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Full Length Research Paper

Physiological traits, yields and nitrogen translocation of ratoon rice in response to different cultivations and planting periods

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Rice (*Oryza sativa L.*) ratooning is the production of a second rice crop from the stubble left after the main crop harvest. Its growth and development are affected by the environment factors and the growth condition of the main crop. The objectives of this study were to evaluate the effects of different cultivations (DS: direct-seeding, ST: seedling-throwing, TP: transplanting) and planting periods of the main crop on physiological traits and rice yields, as well as to find the source of the nutrients in the ratoon crop by studying the stubble dry matter and nitrogen translocation of pre-anthesis and its efficiency in the ratoon crop. The yields of the main crop were different significantly. The yield of TP was significantly higher than ST and DS as well as the yield of D3 was more than the yields of other periods. In the ratoon crop, the yield of D1 was more than that in other periods. The ratooning ability was different significantly among different cultivations. The cultivations affected the tillering ability in the ratoon crop and the translocation of the stubble dry matter and nitrogen uptaking in which TP was better than others. From March to April, sowing or transplanting date did not affect the stubble dry matter and N translocation of pre-anthesis and its efficiency. The results suggested that TP treatment could get the highest yield among the three cultivations. The crops could get higher grain yield when the ratoon rice were planted during the period of late March to April in southeastern China.

Key words: Direct-seeding, seedling-throwing, transplanting, ratoon rice, grain yield.

INTRODUCTION

It is known that rice (*Oryza sativa L.*) is the world's most important food crop. More than 40% of the world's population depends on rice as the major source of calories (Sipaseuth et al., 2007). To feed the increasing global population, the world's annual rice production must increase from the present 528 to 760 million ton by 2020 (Kundu and Ladha, 1999). Although, rice production in China is higher than other countries, but like other parts of Asia, the rice yield increase in China have slowed down in recent years. However, the development of ratooning rice is one of the methods to increase the yield all over the world because additional rice yields can be achieved with minimal agricultural inputs (Harrell et al., 2009). Ratooning rice (also called twice harvesting rice in Japan) is one-season rice that has dormant bud on the stubble sprout, head and is harvested on certain cultivation patterns after harvesting the main rice. The ratoon cropping systems have been used in India, Thailand, Taiwan, Swaziland, China, the United States and Philippines (Nakano and Morita, 2007). In China, rice

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ratooning has been practiced first (Guo, 1993) since West Jin dynasty (A.D.265 to 316). Yang et al. (1958) began to study on the ratooning rice in China in 1958. But the yield of the ratooning rice is still lower than the main cropp; so it was only planted in small areas.

However, compared with the traditional rice cultivation, ratooning rice can provide higher resource using efficiency per unit time and per unit land area. Furthermore, better yield of the ratoon crop is possible by adopting appropriate management practices for the main crop as well as for the ratoon crop. For example, the average yield of the main crop was 12633 kg ha^{-1} and the ratoon was 7115 kg ha^{-1} in Fujian province of southeast China (Chen et al., 2007). Both of them were higher than the yields of other provinces in China.

Most areas of southeast China with the middle rice cultivation system would be planted the ratooning rice. In Jiangxi province north districts, there are 242261 ha paddy field to be planted by earlier-ripe ratooning rice (Huang et al., 2001). So, the study of ratooning rice is necessary in Jiangxi province. At present time, different cultivations of the lowland rice comprised direct-seeding (DS), seedling-throwing (ST) and transplanting (TP) in Jiangxi province and other areas of southeast China (Chen, 2003). Traditionally, rice is cultivated with TP pattern consisting of raising nurseries, picking seedlings up and transplanting which cost a large number of man power and financial resources. In the past two decades, DS cultivation, one of the patterns that throw rice seeds into puddled soil by hand or machinery in irrigated field is gradually developed in China. In recent years, the area of DS rice is rapidly increasing. Its seedling stage is a completely different growth environment compared with transplanting cultivation. It has been reported that the direct seeding rice showed favorable changes for high yield formation in comparison with the transplanting rice including earlier seedling emergence, stronger root activity, higher seed setting rate and greater biomass production at the early stage (Naklang et al., 1996). It is easier (less drudgery) and more timely crop establishment, reduced labor costs for crop establishment and possible savings in water use. But DS rice has shallower roots and greater biomass, thus being prone to lodge and competition with weeds is considered as an inevitable barrier of high yield for DS (Yamauchi and Chuong, 1995). ST is one of the planting patterns that throw rice seedlings into the air with soil by hand or machinery, using its own gravity of seedlings with soil into field. It was easier and could reduce labor costs for crop establishment.

