kg N ha^{-1}; N3=100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}; N4=125 kg N ha^{-1}; N5=125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}.
Different letters in the same column mean significantly different at <0.05 levels, the same below.

Table 5: Effects of fertilizer application on physiological N, P and K use efficiency in super rice

Hybrids	Treatments	Physiological use efficiency		
		PNUE (kg kg^{-1})	PPUE (kg kg^{-1})	PKUE (kg kg^{-1})
	No fertilizer applied	542.49 a	446.14 bc	118.70 abc
	100 kg N ha^{-1}	328.15 b	484.45 bc	97.61 d
Yuejinsimiao 2	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	325.42 b	460.04 bc	102.64 bcd
	125 kg N ha^{-1}	406.84 ab	467.53 bc	101.91 cd
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	398.37 ab	435.03 bc	102.62 bcd
	No fertilizer applied	444.43 ab	641.98 ab	120.62 ab
	100 kg N ha^{-1}	403.70 ab	600.55 abc	112.30 bcd
Peizataifeng	100 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	386.13 b	404.02 c	103.97 bcd
	125 kg N ha^{-1}	373.98 b	591.53 abc	110.64 bcd
	125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}	353.95 b	785.30 a	131.34 a

PNEU = Physiological nitrogen use efficiency; PPUE = Physiological phosphorus use efficiency; PKUE = Physiological potassium use efficiency

quality. Since nitrogen is evidently one of the key limiting nutrients in crop growth, finding efficiency levels of nitrogen is important for growth, development, protein synthesis, and yield. However, balanced nutrition from fertilizer use in paddy rice has been studied (Yang, 2011). Experiments have revealed that application of nitrogen alone can double yield, but a combination of nitrogen, phosphorus and potash have greater effect than nitrogen alone (Yang, 2011). In general, phosphorus and potash are recommended to be half of the nitrogen dose. In this experiment fertilizer formulas varied in their N, P, K and/or Si concentrations.

At maturity, *Peizataifeng* - fertilizer interactions produced higher dry panicle weights and above-ground plant weights. High above-ground plant weights resulted from high panicle weights (panicle weight was at least 38% of total above-ground plant weight). High panicle weights emanated from large panicle size and better grain filling. This must have been connected to the very low leaf weight observed at maturity (stem weight was over 95% higher than leaf weight), suggesting that a greater part of leaf weight had come from photosynthates and nitrogen, and these have been translocated to the grains. This was evident as *Peizataifeng* - fertilizer interactions produced higher yields than *Yuejinsimiao 2*. Much to this, the application of 125 kg ha^{-1} N to *Peizataifeng,* which had the highest above-ground dry weight, following the same reasoning had the highest grain yield.

Rice yield could be regarded as a measure of the agronomic effectiveness of the treatment applied to a crop of rice under the prevailing cultural practices and environmental factors. In this experiment variety x fertilizer interaction affected grain yield. The type of nitrogenous fertilizer may also affect yield and quality of grain (Gately and Kelly, 1987).

In all treatments, potassium and silicon had higher concentration in stems. This is necessary for straw strengthening and promotion of plant health, tillering, panicle development, spikelet filling, as well as promoting efficient use of nitrogen as reported by Fallah *et al.* (2004) and Havlin *et al.* (2005). Further, among the four nutrients supplied (i.e., N, P, K and Si), Si had the highest concentration in panicles. Silicon is a beneficial element for plant growth. It helps plants to overcome multiple stresses, alleviates metal toxicity and improves nutrient imbalance (Havlin *et al*., 2005). At maturity stems and panicles from plants fertilized with 100 kg ha^{-1} N + 60 kg SiO_2 ha^{-1} had significantly lower Si content than stems and panicles from plants fertilized with 100 kg ha^{-1} N (data not shown). Similarly, stems of *Peizataifeng* fertilized with 125 kg ha^{-1} N + 60 kg SiO_2 ha^{-1} were found to have a lesser amount of Si in panicles. Silicon distribution for varieties was greatest in stems (*Yuejinsimiao 2* = 48.89%; *Peizataifeng* = 46.57%) as it was for all fertilizer combinations (125 kg ha^{-1} N + 60 kg ha^{-1} SiO_2 = 49.57%; 100 kg ha^{-1} N + 60 kg ha^{-1} SiO_2 = 48.65%; 125 kg ha^{-1} N = 48.23%), and this must have reduced the tendency for plants to lodge. It was also noticed that N concentration in stems and leaves was lower than panicles in all treatments. This could have been due to remobilization of nitrogen to grains, and the remaining senescing stems and leaves at maturity being highly N depleted. As N content in panicles was highest in *Peizataifeng* supplied with 125 kg ha^{-1} N, it follows that it gave the highest grain yield. Phosphorus was also noticed to be the lowest in above-ground plant nutrient concentration. At the end, rice plants had accumulated more Si than K, more K than N and more N than P with the exception of *Yuejinsimiao 2* with no fertilizer added, which had more P than K, and *Peizataifeng* fertilized with 100 kg ha^{-1} N, which had more K than Si. Fageria (1996) observed that on a whole plant basis, rice cultivars accumulated more K than N and more N than P.

