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Effects on Soil Fertility and Microbial Populations of Broadcast-Transplanting Rice Seedlings in High Standing-Stubble Under No-Tillage in Paddy Fields

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1. Introduction

No-tillage broadcast-transplanting of rice is a new cultivation technology developed in recent years (Xia, 2003; Liu et al., 2002). Our system involves no-tillage of rice paddies, which leaves high standing stubble, and raising seedlings on dryland beds. Then, we developed the technology of broadcast-transplanting seedlings in the field with high standing-stubble under no-tillage condition (Fig.1~4), which has several advantages such as lower fuel costs, savings in labour and time (yang et al., 2000; Liu, 2006; Ren et al., 2008). The first experiments of broadcast-transplanting of rice began in 1950s, reported by Peiris (1956) in Sri Lanka. In the 1980s, broadcast-transplanting of rice was successfully used in China (Zhang et al., 1993). From the middle and late 1990s, Guangdong province (Liu et al., 2002) and Guangxi province (Jiang et al., 2005) experimented with no-tillage broadcast-transplanting of rice under two rice crops and Sichuan province (Liu and Li, 2002) under single indica rice crop. Compared with conventional tillage broadcast-transplanting, the no-tillage broadcast-transplanting rice grew slower and had fewer tillers at the early stage (Liu et al., 2002), as well, root biomass and length were reduced during the seedling standing period (Jiang et al., 2005), but it brought to a higher spike-bearing rate and more grains.

Residue management is an important component of this new rice production system (broadcast-transplanting seedlings into high standing-stubble under no-tillage condition). In addition to the 20 to 50 cm of high stubble left upon harvest of the previous crops (wheat or rape) harvested, the farmer is encouraged to return the harvested stubble from previous crops to the field (yang et al., 2000; Ren et al., 2003). This practice increases the soil fertility: soil organic matter, total N and K, and available N and K concentrations were higher than those of conventional tillage paddy fields, either with conventional rice transplanting or broadcast-transplanting rice in one study (Ren et al., 2007). This promising result needs to be verified in other paddy fields, to determine the effects of broadcast-transplanting seedlings into no-tillage fields with high standing-stubble on soil fertility and microbial populations in paddy field. The objectives of this study were to clarify the influence of the new technology on soil fertility and microbial populations of paddy field, and to provide a scientific basis

and give some evidence in the introduction – what type of yields can be achieved with the broadcast-transplanting method in a no-tillage field?



Fig. 1. Field covered with high standing-stubble from the previous rape crop



Fig. 2. Broadcasting rice seedlings into high standing-stubble



Fig. 3. Early growth stage of rice seedlings



Fig. 4. Straw decay and soil surface conditions after rice harvest

2. Materials and methods

2.1 Plant material and condition

Ya' an experiment: The hybrid rice combinations Gangyou22, Ilyou162 and Kyou047 were the cultivars used in this study. The experiments were conducted in the paddy at Daxing town of Ya' an city, Sichuan province, China (lat. 29°59 N, long. 102°59 E) in 2003. The experiment was on a sandy-loam soil with the following chemical properties: organic matter 23.66 g kg⁻¹; total N 1.422 g kg⁻¹, alkali hydrolysable N 109.36 mg kg⁻¹; total P 0.458 g kg⁻¹, available P 12.01 mg kg⁻¹; total K 11.66 g kg⁻¹, available K 30.22 mg kg⁻¹. Previous crop was rape.

Pixian experiment: The hybrid rice combination Ilyou21 were used as plant materials in this study. The experiment was conducted in the paddy at Gucheng town of Chengdu city, Sichuan province, China (lat. 30°93 N, long. 103°91 E) in 2005. The experiment was on a fluvial loam sandy soil, and its chemical properties were as follows: organic matter, 18.73 g kg⁻¹; total N, 1.18 g kg⁻¹, alkali hydrolysable N, 78.26 mg kg⁻¹; total P 0.21 g kg⁻¹, available P, 43.53 mg kg⁻¹; total K, 22.73 g kg⁻¹, available K, 42.21 mg kg⁻¹. Previous crop was wheat.