Its population grows rapidly at the beginning and produces more tillers to increase the plant intensity during early growth period. But with the growing of plants, productive tillers are slightly low and the capability of root lodging resistance becomes weaker (Zhang et al., 1993). ST occurred in Japan on 60th of 20th century. China began to develop seedling-throwing from 80th of 20th century. The growth and development of the main and ratoon rice was also affected by different environmental factors including solar radiation, temperature and rainfall. The different cultivations as well as the planting periods of each pattern are the most important factors which affect directly or indirectly environment factors, the density of rice colony, the space structure of plants, LAI (leaf areas index) and other physiological characteristics of rice. So the objective of this study was to determine how different cultivations and sowing or transplanting dates affect growth and grain yield in the ratooning rice Eryouhang II, then chose feasible cultivation and sowing or transplanting date of the ratooning rice in southeastern China is based local climate.

MATERIALS AND METHODS

Experimental set up

A field experiment was established in Yujiang County, Jiangxi Province in southeast China (28.15 N, 116.55 E) in 2009. The research area was representative of a typical sub-tropical moist climate with a mean annual temperature of about 17.78°C, a maximum daily temperature of around 40°C in summer and a rainfall of 1750 mm, about 50% of which falls from March to early July. The natural conditions such as climate, soil and the social-economic status as well as management (the rotation systems) of Yujiang County are representative of the subtropical regions of China (Kyuma, 2003; Qin et al., 2006; Li et al., 2006). The initial soil properties of plough horizon (0 to 20 cm) before the experiment were as follows: total organic carbon of 35.42 g kg^{-1}, total N of 1.85 g kg^{-1}, total P of 0.42 g kg^{-1} and total K of 26.92 g kg^{-1} as well as available N of 163.98 mg kg^{-1}, available P of 10.11 mg kg^{-1}, available K of 159.72 mg kg^{-1} and pH (H_2O) of 4.99, respectively.

Experimental design and crop management

The variety of rice is Eryouhang II, which was offered by Fujian Academy of Agricultural Sciences in China. This experiment had 3 (cultivations) × 3 (sowing or transplanting date) factorial design arranged as a randomized complete block split-plot design with three replications (Table 1). The plot size was 48 m^2 (8 × 6 m) and the plots were separated by sealed bank (the height was 40 cm over the soil surface). DS was broadcast onto the soil surface on 21th, 31th of March and 10th of April. The amount of seeds was 5.25 kg ha^{-1} and 30 hills m^{-2}. Sowing date of ST and TP occurred on 10, 20 and 30th of March. Seedlings grown in a nursery and then planted on 11th, 21th of April and 1st of May. They were planted to a paddy field with a mean of 18 hills m^{-2} (TP is 30 × 18 cm) by ST and TP, respectively. The crop was harvested at the same time based on the local condition. The experimental field was irrigated for land soaking and plowed the saturated soil. All the plots were prepared under submerged condition (the depth of water about 5 cm) before planting. In the main rice, a total amount of fertilizers of urea, calcium magnesium phosphate and potassium chloride were applied at the rates of 288.0 kg N, 72.0 kg P and 144.0 kg K ha^{-1}. Full phosphorus and 30% of the total K and 20% of the total N were added in the soils by hand as basal fertilizer just before transplanting. Additional N and K was spread over at early tillering stage at 5 and 6 leaf rice growing period (30% of the total N), as well as at booting stage at 12 and 13 leaf period (20% of the total N and 35% of the total K) and 14 and 15

Table 1. Treatments of cultivations and sowing or transplanting dates in Yujiang County in southeastern China.

