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Effect of Interplanting with Zero Tillage and Straw Manure on Rice Growth and Rice Quality

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Abstract: The interplanting with zero-tillage of rice, i.e. direct sowing rice 10-20 days before wheat harvesting, and remaining about 30-cm high stubble after cutting wheat or rice with no tillage, is a new cultivation technology in wheat-rice rotation system. To study the effects of interplanting with zero tillage and straw manure on rice growth and quality, an experiment was conducted in a wheat-rotation rotation system. Four treatments, i.e. ZIS (Zero-tillage, straw manure and rice interplanting), ZI (Zero-tillage, no straw manure and rice interplanting), PTS (Plowing tillage, straw manure and rice transplanting), and PT (Plowing tillage, no straw manure and rice transplanting), were used. ZIS reduced plant height, leaf area per plant and the biomass of rice plants, but the biomass accumulation of rice at the late stage was quicker than that under conventional transplanting cultivation. In the first year (2002), there was no significant difference in rice yield among the four treatments. However, rice yield decreased in interplanting with zero-tillage in the second year (2003). Compared with the transplanting treatments, the number of filled grains per panicle decreased but 1000-grain weight increased in interplanting with zero-tillage, which were the main factors resulting in higher yield. Interplanting with zero-tillage improved the milling and appearance qualities of rice. The rates of milled and head rice increased while chalky rice rate and chalkiness decreased in interplanting with zero-tillage. Zero-tillage and interplanting also affected rice nutritional and cooking qualities. In 2002, ZIS showed raised protein content, decreased amylose content, softer gel consistency, resulting in improved rice quality. In 2003, zero-tillage and interplanting decreased protein content and showed similar amylose content as compared with transplanting treatments. Moreover, protein content in PTS was obviously increased in comparison with the other three treatments. The rice in interplanting with zero-tillage treatments had higher peak viscosity and breakdown, lower setback, showing better rice taste quality. The straw manure had no significant effect on rice viscosity under interplanting with zero-tillage, but had the negative influence on the rice taste quality under transplanting with plowing tillage.
Key words: rice; conservation tillage; zero-tillage; interplanting; straw manure; yield components; rice quality; leaf area; biomass accumulation; root activity; milling and appearance quality; nutritional quality; RVA profile characteristics

Conservation tillage is an important practice for improving crop productivity and maintaining sustainability of agricultural system. As an important technology of conservation tillage, zero-tillage combined with straw manure has attracted the attention from researchers all over the world. This technique could ameliorate soil structure, enhance soil fertility, retain soil water, coordinate field temperature, restrain weeds, and so on, especially on upland crop [1-5]. It was reported that zero-tillage and organic manure usage had profound effects on crop yield, soil structure and fertility in the wheat-rice rotation system [6-7]. The interplanting with zero-tillage in wheat-rice rotation system refers to direct sowing rice 10-20 days before wheat harvesting, and remaining about 30-cm height stubble after cutting wheat or rice as straw manure. In general, zero-tillage saves both labors and inputs in seedling raising, transplanting, and plowing tillage for rice, and wheat straw manure could improve soil fertility and resolve the environmental problems resulting from wheat straw burning. Therefore, it was regarded as an important innovation in wheat-rice rotation system [8]. As the proceeding of experiments on interplanting with zero-tillage of rice, the method has been becoming integrated in practice [9-12]. However, the systematic study on this new practice is still lacking, and its effect on rice quality has not been reported yet. In order to provide technical reference for soil management and rice cultivation, an experiment with different cultivation methods combined with straw

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manure was carried out to analyze the effects of the zero-tillage and interplanting on rice growth and quality.

MATERIALS AND METHODS

Soil conditions

The experiment was carried out at the experimental farm of Yangzhou University, Yangzhou, Jiangsu Province, China. The type of soil is sandy loam. The contents of soil organic matter and total nitrogen were 14.7 and 0.97 g/kg, and the contents of available nitrogen, phosphorus and potassium of the soil were 87.9, 30.80 and 75.5 mg/kg, respectively.