2.2 Experimental treatment and cultivation management

Ya' an experiment: The experiment was laid out in a split plot design with tillage and cultivation methods in the main plots and hybrid combination in the sub-plots with three replicates. Plot area was 15.84 m². In the tillage and cultivation methods, there were three levels, including as conventional tillage and transplanting (CTT), conventional tillage and broadcast-transplanting of seedlings (CTB) and broadcast-transplanting of seedlings in the field with high standing-stubble under no-tillage condition (BSNT). The hybrid combination tested were Gangyou22, Ilyou162 and Kyou047. The seedlings of CTT were raised on wet land and seeded at a rate of 30 g m⁻²; those of CTB and BSNT were raised on plastic trays with 428 holes and each hole was seeded about 2 seeds. Seeds were sown on March 30, then transplanted on May 9. When previous rape was harvested, 50 cm of stubble was left in the

field. The soil was plowed and plugged after removing the rape stubble in tillage treatments; for no-tillage treatments, a herbicide was used 5 days after harvesting rape. Then paddies were irrigated to reach soil water saturation prior to broadcast-transplanting. Fertilizer inputs as a basal dressing were at the following rates: 90 kg P₂O₅ ha⁻¹ as superphosphate, 45 kg K₂O ha⁻¹ as KCl and 105 kg N ha⁻¹ as urea. Additional 45 kg N ha⁻¹ was broadcasted at the tillering stage and 45 kg K₂O ha⁻¹ at the booting stage. The transplanting density was 30×10⁴ hills ha⁻¹. Irrigation water was kept at 1-5 cm depth for 1 week following transplanting to aid in seedling establishment. Pests were controlled according to the standard recommendation and other rice management was similar as that in the paddy field (Ren et al., 2003).

Pixian experiment: The experiment was carried out in a randomized plot design with four treatments: No-tillage+Straw (NT+S), No-tillage (NT), Tillage+Straw (T+S) and Tillage (T). There were three replicates of each treatment, in plots of 30 m². Ridges were built between plots to avoid fertilizer and water movement to adjacent plots. The +S treatment involved returning straw to soil that was removed when the previous wheat crop was harvested (leaving 25 cm of stubble in the field). After rice seedlings were survived, the straw was returned and scattered evenly in the plots. Returned straw provided an organic residue input of about 5-6 t ha⁻¹. In the NT+S treatment, straw was left on the soil surface, but the T+S treatment involved cultivating and mixing straw with soil. For tillage treatments, we plowed and plugged the soil after removing the wheat stubble. In the no-tillage treatments, a herbicide was used 5 days after harvesting wheat. Then we irrigated the paddy until it reached soil water saturation prior to broadcast-transplanting. Seeds were sown on March 20, then transplanted on May 23. Fertilizer inputs as a basal dressing were at a rate of 75 kg P₂O₅ ha⁻¹ as superphosphate, 75 kg K₂O ha⁻¹ as KCl and 105 kg N ha⁻¹ as urea. Additional 30 kg N ha⁻¹ was broadcasted at the tillering stage and 75 kg K₂O ha⁻¹ and 15 kg N ha⁻¹ at the booting stage. The transplanting density was 25.5×10⁴ hills ha⁻¹. Irrigation water was kept at 1-5 cm depth for 1 week following transplanting to aid in seedling establishment. Pests were controlled according to the standard recommendation and other rice management was similar as that in the paddy field (Ren et al., 2003).

2.3 Soil and plant analysis

2.3.1 Soil fertility

Samples for nutrient measurement were sampled randomly with soil drill (25 mm in diameter). Five cores were taken after rice harvest from the 0-10 cm (upper layer) and 10-20 cm (deep layer) from each plot and pooled together. Large pieces of plant and animal residues, gravel, etc., were removed by sieving soil through a 2-mm mesh, mixing and a subsample was taken for analysis. Concentrations of soil organic matter, total N, P and K, alkali hydrolysable N, available P and K were tested by the methods described by Lu (2000).

