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NO-TILLAGE AND WIDE PLANT SPACING FOR HYBRID RICE PRODUCTION IN SOUTHWEST CHINA

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ABSTRACT

No-tillage and wide plant spacing (NTWP) is an effective rice production method for saving labour. In order to understand performance of hybrid rice under NTWP in Southwest China, a field experiment was conducted to compare different tillage (conventional tillage or no-tillage) and plant spacing (normal or wide) in 2010–2014. Grain yield, yield components and maximum tillers per m^2 were measured each year, and biomass production was determined in 2013-2014. A three-line hybrid rice, Chuangxiang9838 was grown in each cultivation method in 2010-2014. Grain yield of hybrid rice under NTWP and conventional tillage and normal plant spacing (CTNP) were equal. Compared with under CTNP, hybrid rice under NTWP was characterized by more spikelet number per panicle but less panicle number per m^2, lower biomass production but higher harvest index. The mean grain filling across years was slightly higher under NTWP than under CTNP. Lower maximum tillers per m^2 were partially responsible for difference in panicle number per m^2 between NTWP and CTNP, because there was no significant difference observed in panicle-bearing rate in them. Our study suggested that CTNP could be replaced with NTWP to save labour for hybrid rice production in Southwest China, while maintaining rice yield.

Key words: no-tillage, hybrid rice, grain yield, yield components.

INTRODUCTION

Rice is the staple food crop for about 65% of the population of China. Productivity of rice-based cropping system is critical to national food security. In the past ten years, rice yields have shown declining or stagnant trends in most rice production provinces of China (Fan et al., 2009), but a rice yield increase of more than 1.2% per year will be required in the next decade (Normile, 2008). In order to break rice yield stagnation, many new cultivars with great yield potential have developed through China's "super" hybrid rice breeding project.

Rice yield depends upon not only the genetic characteristics but also the agronomic practices (Zou et al., 2003). In China, conventional tillage is the most widely used method for land preparation of paddy fields. However, this method requires a large amount of labour (Bhushan et al., 2007), and increases water consumption and deteriorate chemical and physical properties of soil. Paradoxically, labour availability is limited in China owing to an increasing number of young farmer leaving for jobs in the cities, while leaving the older farmers behind (Derpsch and Friedrich, 2009). Therefore, the growing labour shortage is likely to adversely affect the productivity of rice in most rice production provinces of China. One way to reduce labour demand is no-tillage (NT) instead of the conventional tillage (CT). NT may be a good choice for paddy land preparation because it has potential benefits, including reduced production costs through savings in fuel, equipment and labour (Allmaras and Dowdy, 1985). Grain yield of hybrid rice under NT and CT were equal (Bhushan et al., 2007; Huang et al., 2012; Badshah et al., 2014). Biomass production before heading under CT was significant higher than under NT, while there was no significant difference in biomass at maturity between CT and NT (Huang et al., 2011). Another way to save labour is by

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greatly simplified crop management practices (Cai and Chen, 2000). For example, some farmers transplant rice at wide spacing to reduce labour (Peng et al., 2009). In addition, the climate during rice growing season is characterized by frequent fog and clouds, high humidity and insufficient sunlight in Sichuan province, Southwest China (Zhou, 1998). Under these climatic conditions, rice cultivars with heavy panicle generally were transplanted in wide spacing to alleviate the conflict between individuals and the whole population. Ma and Tao (1997) stated that grain yield of hybrid rice under wide plant spacing was 10% higher than that under normal plant spacing, and the optimum planted density ranged from 112,500 to 150,000 hills ha^{-1}. Some information is available about NT and wide plant spacing effects on grain yield and yield components of hybrid rice, but very little information is available describing the combined effect of NT and wide plant spacing on grain yield, yield components and biomass production of hybrid rice grown under all-time water-logged paddy field in Sichuan province, Southwest China.