Treatments

The experiment started at the autumn of 2001 in the fields with wheat-rice rotation system. Four treatments were as follows: ZIS (Zero-tillage, straw manure and rice interplanting), ZI (Zero-tillage, no straw manure and rice interplanting), PTS (Plowing tillage, straw manure and rice transplanting), PT (Plowing tillage, no straw manure and rice transplanting). The treatment was arranged in a randomized complete block design with three replications. The plot size was 50 m^2. For zero-tillage, 25-30 cm wheat stubble or 20-25 cm rice stubble was remained after harvesting. For straw manure, the wheat or rice was cut down with a harvesting machine, leaving the straw at a fragment length of about 10 cm in the fields. The seasonal straw returned to the fields was 4500 kg/ha for ZIS (including remained stubble and returned straw), 3000 kg/ha for ZI (only remained stubble), and 3000 kg/ha for PTS (only returned straw).

Plant materials and fertilizer managements

The rice variety used for the experiment was Huajing 3, and the preceding wheat variety was Yangmai 11. In the treatments of transplanting and interplanting, the seeds were both sown at the same time on May 15-17. For interplanting treatment, the seeding rate was 90 kg/ha. The emergence percentage of rice was 30%, and the actual plant density was 1.08×10^6 seedlings/ha in ZIS and ZI treatments. When wheat was harvested (about May 28-30), the rice had grown for about 14-15 days together with wheat. In PTS and PT treatments, the seedlings were transplanted to plots on June 10 or 11, with a row spacing of 25 cm ×13.3 cm, and two seedlings per hill. For each treatment, 750 kg/ha compound fertilizer was used as basal fertilizer (The mass fraction of N, P_2O_5 and K_2O were 15%), and 245 kg/ha urea as topdressing fertilizer. It meant that 225 kg/ha nitrogen were used in the whole rice growth period with a proportion of 6:4 between the early and the late periods.

Measure methods

The plant height and dry matter weight of rice were investigated at the stages of early tillering, late tillering, elongation and heading. Because of the shortage of water and fertilizer during rice seedling growth for interplanting treatments, the rice growth in ZIS and ZI treatments was delayed three days compared with transplanting treatments (PTS and PT) [9]. The plants were sampled on July 1, July 19, August 9 and September 6 for transplanting treatments, and on July 1, July 22, August 12 and September 9 for interplanting treatments. The amount of bleeding sap of rice root system was determined on 0, 14, 21 and 30 days after heading [13]. At the ripening stage, rice yield and quality were investigated, including brown rice rate, milled rice rate, head rice rate, chalky grain rate and chalkiness, according to *China National Standard GB/T17891-1999*. The contents of protein and amylose were determined by using a near-infrared grain analyzer (Infratee 1241) produced by FOSS TECATOR (Sweden). RVA profile characteristic values were tested using a Super 3 RVA produced by the Newport Scientific (Australia) and were analyzed with the software TWC.

RESULTS

Effects of different treatments on rice plant growth

The plant growth characteristics of rice were investigated in both 2002 and 2003. The rice plants showed similar trends in the main characteristics in the two years. Thus, the following analysis was conducted mainly with the data from 2002.

On rice plant height

As shown in Table 1, the rice plants in the interplanting with zero-tillage treatments were shorter than those in transplanting with plowing tillage treatments all through the growth period. This was attributed to that the interplanting rice was sown at the late growth stage of wheat, and the rice growth was restrained by the competition of wheat. As for the effect of straw manure, the rice plant height of ZIS was lower than ZI at the early stage, whereas the difference was not significant at the late stage; the difference in rice plant heights of PTS and PT were not significant at all the growth stages.

Table 1. Rice plant height (cm) under different treatments (2002).

Treatment	Growth stage of rice			
	Early tillering	Late tillering	Elongation	Heading
ZIS	27.94 c	40.28 c	64.75 b	99.35 b
ZI	32.45 b	46.41 b	67.09 b	99.83 b
PTS	44.06 a	55.69 a	80.89 a	108.48 a
PT	42.69 a	55.65 a	76.88 a	106.71 a

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

On the area of the top three leaves at the late growth stage of rice

The lengths and widths of the top three leaves were determined at the heading stage (Table 2). The results showed that comparing with PTS and PT treatments, the first and the second leaves from the top in ZIS and ZI treatments were shorter, especially the first leaf, whereas the third leaves from the top in ZIS and ZI were not different from those in PTS and PT in leaf length. However, the widths of the top three leaves in ZIS and ZI treatments were higher than those in PTS and PT treatments. The lengths of the leaves in the treatments with straw manure (ZIS or PTS) were similar to those in the treatments without straw manure (ZI or PT). Leaf area per stem was not significantly different among the treatments.