Cultivations	Description	
	Abbreviations of treatments	**Sowing or transplanting dates**
Direct-seeding (DS)	DS1	Sowing date occurred on the 21th of March.
	DS2	Sowing date occurred on the 31th of March.
	DS3	Sowing date occurred on the 10th of April.
Seedling-throwing (ST)	ST1	Sowing date occurred on the 10th of March and planted on the 11th of April.
	ST2	Sowing date occurred on the 20th of March and planted on the 21th of April.
	ST3	Sowing date occurred on the 30th of March and planted on the 1st of May.
Transplanting (TP)	TP1	Sowing date occurred on the 10th of March and planted on the 11th of April.
	TP2	Sowing date occurred on the 20th of March and planted on the 21th of April.
	TP3	Sowing date occurred on 30th of March and planted on the 1st of May

leaf period (20% of the total N and 35% of the total K), respectively.

In the twice rice, nitrogen was supplied as urea at a rate of 195 Kg N ha^{-1} which was split as the budding fertilizer (80% of the twice total N, 15 and 20 days after full heading of main rice) and tillering fertilizer (20% of the twice total N, 1 and 2 days after harvesting of main rice). The main crop was mowed by hand with a stubble height of 40 cm at the yellow ripe stage. Weeds and diseases were controlled by applying herbicides and fungicides as required during growth of the main and ratoon rice.

Plant sampling and measurements

Plants were sampled at harvesting stage of the main crop and heading stage of the ratoon crop. In order to ensure the representativeness of the sampling, we counted 50 hills from 3 different locations in each subplot before sampling and recorded the tiller number for each hill. Then, based on the tiller number distribution of the 50 hills, three representative hills were reselected and destructively sampled to observe tillers in stubble nodes at stubble of the main crop. After this, the plants were oven-dried at 80°C to constant weight and weighed. Then the plants were ground to paste and then sieved with a 0.5-mm mesh and digested and analyzed for nitrogen content by micro-Kjeldahl method.

Calculations and statistical analysis

The various parameters referring to stubble dry matter and N translocation and translocation efficiency in the ratoon crop discussed in this paper were calculated as follows according to Ntanos and Koutroubas (2002), Zhang et al. (2009) and Dordas (2009):

a) Stubble dry matter of main crop translocation at pre-anthesis equal to the stubble dry matter of main crop at harvesting stage minus the stubble dry matter of the ratoon crop at heading stage.
b) Stubble dry matter translocation efficiency at pre-anthesis equal to (a) minus the stubble dry matter of main crop at harvesting stage.

The calculations of N translocation and translocation efficiency are same to the calculations of dry matter. Data was analyzed with the statistical package SPSS10.0 and EXCEL2003 for Windows XP. The Tukeystes' test (P = 0.05) was used to find significant differences among different treatments.

RESULTS

Grain yield of the main and ratoon crops

The actual grain yield of main crop varied between 6000 and 7000 kg ha^{-1}, and the ratoon was more than 4000 kg ha^{-1}; in the main crop, DS was lower in significant difference than ST and TP by 10.8 and 19.0%. D2 and D3 were higher than D1 by 0.6 and 12.2% in three sowing or transplanting dates. But there was no significant difference among three cultivations in the ratoon crop. D1 was higher than D2 and D3 by 0.8 and 0.9%. The yield of the total crops was more than 10000 kg ha^{-1}, and TP and ST were higher than DS by 10.0 and 0.6%.