2.3.2 Soil microorganism enumeration

Soil samples for microbiological assessment and cellulose decomposition intensity were collected from the Pixian experiment only at the tillering stage, elongation stage, booting stage

and maturity stage of rice from the 0-10 cm (upper layer) and 10-20 cm (deep layer) from each plot and pooled together. Samples were cooled with ice packs in the field immediately after collection, and were stored at 4°C for later analysis. Microbial communities were enumerated using the dilution plate method. Bacteria was isolated by BF medium, fungi was cultured by Martin agar medium and actinomyces were determined by modified Goss I medium (Department of Microbiology, 1985). Cellulose decomposition intensity was tested by the method of burying fabric into situ in the laboratory (Department of Microbiology, 1985).

2.3.3 Rice development and yield

Sixty (60) hill plants from each plot were investigated to study panicle development. Five (5) hills from each plot were harvested at maturity to estimate the yield components. The grain filling percentage was determined according to Zhu et al (1995). All plants from each plot were harvested at maturity for the determination of grain yield.

2.4 Statistical method

Statistical analyses were made by Office Excel 2003 and the SAS-Stat package (SAS Institute Inc. 1996). The Duncan test and least significant difference test at the 90% and 95% confidence levels were used to compare treatment means.

3. Results

3.1 Effects on soil fertility of tillage and residue management in a system with broadcast-transplanting of rice seedlings

Soil fertility was increased when rice seedlings were broadcast-transplanted among high standing-stubble under no-tillage condition (BSNT), as the organic matter, total N and K, and available N and K concentrations were higher than those of conventional tillage systems with conventional transplanting or broadcast-transplanting (Table1).

Treatment	Organic matter (g kg ⁻¹)	Total N (g kg ⁻¹)	Total P (g kg ⁻¹)	Total K (g kg ⁻¹)	Alkali hydrolysable N (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Available K (mg kg ⁻¹)
CTT	23.42	1.444	0.604	14.24	109.89	15.88	33.45
CTB	23.31	1.506	0.583	12.55	105.29	13.66	36.59
BSNT	30.04	2.375	0.524	15.18	131.72	14.25	61.93
Initial soil fertility	23.66	1.422	0.458	11.66	109.36	12.01	30.22

CTT: conventional tillage and conventional transplanting; CTB: conventional tillage and broadcast-transplanting of seedlings; BSNT : broadcast-transplanting of seedlings in the field with high standing-stubble under no-tillage condition.

Table 1. Effects of different tillage and transplanting methods on soil fertility (0-20 cm depth) in paddy field. The experiment was conducted near Ya' an city, Sichuan province, China in 2003.

As shown in Table 2, in the upper 0-10 cm soil layer, the organic matter content for 'no-tillage + returning straw' treatment was 5.33, 2.79 and 5.37 g kg⁻¹ higher than that for 'no-tillage', 'tillage + returning straw' and 'tillage' treatment, respectively. However, in the deep 10-20 cm layer, content of organic matter in 'tillage + returning straw' and 'tillage' treatments were higher than others. Since residues are mostly left on the surface in the no-tillage treatment, there organic matter accumulation was found in the surface soil, whereas a tilled soil had organic matter incorporated into the deeper soil layer. The maximum difference of two soil layers was noted for the 'no-tillage + returning straw' treatment, and there was little difference in soil organic matter in the 'no-tillage' treatment, and 'tillage' treatment without the extra straw residue input.

In upper soil layer, total and available N, P and K concentrations were greatest in the 'no-tillage + returning straw' treatment, those in the 'no-tillage' treatment and 'tillage + returning straw' treatment followed, and those in the 'tillage' treatment were the lowest. In the deep layer, the soil fertility indicators for 'tillage + returning straw' treatment were greater than those for other treatments. At the same time, the difference of nutrient status between two soil layers was the maximum for 'no-tillage + returning straw' treatment, therefore, the 'no-tillage + returning straw' treatment enriched soil fertility in the surface soil layer.