On biomass accumulation of rice

The results showed that zero-tillage and straw manure hampered the increment of biomass accumulation mostly before heading (Table 3). The biomass accumulations of ZIS and ZI were obviously lower than those of PTS and PT at early and late tillering stages. At the ripening stage, the differences in biomass accumulation were not significant among the treatments. As for the effect of straw manure, it was found that the biomass accumulation of PTS was lower than that of PT, and that of ZIS was lower than that of ZI, with significant difference only at the elongation stage.

The dry matter accumulations at different developmental stages (Table 4) showed that before heading dry matter of rice plant in the interplanting treatments increased slowly due to smaller seedlings at the early growth stage as compared with the

Table 2. The area of the top three leaves at the heading stage as affected by different treatments (2002).

Treatment	First leaf from the top (cm)		Second leaf from the top (cm)		Third leaf from the top (cm)		Leaf area per stem (cm^2)
	Length	Width	Length	Width	Length	Width	
ZIS	22.01 b	1.53 ab	30.98 b	1.32 a	33.83 a	1.26 a	82.04 a
ZI	23.02 b	1.56 a	32.61 b	1.34 a	32.24 ab	1.27 a	84.39 a
PTS	29.26 a	1.49 b	34.72 a	1.24 b	32.01 ab	1.16 b	86.65 a
PT	28.43 a	1.51 b	33.51 a	1.26 b	31.27 b	1.16 b	85.00 a

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

Table 3. Effect of different treatments on biomass accumulation (kg/ha) of rice plant (2002).

Treatment	Growth stage of rice				
	Early tillering	Late tillering	Elongation	Heading	Ripening
ZIS	157.5 b	1444.5 b	6880.5 b	12322.5 b	16942.5 a
ZI	217.5 b	1591.5 b	7420.5 a	12768.0 ab	17182.5 a
PTS	564.0 a	1965.0 a	6811.5 b	12699.0 ab	17013.0 a
PT	580.5 a	1989.0 a	7836.0 a	13510.5 a	17649.0 a

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

Table 4. Dry matter accumulation under different treatments at different developmental stages (2002).

Treatment	Sowing to early tillering		Early tillering to late tillering		Late tillering to elongation		Elongation to heading		Heading to ripening	
	DWI [a] (kg/ha)	DWID[b] (kg/ha • d)	DWI (kg/ha)	DWID (kg/ha • d)	DWI (kg/ha)	DWID (kg/ha • d)	DWI (kg/ha)	DWID (kg/ha • d)	DWI (kg/ha)	DWID (kg/ha • d)
ZIS	157.5 c	3.51 c	1285.5 c	61.23 c	5437.5 b	271.84 b	5442.0 c	201.56 c	4620.0 a	115.50 a
ZI	217.5 b	4.82 b	1375.5 b	65.46 b	5829.0 a	291.45 a	5347.5 c	198.06 c	4414.5 b	110.36 b
PTS	564.0 a	12.52 a	1401.0 a	77.83 a	4848.0 c	242.36 c	5887.5 a	218.06 a	4314.0 c	107.85 c
PT	580.5 a	12.88 a	1410.0 a	78.29 a	5847.0 a	292.35 a	5674.5 b	210.17 b	4138.5 d	103.46 d

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.
[a] DWI, Dry weight increased; [b] DWID, Dry weight increased per day.

transplanting treatments. The dry matter accumulation of PTS had a lower value during late tillering to elongation compared with other treatments, which was possibly connected with the paddy field drainage and straw degradation. The dry matter accumulations in straw manure treatments (ZIS or PTS) were faster than those in no straw manure treatments (ZI or PT) after the elongation stage. From heading to ripening, the tendency of dry matter accumulation in the four treatments was contrast to the total biomass accumulation. The dry weight in ZIS increased the fastest while that in PT did the slowest. Generally speaking, dry matter accumulations in zero-tillage treatments were faster than those in plowing tillage treatments, and dry matter accumulations were quicker in treatments with straw manure than those without straw manure or just with wheat stubble after heading.

Effects of different treatments on the amount of bleeding sap of rice root system

The bleeding sap of rice root system was weighed at 0, 14, 21 and 30 days after heading. As shown in Table 5, the bleeding saps of ZIS and ZI were significantly heavier than those of PTS and PT at 14, 21 and 30 days after heading. The PTS showed the lowest root activity in all the treatments. The bleeding sap amount and the activity of rice root decreased as the time passing after heading. The bleeding sap amounts in the interplanting treatments 21 days after heading were still higher than those in the transplanting treatments 14 days after heading. This suggested that the root activities of the interplanting treatments were higher at the late stage compared with the transplanting treatments.