Rice yield is determined by sink size (spikelets per m^2), grain filling and grain weight. Sink size is considered as the primary determinant of the rice yield (Kropff et al., 1994). Sink size can be increased by increasing panicle number per unit land or spikelet number per panicle or both (Ying et al., 1998). Tillering in rice is an important agronomic trait for panicle number per unit land as well as grain yield (Moldenhauer and Gibbons, 2003). Generally, higher panicle numbers per m^2 under high planting density are due to higher maximum tiller number per m^2 but not to higher panicle-bearing rate (Zhu et al., 2014). Higher panicle-bearing rate under NT than under CT was mainly due to lower tiller mortality under NT than CT (Badshah et al., 2014), while there was no significant difference in panicle number per m^2 between CT and NT (Huang et al., 2011). In another approach, rice yield is determined by biomass production and harvest index. Further improvement in rice yield might come from an increase in biomass production rather than in harvest index (Peng et al., 1999), because there was little scope to further increase the harvest index (Evans and Fischer, 1999).

In the present study, we compared grain yield and yield components, and biomass production by hybrid rice under no-tillage and normal plant spacing (NTNP), no-tillage and wide plant spacing (NTWP), conventional tillage and normal plant spacing (CTNP), and conventional tillage and wide plant spacing (CTWP). The objective of this study were (1) to determine yield performance of the hybrid rice under the NTWP in Southwest China and (2) to identify the critical factors that determine the grain yield of hybrid rice under the NTWP.

MATERIAL AND METHODS

A fixed experiment was conducted in Luxian county (29°10′ N, 105°23′ E, 280 m asl), Sichuan province, China during 2010-2014. The location has a subtropical zone humid climate with mean annual temperature of about 18.1°C, extreme high-temperature of about 38.2°C, extreme low-temperature of about 0.7°C, mean annual rainfall of 1179 mm and mean annual sunshine of about 950 hr. The soil properties of the experimental field was tidal clay with pH 5.24, 42.4 g organic C kg^{-1}, 1.68 g total N kg^{-1}, 0.46 g total P kg^{-1}, 16.0 g total K kg^{-1}, 124.0 mg available N kg^{-1}, 100.0 mg available P $kg^{-1}$and 138.0 mg available K kg^{-1}.

Chuanxiang9838, an indica-inclined three-line hybrid from the cross Chuanxiang29A × Fuhui838, was used in the experiment. The cultivar was developed by Sichuan Academy of Agricultural Sciences and released in 2004. This cultivar has been widely grown by rice farmers in Sichuan province because of its high yield and good quality. In each year, Chuanxiang9838 was grown under conventional tillage and normal plant spacing (26 cm × 20 cm, CTNP), no-tillage and normal plant spacing (26 cm × 20 cm, NTNP), conventional tillage and wide plant spacing (26 cm × 32 cm, CTWP) and no-tillage and wide plant spacing (26 cm × 32 cm, NTWP). Plots were arranged in a randomised complete block design with three replications using plot size of 20 m^2. Land preparation for the plots of conventional tillage was carried out by water buffalo ploughing followed by harrowing, and for the plots of no-tillage was soaking all round year.

In each year, pre-germinated seeds were sown in a seedbed in 5th third, and thirty-days-old seedlings were manually transplanted at two seedlings per hill on 4th April. Fertilizers use were urea for N, single superphosphate for P and potassium sulphate for K with doses of 120 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 75 kg K_2O ha^{-1}. N was split-applied: 90 kg ha^{-1} at basal, 30 kg ha^{-1} at 10 days after transplanting. P and K were applied as basal. Weeds, insects and disease were controlled as required to avoid yield loss.

In each growing season, yield components including number of spikelet per panicle, percentage of grain filling and grain weight were determined from five representative hills (except border plants) sampled from each plot at maturity. At maturity stage, 20 hills were counted in each plot to determine panicle number per m^2. At maximum tillering stage, 20 hills (except border plants) were selected and counted to determine the maximum tillers in each plot. Tillers with at least one visible leaf were counted. Panicle-bearing rate was calculated as the ratio of panicle number at maturity to maximum tiller number. In 2013-2014, five representative hills (except border plants) were sampled from each plot. Plant samples were separated into straw (including rachis), filled spikelets and unfilled spikelets. Dry weights of straw and filled and unfilled spikelets were determined after oven-drying at 70°C to constant weight. Biomass was the total dry matter of straw and filled and unfilled spikelets. Harvest index was calculated as the ratio of filled grain dry weight to aboveground biomass at maturity. Spikelet production efficiency was calculated as the ratio of spikelet number per m^2 to aboveground biomass at maturity. Grain yield was determined by harvesting the whole plot and adjusting to the standard moisture content of 140 g H_2O kg^{-1}.