Soil layer	Treatment	Organic matter (g kg ⁻¹)	Total N (g kg ⁻¹)	Total P (g kg ⁻¹)	Total K (g kg ⁻¹)	Alkali		
						hydrolysable N (mg kg ⁻¹)	Available P (mg kg ⁻¹)	Available K (mg kg ⁻¹)
Upper layer	NT+S	30.02a	1.67a	0.260a	29.114a	120.250a	82.593a	81.063a
	NT	24.69b	1.62ab	0.255a	26.556a	113.436b	70.739b	71.095ab
	T+S	27.23ab	1.59b	0.254a	22.900b	110.966c	69.013bc	64.718ab
	T	24.65b	1.56b	0.244b	21.920c	101.778d	64.001c	60.497b
Deep layer	NT+S	20.69a	1.35b	0.223a	11.255b	85.162a	40.305a	48.983a
	NT	18.12b	1.34b	0.221a	10.241b	84.572a	40.622a	46.781a
	T+S	22.20a	1.42a	0.224a	18.784a	89.686a	42.890a	54.674a
	T	22.20a	1.40ab	0.226a	16.345a	87.918a	40.755a	51.640a

NT+S: No-tillage+Straw; NT: No-tillage; T+S: Tillage+Straw; T: Tillage. Values followed by different small letters meant significant difference at 0.05 level, respectively (LSD test).

Table 2. Effect of different tillage methods on soil fertility in paddy field with broadcast-transplanting of rice. The upper soil layer was 0-10 cm depth and the lower soil layer was 10-20 cm depth. The experiment was conducted at Pixian near Chengdu city, Sichuan province, China in 2005.

3.2 Effects on soil microorganisms of tillage and residue management in a system with broadcast-transplanting of rice seedlings

3.2.1 Bacterial numbers

The average numbers of soil bacteria under different treatments are given in Table 3. The results showed that soil bacterial numbers for 'returning straw to soil' treatments were

higher than that for 'no returning straw' treatments, and those in upper soil layer were higher than in deep layers too. In upper soil layer, the highest soil bacteria' numbers appeared in the 'no-tillage + returning straw' treatment at five growth stages, and the lowest bacteria' numbers were in the soil under 'tillage'. Bacterial numbers for 'no-tillage + returning straw' treatment were 15.86%, 14.0%, 2.53% and 40.44% higher than that for 'no-tillage', and 22.62%, 13.25%, 6.32% and 29.05% higher than that for 'tillage + returning straw' treatment at the tillering stage, elongation stage, booting stage and maturity stage of rice, respectively. In the deep soil layer, bacterial numbers appeared lower at tillering stage, and increased during elongation to booting stage, reaching a maximum value at rice booting and declined thereafter. In this soil layer, the highest bacterial numbers appeared in the 'tillage + returning straw' treatment, and the lowest bacteria' numbers were in the soil treated with 'tillage', too.

3.2.2 Fungal numbers

The data in Table 3 showed that fungal populations assessed by direct counting were lower than the other microbial groups. Fungal numbers increased during the rice growing season. Soil fungi were more abundant in the upper soil layer than in the deep layer, and greater in 'returning straw to soil' treatments than that for 'no returning straw' treatments. In the upper soil layer, fungal numbers were the highest in the 'no-tillage + returning straw' treatment, followed by the 'no-tillage' treatment, and the lowest fungal numbers were in the soil treated with 'tillage'. In deep soil layer, the order of fungal numbers in all treatments was 'tillage + returning straw' > 'no-tillage + returning straw' > 'no-tillage' > 'tillage'.