Table 5. Effect of different treatments on amount of bleeding sap of rice root system (mg/plant·h).

Treatment	Days after heading			
	0 d	14 d	21 d	30 d
ZIS	85.38 a	84.3 a	74.1 a	44.54 b
ZI	87.95 a	88.5 a	77.0 a	57.97 a
PTS	80.55 a	53.3 b	35.0 c	22.64 d
PT	79.98 a	59.6 b	51.2 b	33.16 c

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

Effects of different treatments on rice yield and its components

The rice yield components under different treatments were shown in Table 6. The interplanting treatments had lower or similar number of panicles,

Table 6. Rice yield and its components in different treatments.

Year	Treatment	No. of panicles ($\times 10^4$/ha)	No. of filled grains per panicle	1000-grain weight(g)	Actual yield (kg/ha)
2002	ZIS	276.30 a	137.13 b	23.74 a	8995.5 a
	ZI	283.65 a	131.98 b	23.91 a	8584.5 a
	PTS	281.10 a	143.70 a	22.18 b	8739.0 a
	PT	279.55 a	144.74 a	22.06 b	8638.0 a
2003	ZIS	249.60 b	134.89 b	23.03 a	7659.0 b
	ZI	256.10 b	138.11 b	21.89 b	7728.0 b
	PTS	297.70 a	143.61 a	19.80 c	8334.0 a
	PT	280.15 a	144.21 a	20.38 c	7998.0 ab

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

Table 7. Effect of different treatments on milling and appearance qualities.

Year	Treatment	Brown rice rate (%)	Milled rice rate (%)	Head rice rate (%)	Chalky grain rate (%)	Chalkiness (%)
2002	ZIS	83.67 a	75.55 a	72.74 a	7.00 ab	0.47 b
	ZI	83.67 a	75.77 a	73.61 a	5.50 b	0.42 b
	PTS	83.20 a	74.96 ab	71.24 b	7.75 a	1.00 a
	PT	83.34 a	74.59 b	69.37 c	8.50 a	1.10 a
2003	ZIS	83.55 a	73.61 a	69.5 a	5.20 b	0.48 b
	ZI	83.79 a	73.62 a	69.2 a	5.60 b	0.46 b
	PTS	83.38 a	72.68 ab	68.5 b	7.00 ab	1.50 a
	PT	83.22 a	72.36 b	68.2 b	8.20 a	1.80 a

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

higher 1000-grain weight and lower number of filled grains per panicle than those of the transplanting treatments. In 2002, there was no significant difference in rice yield among the treatments. However, the yields of ZIS and ZI decreased in the following year (2003), being significantly lower than that of PTS. This suggested that interplanting could achieve higher yield in the first year, and straw manure could increase rice yield especially in the circumstances of continuous plowing and straw manure.

Effects of different treatments on rice quality

Zero-tillage and interplanting ameliorated rice milling and appearance quality (Table 7). The milled rice rate, head rice rate in ZIS and ZI treatments were all increased, and the chalky grain rate and chalkiness were decreased compared with those in PTS and PT treatments. There was no significant difference in brown rice rate among the treatments, whereas the differences of head rice rate and chalkiness between zero-tillage and plowing tillage were significant.

Zero-tillage and interplanting also affected rice nutritional and cooking qualities (Table 8). In 2002, ZIS showed raised protein content, decreased amylose content, softer gel consistency, resulting in improved rice quality. In 2003, zero-tillage and interplanting decreased protein content and showed similar amylose content as compared with transplanting treatments. Moreover, protein content in PTS was obviously higher than those in the other three treatments.

Table 8. Nutritional and cooking qualities of rice under different treatments.

Year	Treatment	Protein content (%)	Amylose content (%)	Gel consistency (mm)
2002	ZIS	7.68 a	18.24 b	75.5 a
	ZI	7.50 b	18.00 b	78.0 a
	PTS	7.43 bc	19.92 a	67.5 b
	PT	7.35 c	19.39 a	72.3 ab
2003	ZIS	8.50 b	16.97 a	71.0 a
	ZI	8.48 b	16.82 a	72.1 a
	PTS	8.90 a	16.25 a	66.0 b
	PT	8.53 b	16.18 a	69.2 ab

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

Effects of different treatments on rice RVA profile characteristic values

RVA characteristic values of rice are closely related with the taste quality [14-16]. The rice hardness is related with peak viscosity, breakdown, setback. Generally speaking, the higher the peak viscosity and breakdown, and the smaller the setback, the better the rice quality. This kind of cooked rice is soft and glutinous in the situation both of cold and hot. As shown in Table 9, the rice in interplanting with zero-tillage treatments had higher peak viscosity and

Table 9. Effect of different treatments on the RVA profile characteristic value (RVU) (2003).