Tillering ability of the ratoon crop

Tillers in stubble of TP were significantly more than ST and DS by 38 and 75% respectively (Table 2). Furthermore, the tillers in the 3rd, 4th, 5th stubble nodes and the total tillers of TP were significantly more than other cultivations. D1 and D2 were more than D3 by 50 and 42%. The 1st and 3rd stubble nodes were more than others in DS, while the 3rd and 4th were more in ST and TP.

Stubble dry matter and nitrogen translocation at pre-anthesis in the ratoon crop

Stubble dry matter translocation and efficiency of pre-anthesis in TP were significantly higher than ST and DS. There were no significant different among three sowing or transplanting dates; although the stubble dry matter of D2 was highest at both harvesting stage of the main crop and heading stage of the ratoon crop (Table 3). Stubble N translocation of pre-anthesis in ST was significantly higher than other cultivations. Although the

Table 2. Tillers in stubble nodes at stubble of the main crop.

Treatments	Tillers in stubble nodes (No. hill^{-1})					
	Total	First	Second	Third	Fourth	Fifth
DS1	15	3	1	3	5	2
DS2	13	4	3	3	2	2
DS3	9	0	1	3	3	1
ST1	19	3	2	4	7	4
ST2	18	3	3	4	6	2
ST3	10	0	1	3	4	2
TP1	23	2	3	6	7	5
TP2	23	3	5	6	6	3
TP3	19	0	1	5	8	5
Mean across of C						
DS	b	a	a	b	b	C
ST	b	a	a	b	a	B
TP	a	a	a	a	a	A
Mean across of D						
D1	a	a	a	a	a	A
D2	a	a	b	a	b	A
D3	b	b	b	a	b	A

Means in the same column followed by the same letter do not differ significantly according to the Tuckey's test (P = 0.05). DS is the mean of DS1, DS2 and DS3, ST is the mean of ST1, ST2 and ST3, TP is the mean of TP1, TP2 and TP3. D1 is the mean of DS1, ST1 and TP1, D2 is the mean of DS2, ST2 and TP2, D3 is the mean of DS3, ST3 and TP3.

Table 3. Stubble dry matter translocation of pre-anthesis (SDMTPA) and stubble dry matter translocation efficiency of pre-anthesis (SDMTEPA) in the ratoon crop.

Treatments	Stubble dry matter (kg ha^{-1})		DMT (kg ha^{-1})	DMTE (%)
	Harvesting stage of the main crop	Heading stage of the ratoon crop		
DS1	2499.00	1911.00	588.00	23.53
DS2	3021.00	2554.48	466.52	15.44
DS3	3225.00	2266.10	958.90	29.73
ST1	2075.40	1677.63	397.77	19.17
ST2	2410.20	1926.50	483.70	20.07
ST3	1913.40	1556.15	357.25	18.67
TP1	3618.00	2527.88	1090.12	30.13
TP2	4194.00	2959.67	1234.33	29.43
TP3	3288.60	2474.92	813.68	24.74
Mean across of C				
DS	b	b	b	b
ST	c	c	c	b
TP	a	a	a	a
Mean across of D				
D1	b	b	a	a
D2	a	a	a	a
D3	b	b	a	a

Means in the same column followed by the same letter do not differ significantly according to the Turkey's test (P = 0.05).

Table 4. Stubble N translocation of pre-anthesis (NT) and stubble N translocation efficiency of re-anthesis of pre-anthesis (SNTEPA) in the ratoon crop.