Soil layer	Treat- ment	Bacteria ($\times 10^3$ CFU \cdot g $^{-1}$)				Fungi ($\times 10^3$ CFU \cdot g $^{-1}$)				Actinomyce ($\times 10^3$ CFU \cdot g $^{-1}$)			
		Tille- ring	Elonga- tion	Booti- ng	Matu- rity	Tille- ring	Elonga- tion	Booti- ng	Matu- rity	Tilleri- ng	Elonga- tion	Booti- ng	Matu- rity
Upper layer	NT+S	168	171	202	191	2.6	2.89	5.16	6.23	130	108	155	189
	NT	145	150	197	136	1.6	2.64	4.35	5.29	135	90	120	134
	T+S	137	151	190	148	1.2	1.7	3.38	4.82	134	72	104	108
	T	85	103	157	94	0.8	1.44	2.56	4.45	104	44	96	97
Deep layer	NT+S	72	89	132	94	1	1.1	2.7	3.1	50	30	67	57
	NT	75	78	138	98	0.5	0.7	2.3	2.2	46	27	59	48
	T+S	83	99	143	100	1.1	1.5	2.9	3.9	64	41	77	66
	T	64	70	109	63	0.3	0.5	1.5	2.7	32	12	48	39

NT+S: No-tillage+Straw; NT: No-tillage; T+S: Tillage+Straw; T: Tillage.

Table 3. Effect of different tillage methods on soil microbial population in paddy field with broadcast-transplanting of rice. The upper soil layer was 0-10 cm depth and the lower soil layer was 10-20 cm depth. The experiment was conducted at Pixian near Chengdu city, Sichuan province, China in 2005.

3.2.3 Actinomycete numbers

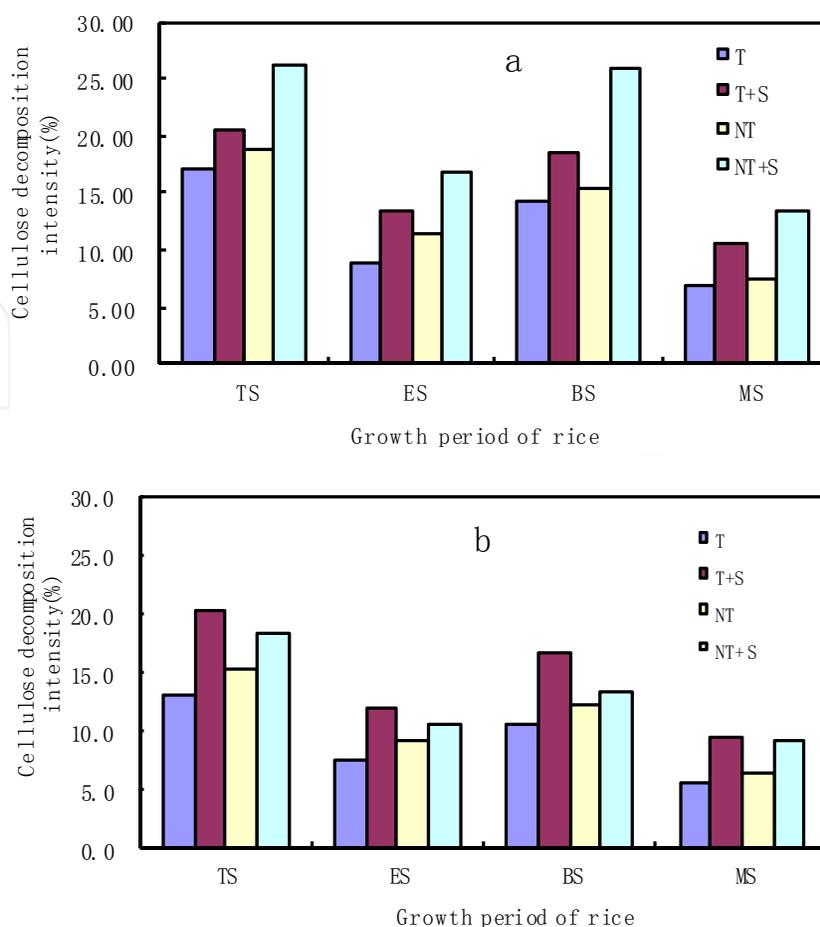
Actinomycete numbers are affected by gas permeability of soil because that this microbial group are facultative aerobes. The data in Table 3 showed that actinomycete numbers were the lowest at elongation stage, increasing thereafter and reaching a peak at booting stage (deep soil layer) or maturity stage (upper soil layer) of rice. In upper soil layer, 'no-tillage + returning straw' treatment appeared to possess aerobic microsites, therefore, it had the highest actinomycete numbers except at tillering stage. The lowest actinomycete numbers were in the 'tillage' treatment, presumably because conditions were not favorable for aerobic microorganisms, particularly in the deep soil layer, which had fewer actinomycetes than in the upper soil layer. In deep soil layer, actinomycetes abundance in four treatments followed the order 'tillage + returning straw' > 'no-tillage + returning straw' > 'no-tillage' > 'tillage'.