Treatment	Peak viscosity	Hot viscosity	Breakdown	Cool viscosity	Setback	Consistence
ZIS	225.25 a	104.42 a	120.83 a	198.92 a	-26.33 ab	94.50 a
ZI	224.17 a	103.75 a	120.42 a	196.33 a	-27.83 a	92.58 ab
PTS	221.96 b	105.67 a	116.29 b	197.17 a	-24.79 b	91.50 b
PT	218.75 c	99.33 b	119.42 a	193.08 b	-25.67 b	93.75 ab

Within a column, data followed by the common letters indicate no significant difference at 0.05 level.

breakdown, lower setback, showing better rice taste quality. As for the effect of straw manure, RVA characteristic values in the two interplanting with zero-tillage treatments had no significant difference, but the values in the two transplanting with plowing tillage treatments existed difference, e.g. PTS had higher peak viscosity, hot viscosity and cool viscosity but lower breakdown than PT. This meant that straw manure had no significant effect on rice viscosity under interplanting with zero-tillage, but might have a negative effect on the rice taste quality under transplanting with plowing tillage.

DISCUSSION

Our study showed that the biomass accumulation of interplanting with zero-tillage treatment was lower than that of transplanting with plowing tillage treatment at the early stage, but the difference was not significant at the ripening stage. At the early stage, due to the shortage of water and sunlight for rice plants, the growing circumstance in the interplanting treatment was bad for rice seedlings, which hampered the growth and biomass accumulation of rice. In the straw manure treatments, both of interplaning with zero-tillage and transplanting with plowing tillage, the biomass accumulation was lower, especially at the elongation stage. This might be associated with the degradation of straw at the early stage, which had a competition against rice plant for nitrogen and then affected the tillering of rice and the growing of the root. This was also the reason for that straw manure could not improve rice yield in the current crop season. Therefore, zero-tillage and straw manure affected the biomass accumulation before the heading stage. As the time passing, straw manure could improve soil fertility, ameliorate soil structure, and enhance the efficiency of fertilizer, being beneficial to the improvement of rice yield in the following crop season.

The effects of climate, soil and cultivation on rice quality were frequently reported, but the effects of different cultivations and straw manure were less reported. This study showed that interplanting with zero-tillage and straw manure improved the rates of milled rice and head rice, and decreased the chalky grain rate and chalkiness, ameliorating rice milling and appearance quality. This might be attributed to the improvement of root activity, dry matter accumulation and grain filling. Xia et al [17] and Dai et al [18] noted that rice quality was also affected by soil eco-factors. Furthermore, zero-tillage and interplanting improved the contents of soil organic matter, total nitrogen, available phosphorus and available potassium [19]. In our experiment, biomass accumulations in PTS from elongation to ripening and in ZIS and ZI from heading to ripening were significantly higher than those in PT. It was reported that the amelioration of nutrition conditions and bioactivity could enhance the photosynthetic capacity of the population and accelerated the transportation of photosynthetic products to the panicles, and finally improved rice quality and yield [20]. PTS ameliorated soil characteristics, improved fertilizer efficiency and prolonged the function of the three top leaves, which enhanced the photosynthesis and transport ability at the grain filling stage. This was why PTS improved the head rice rate, slightly decreased the chalky grain rate and chalkiness as compared with PT. Furthermore, ZIS increased rice protein content and ameliorated the nutritional quality, which might be related with the nitrogen supplement of the soil, the absorption and transport of nitrogen in rice plant [21]. The previous study of fertilizer application showed that nitrogen affected rice quality significantly, for example, Jin et al [22] and Jin et al [23] reported that rice quality was negative related with nitrogen fertilizer, and Liu et al [24] found that the reduction of indigenous nitrogen supply of soil or using less nitrogen on the soil with high indigenous nitrogen profited rice quality. In this study, interplanting with zero-tillage treatments decreased rice amylose content, increased gel consistency and ameliorated rice cooking quality. Straw manure increased rice amylose content and decreased gel consistency, especially in the transplanting with plowing tillage treatments. The reason needed to be studied in the future research.

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