Nitrogen is normally a key factor in achieving optimum lowland rice grain yields (Fageria *et al.*, 1997). Usually it is the most yield-limiting nutrient in irrigated rice production around the world (Samonte *et al*., 2006). Nitrogen use efficiency by flooded rice is less than 50% (Fageria and Baligar, 2001, 2005). The low N use efficiency of lowland rice is associated with its loss by several mechanisms in the soil-plant systems. The main N loss mechanisms are volatilization of ammonia (NH_3), leaching loss of nitrate (NO_3), loss through de-nitrification and soil erosion. Use of N fertilizers in adequate amount, form and methods of application are important management strategies of this element. In this experiment, N-fertilizer was deeply placed in soil at time of sowing. The non-fertilizer receiving treatments of both varieties had the highest physiological nitrogen use efficiency at maturity, and they had produced the lowest dry matter. This was largely because the native nitrogen of the soil which accumulated in the plants thereof was efficiently used for crop growth (dry matter production). Amongst the fertilizer-receiving treatments *Yuejinsimiao 2* fertilized with 125 kg ha^{-1} N had the highest physiological nitrogen use efficiency at maturity and was insignificantly different from *Peizataifeng* fertilized with 125 kg ha^{-1} N which produced the highest yield.

Phosphorus deficiency is also one of the major limiting factors for rice production, mostly in highly weathered soils all over the world such as Oxisols and Ultisols (Sanchez and Salinas, 1981). At maturity P use efficiency was highest when *Peizataifeng* was fertilized with 125 kg N ha^{-1} + 60 kg ha^{-1} SiO_2 (785.30 kg kg^{-1}), but was insignificantly different from *Peizataifeng* fertilized with 125 kg N ha^{-1} (591.53 kg kg^{-1}), which produced the highest grain yield.

Under the current fertilizer application regime of the rice-rice cropping system in south China, K is usually 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 has been advanced. In order to apply K 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. In this experiment, at maturity *Peizataifeng* fertilized with 125 kg N ha^{-1} (131.40 kg kg^{-1}) was highest in physiological potassium use efficiency and significantly different from *Peizataifeng* fertilized with 125 kg N ha^{-1}, which had the highest grain yield.

Physiological nitrogen use efficiency of all varieties decreased with increase in N application (Tayefe *et al.,* 2011). It showed that yield increase per kilogram N accumulated in rice plant decreased with increase in N application. Quanbao *et al.* (2007) in the same research showed that under two soil conditions, physiological nitrogen use efficiency of all genotypes decreased significantly with increase in N application. In this experiment, it was shown that in the fertilized treatments PNUE decreased with increase in N rate in hybrid *Peizataifeng*, while it increased with increase in N rate in inbred *Yuejinsimiao 2*. Also, it was observed that the silicon-receiving treatments were lower in nitrogen use efficiency.

In conclusion, grain yield and physiological N, P and K use efficiency were affected by both variety and fertilizer combinations. Physiological N, P and K use efficiency was in the ascending order of PKUE; PNUE; PPUE. At 125 kg N ha^{-1} physiological nitrogen use efficiency (PNUE) decreased in hybrid *Peizataifeng,* while it increased in inbred *Yuejinsimiao 2*. We concluded that deep application of super rice special fertilizer in super rice (*Oryza sativa* L.) production with precision hill-drilling machine, having shown intriguing effects on Si accumulation and NPK use efficiency, was beneficial for increasing yield especially at the rate of 125 kg N ha^{-1} and 125 kg N ha^{-1} + 60 kg SiO_2 ha^{-1}, and more so for *Peizataifeng* than *Yuejinsimiao 2.*

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