3.3 Effects on cellulose decomposition intensity of tillage and residue management in a system with broadcast-transplanting of rice seedlings

The cellulose decomposition intensity under as affected by residue management and tillage at the Pixian experiment was shown in Fig. 5. The highest cellulose decomposition intensity appeared at the tillering stage and booting stage during different growth periods of rice. At the same time, cellulose decomposition intensity in 'returning straw to soil' treatments were higher than 'no returning straw' treatments. In upper soil layer, cellulose decomposition intensity in 'no-tillage + returning straw' treatment was always higher than that in other treatments. At the tillering stage of rice, cellulose decomposition intensity in 'no-tillage + returning straw' treatment was 28.20%, 39.76% and 52.93% higher than that in 'tillage + returning straw', 'no-tillage' and 'tillage' treatment; furthermore, 25.51%, 46.27% and 91.62% higher at elongation stage of rice; 38.76%, 68.60% and 79.71% higher at booting stage of rice; and 26.44%, 79.01% and 98.15% higher at maturity stage of rice, respectively. There was little difference between 'no-tillage' and 'tillage' treatment. In the deeper soil layer, the highest cellulose decomposition intensity was the treatment of 'tillage + returning straw', probably due to incorporation of straw into the deep soil layer, which enhanced the activity of cellulose decomposing bacteria.

3.4 Correlation between soil microorganisms and soil fertility in paddy field with broadcast-transplanting of rice seedlings in no-tillage and conventional tillage plots

The relationship between soil microorganisms and soil fertility at the Pixian experiment was analyzed (Table 4). There were significant positive correlations between soil bacterial numbers and the soil organic matter, total N, total P, total K, alkali hydrolysable N and available P concentrations. In contrast, soil fungi numbers were not correlated with soil fertility indicators. There were significant positive correlations between soil actinomycete numbers and the soil organic matter, total N, total P, total K, alkali hydrolysable N, available P and K concentrations. The cellulose decomposition intensity was significantly and positively correlated with the soil fertility indicators, which indicated that high cellulose decomposition intensity was related to improved soil nutrient status.



TS: Tillering stage; ES: Elongation stage; BS: Booting stage; MS: Maturity stage. NT+S: No-tillage+Straw; NT: No-tillage; T+S: Tillage+Straw; T: Tillage.

Fig. 5. Effect of different tillage and residue management methods on cellulose decomposition intensity in paddy field with broadcast-transplanting of rice. Results are for (a) the upper soil layer, 0-10 cm depth and (b) the lower soil layer, 10-20 cm depth. The experiment was conducted at Pixian near Chengdu city, Sichuan province, China in 2005.

Factor	Total K	Total N	Total P	Available K	Alkali hydrolysable N	Available P	Organic matter
Bacteria	0.5858*	0.6447*	0.7107**	0.5253	0.6610*	0.5625*	0.7139**
Fungi	0.3956	-0.0925	0.5613	-0.6073	-0.4090	-0.5324	0.0360
Actinomycete	0.8217**	0.8310**	0.8393**	0.7307**	0.8404**	0.7552**	0.6110*
Cellulose decomposition intensity	0.6781*	0.7854**	0.8848**	0.8535**	0.8339**	0.8623**	0.8818**

All the data was used for correlation analysis.* $P < 0.05$; ** $P < 0.01$.

Table 4. Correlation (r values) between soil microorganisms and soil fertility in paddy field with broadcast-transplanting of rice seedlings in no-tillage and conventional tillage plots. The experiment was conducted at Pixian near Chengdu city, Sichuan province, China in 2005.