Treatments	Stubble N (kg ha^{-1})		NT (kg ha^{-1})	NTE (kg ha^{-1})
	Harvesting stage of the main crop	Heading stage of the ratoon crop		
DS1	38.22	24.52	13.70	35.85
DS2	43.88	27.93	15.95	36.35
DS3	54.90	31.47	23.43	42.67
ST1	26.17	17.08	9.09	34.73
ST2	35.92	22.62	13.30	37.04
ST3	25.76	15.81	9.96	38.65
TP1	48.47	28.80	19.68	40.59
TP2	61.28	39.92	21.36	34.85
TP3	44.16	28.21	15.96	36.13
Mean across of C				
DS	b	b	a	a
ST	c	c	b	a
TP	a	a	a	a
Mean across of D				
D1	c	b	a	a
D2	a	a	a	a
D3	b	b	a	a

Means in the same column followed by the same letter do not differ significantly according to the Turkey's test (P = 0.05).

stubble dry matter of TP was highest at both harvesting stage of the main crop and heading stage of the ratoon crop, there was no significant difference in the nitrogen using efficiency among the three sowing or transplanting dates. There was no difference in the three sowing or transplanting dates on stubble N translocation and efficiency of pre-anthesis although D2 was highest at both harvesting stage of the main crop and heading stage of the ratoon crop (Table 4).

DISCUSSION

The yield of the ratoon crop was more than 4000 kg ha^{-1} (Figure 1). It was lower significantly than the highest yield in Fujian province (Chen et al., 2007), but it was more than others, for example in the USA located along the Gulf Coast, the ratoon yield was about 3000 kg ha^{-1} (Harrell et al., 2009). The growth of the main crop was important and critical for the high yield of the ratoon crop. He et al. (2008) reported that it was necessary for high yield in main rice to foster big and erect leaf of canopy and keep the function of root and leaf in the late stage for improving population growth rate. Generally, the main factors leading to lower and variable grain yield under direct-seeding cultivation for rice are poor and uneven establishment, inadequate weed control and lodging susceptibility (Sanoh et al., 2004). In this study, the lower grain yield under directing-seeding cultivation might be attributed to more excessive tillers, more LAI and biomass and N accumulation. Therefore, it is important to control tillering and the population size for directing-seeding rice by using suitable varieties or reasonable water and fertilizer managements. Different sowing or transplanting dates had effect greatly on the growth and grain yield in the main crop. Tillering ability of the rice plant plays a major role in determining rice grain yield (Li et al., 2003). Tiller growth depend partially on species and cultivar, growing conditions and crop management such as radiation, temperature, soil water status, nutritional conditions and partially on varietal characteristics (Lafarge, 2000; Zhong et al., 2003). Death rate of axillary buds was very high before harvest of midseason rice especially at the 4th and 5th nodes from top (Xu, 2000).

The first and third stubble nodes were more prone than others in directing-seeding while the 3rd and 4th were more in ST and TP (Table 2), and the development of axillary buds in higher nodes was less. A similar result was reported by Chen (2000). The photosynthetic products and nutrient left in the rice stubbles had a great effect on the growth and development of the ratoon crop. Liu et al. (1993) reported that the photosynthetic products of the main crop after completion of heading were mostly transported to its panicles and the rest (27 and 51%) were