3.5 Effects on rice yield and its components in paddy field with contrasting tillage and transplanting methods, including broadcast-transplanting of rice seedlings

Analysis of variance showed that the main effect of yield by tillage and transplanting methods was significant at $P < 0.1$ ($F_A = 3.17$, $F_{0.05} = 3.63$, $P = 0.069$) and yield followed the order: CTT > BSNT > CTB (Table 1). There was no difference due to the hybrid grown ($F_B = 0.36$, $F_{0.05} = 3.63$) and interaction of the hybrid by tillage and transplanting method ($F_{A \times B} = 1.99$, $F_{0.05} = 3.01$) was not significant. Among three tillage and transplanting methods,

Treatment	Effective panicle (No. m ⁻²)	Spikelet (No. ear ⁻¹)	Seed-setting rate (%)	Filled grain percentage (%)	1 000-grain weight (g)	Yields (kg.m ⁻²)	
Gangyou22	175.2 b	167.6 a	87.69 a	77.67 a	26.31 a	0.683 a	
CTT	Ilyou162	189.0 b	179.4 a	77.23 b	73.71 a	26.65 a	0.689 a
	Kyou047	214.7 a	140.1 b	89.20 a	77.93 a	26.46 a	0.697 a
	Mean	193.0 ab	162.4 b	84.71 a	76.44 ab	26.47 a	0.690 a
Gangyou22	177.4 b	155.5 a	82.16 a	73.56 b	25.57 a	0.650 ab	
CTB	Ilyou162	184.6 b	172.4 a	72.90 b	72.20 b	25.49 a	0.596 b
	Kyou047	227.0 a	131.8 b	80.90 a	78.47 a	25.68 a	0.676 a
	Mean	196.3 a	153.2 b	78.65 b	74.74 b	25.58 b	0.641 b
Gangyou22	172.7 b	187.6 a	82.35 b	77.58 ab	26.77 a	0.676 a	
BSNT	Ilyou162	172.0 b	201.0 a	79.48 b	75.29 b	26.98 a	0.677 a
	Kyou047	205.5 a	141.1 b	87.12 a	80.57 a	26.60 a	0.628 a
	Mean	183.4 b	176.6 Aa	82.99 a	77.81 a	26.78 a	0.660 ab

CTT: conventional tillage and transplanting; CTB: conventional tillage and broadcasting seedlings; BSNT: broadcasting seedlings in the field with high standing-stubbles under no-tillage condition.

Table 5. Effect on rice yield and yield components of rice of different tillage and transplanting methods, and hybrid types, in a paddy field. The experiment was conducted near Ya' an city, Sichuan province, China in 2003.

effective panicles were affected as follows: CTB > CTT > BSNT, and there were significantly more effective panicles in CTB than in BSNT ($F_A = 4.06$, $F_{0.05} = 3.63$, $F_{0.01} = 6.23$). Under three tillage and transplanting methods, effective panicles of Kyou047 were the highest among three combinations. There were significant differences in the number of spikelets among different tillage and transplanting methods and between hybrids ($F_A = 12.30$, $F_B = 50.68$, $F_{0.01} = 6.23$), and BSNT had 8.74% and 15.27% more spikelets than CTT and CTB, respectively.

Among three combinations, Ilyou162 had the greatest number of spikelets, and Kyou047 had the fewest. CTB had the lowest seed-setting rate, at 6.06% and 4.34% less seed-setting rate than CTT and BSNT, and this was significant ($P<0.05$). Among three hybrids, Ilyou162 had the lowest seed-setting rate. BSNT had the highest percentage of filled grain, which was significantly ($P<0.05$) higher than that of CTB; filled grain percentage of Kyou047 was also significantly ($P<0.05$) higher than Gangyou22 and Ilyou162. The 1000-grain-weight values were ranked BSNT>CTT>CTB, and those of BSNT and CTT were 1.20 g and 0.89 g higher than CTB, but no significant difference due to or hybrid combinations was detected for 1000-grain-weight.