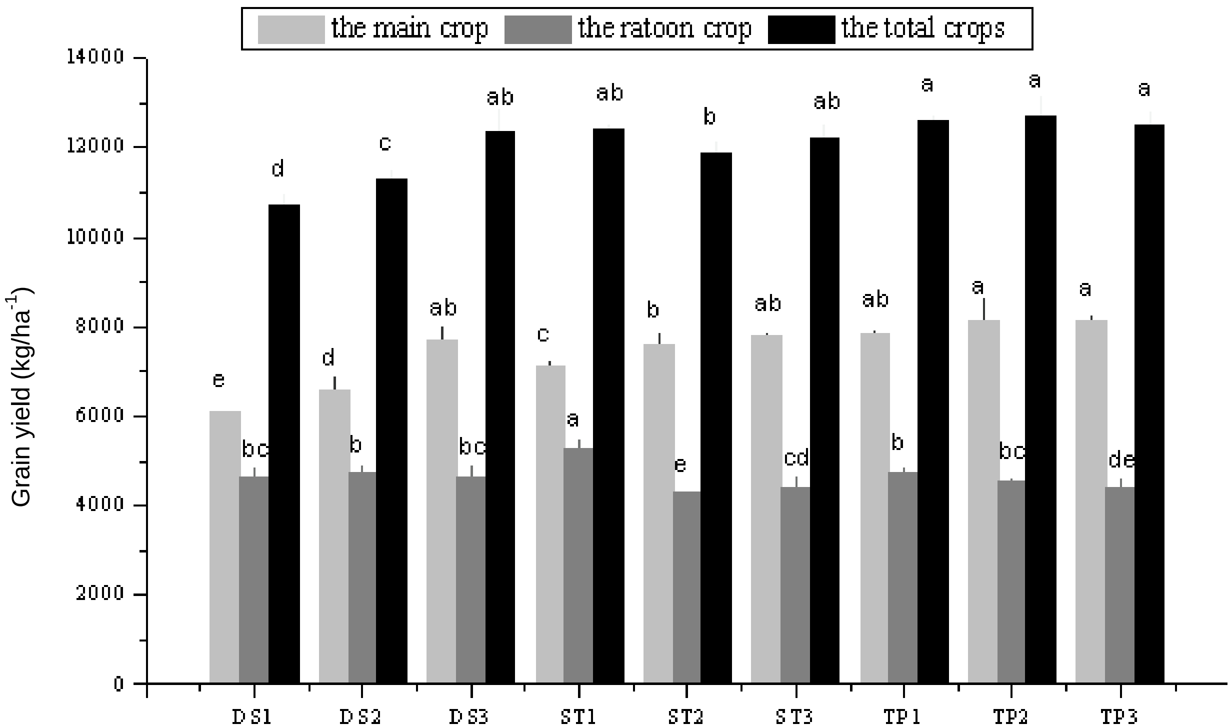

Figure 1. The difference of the grain yield between the main and ratoon crops. Means in the same column followed by the same letter do not differ significantly according to the Turkey's test (P = 0.05).

partitioned to its vegetative organs. Stubble dry matter translocation and efficiency of pre-anthesis in TP were significantly higher than ST and DS by about 20 and 30%, and assimilation dry matter stored in stubble was distributed in ratooning rice (Table 3). The photo-production was significantly enhanced in the main rice which would increase in the ratoon crop because the stubble of the main rice remained the larger share in the dry matter after harvesting and contributed to the increase of productive tillers and leaf areas (Jiang et al., 2004). The nitrogen source in the stubble of the main crop was gradually transported to the tillers of the ratoon crop after the main rice was harvested, it played a great role in bud sprouting and tiller growing.

The nitrogen transported from the stubble and the other parts including leaves and stem-sheath were the main nitrogen sources deposited in grains of the ratooning rice (Jiang et al., 2003); but in our results the stubble N translocation and efficiency at pre-anthesis in three cultivations was not different significantly. About 30 and 40% assimilated N stored in stubble was distributed in the ratooning rice (Table 4). The stubble dry matter translocation of D2 was better than others. This indicated that sowing or transplanting dates would affect tillering ability in stubble nodes and the stubble dry matter and N translocation among the ratooning growth and development, and suitable dates would improve the characters and develop higher yield of the ratoon crop.

Conclusions

The growth and development of the ratoon rice was normal and healthy in Jiangxi province in southeast China. The actual grain yield of the main crop varied between 6000 and 7000kg ha^{-1}. The total yield of DS was lower than others, but the yield of the ratoon crop was not different significantly. There were no significant differences among the three sowing or transplanting dates on the stubble dry matter and N translocation of pre-anthesis in the ratoon crop. The tillering ability and the stubble dry matter translocation of the ratoon crop were different significantly under different cultivations. The crops could get higher grain yield when the ratoon rice were planted during the period of late March to April in southeastern China. But the best suitable date will be determined and tested by more advanced experiments.

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