4. Discussion

Our results showed that the method of broadcast-transplanting seedlings in the field with high standing-stubble and extra straw residues under no-tillage condition ('no-tillage + returning straw' treatment) promoted soil microbial populations at the surface soil layer because it returned about 5-6 t ha⁻¹ of straw to soil. Larger soil microbial populations are attributed to a more favorable soil ecological environment, with good conditions of water, nutrients, gas exchange and heat, that were beneficial for soil microorganisms. Therefore, the populations of bacteria, fungi, actinomycetes and cellulose decomposition intensity in the upper soil layer (0-10 cm depth) of the 'no-tillage + returning straw' treatment were the highest among four tillage and residue management systems. However, the cultivation method of 'tillage + returning straw' had a highest soil microbial communities in deep soil layer because it incorporated the straw input into the deeper soil layer (10-20 cm depth) and promoted soil microbial growth and activity.

Soil quality is a concept that generally refers to the soil's ability to sustain productivity, environmental quality, human and animal health (Doran and Parkin, 1994). Therefore, analysis of soil quality should consist of a minimum data set that includes measures of soil physical, chemical, and biological properties (Papendick et al., 1994). Soil microorganisms are important for maintaining soil quality due to their role in decomposition of organic matter and nutrient cycling and storage, and potentially represent a very sensitive biological marker (Turco et al., 1994). Morris and Boerner (1999) suggested that the spatial distributions of soil microorganisms and the factors affecting them should be further investigated since both soil chemistry and vegetation are affected by soil microbial communities. Different tillage systems have significantly effect on soil microorganism (Gao et al., 2004; Balesdent et al., 1990; Wei et al., 1993). Ridge no-tillage was advantageous to improve soil ecological environment and soil fertility in paddy field (Fan and Liu, 2002).

The straw return significantly improved soil structure and increased soil nutrient concentration (Fan and Liu, 2002), and increased soil organic matter and available N, P, and K (Luo and Zhang, 1999), furthermore, the straw's cellulose, hemicelluloses, lignin and other components were decomposed slowly to release nutrients in the field with no-tillage condition, so there was a higher soil fertility later in the rice growth period. In the upper soil layer, the organic matter content for 'no-tillage + returning straw' treatment was 5.33, 2.79 and 5.37 g kg⁻¹ higher than that for 'no-tillage', 'tillage + returning straw' and 'tillage'

treatment, respectively. Also, the concentration of total and available N, P and K were greatest in the 'no-tillage + returning straw' treatment, followed by the 'no-tillage' treatment and 'tillage + returning straw' treatment, and the lowest concentrations were in the 'tillage' treatment. In the deep layer, the fertility indicators for 'tillage + returning straw' treatment were higher than those for other treatments. The populations of bacteria, actinomycetes and cellulose decomposition intensity were significantly and positively correlated with the soil fertility indicators, which indicated that soil bacteria and actinomycetes were especially important for improving soil nutrient availability. The method of broadcast-transplanting seedlings in the field with high standing-stubble under no-tillage condition increased soil nutrient concentrations and soil microbial communities, and delayed senescence of root and shoots in the later growth stage (Xiao et al., 2009), and prolonged the grain-filling time, therefore, the spikelets of per ear, seed-setting rate, and 1 000-grains weight were increased, in comparison with conventional tillage and broadcasting seedlings. The findings provide insight into the physiological and ecological mechanisms whereby stable and high yield of broadcast-transplanted rice can be achieved in paddy field with high standing-stubble under no-tillage condition.

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6. References

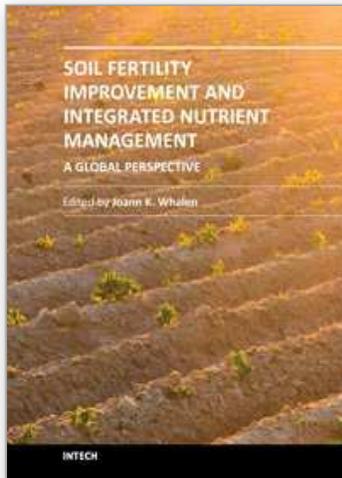
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