Statistix 8 software package (Analytical software, Tallahassee, Florida, USA) was used for analysis of variance. Means of cultivation methods were subjected to the least significant difference test (LSD) at the 0.05 probability level.

RESULTS AND DISCUSSION

Table 1 shows grain yield of hybrid rice Chuanxiang9838. Grain yield in hybrid rice Chuanxiang9838 was 7.44-8.23 t ha^{-1} under CTNP, 7.09-8.44 t ha^{-1} under CTWP, 7.55-8.40 t ha^{-1} under NTNP, and 7.59-7.90 t ha^{-1} under NTWP during growing seasons of 2010-2014. On average, the difference in grain yield was not significant among the four cultivation methods. When averaged across five years, grain yields under CTNP, CTWP, NTNP and NTWP were 7.80, 7.70, 7.92 and 7.67 t ha^{-1}, respectively. This finding was consistent with other reports that no-tillage and transplanting (NTTP) had equal or higher grain yield than conventional tillage and transplanting (CTTP) (Feng et al., 2006; Dong et al., 2008; Feng et al., 2011).

Table 1. Grain yield (t ha^{-1}) of hybrid rice Chuanxiang9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Southwest China in 2010-2014

Cultivation method	Year					Mean*	LSD(0.05)**
	2010	2011	2012	2013	2014		
CTNP	7.44	8.15	7.46	8.23	7.71	7.80 a	0.69
CTWP	7.09	8.44	7.53	7.79	7.65	7.70 a	0.55
NTNP	7.63	8.40	7.55	8.33	7.68	7.92 a	0.62
NTWP	7.62	7.90	7.63	7.61	7.59	7.67 a	0.48

* Means of cultivation methods for each parameter with the same letters are not significantly different according to LSD at p=0.05.

** LSD values are for the comparison of years for each parameter under each cultivation method.

Panicle number per m^2 was significantly affected by cultivation method. When averaged across five years, panicle number per m^2 under CTNP was higher than under CTWP by 18.1% and that under NTNP were higher than under NTWP by 14.1%, while there were no significant differences observed between CTNP and NTNP as well as between CTWP and NTWP (Table 2). The mean spikelet number per panicle across years under CTNP and NTNP was significantly lower than that under CTWP and NTWP, while there were no significant differences observed between CTNP and NTNP, as well as between CTWP and NTWP.

Table 2. Yield components of hybrid rice Chuanxiang9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Southwest China in 2010-2014

Year	Panicles per m^2	Spikelets per panicle	Spikelets per m^2 ($\times 10^3$)	Grain filling (%)	Grain weight (mg)
CTNP					
2010	179	181	32.4	83.3	29.5
2011	198	199	39.4	71.2	29.0
2012	192	163	31.1	86.1	29.9
2013	201	170	34.2	89.4	29.6
2014	210	154	32.2	84.0	30.4
Mean*	196 a	173 b	33.9 a	82.8 a	29.7 a
LSD(0.05)**	26	24	6.6	4.6	0.5
CTWP					
2010	158	188	29.8	85.1	29.6
2011	168	208	34.9	78.6	28.9
2012	169	203	34.2	83.2	28.9
2013	163	188	30.7	91.8	29.6
2014	173	172	29.8	88.4	30.2
Mean	166 b	192 a	31.9 a	85.4 a	29.5 a
LSD(0.05)	18	11	2.8	3.9	1.1
NTNP					
2010	170	185	31.5	85.1	29.8
2011	197	197	38.7	73.7	28.7
2012	185	154	28.4	86.2	30.2
2013	185	174	32.0	89.5	30.0
2014	190	155	29.5	85.8	30.4
Mean	186 a	173 b	32.0 a	84.1 a	29.8 a
LSD(0.05)	21	15	2.6	2.3	1.3
NTWP					
2010	144	220	31.8	85.1	29.3
2011	166	206	34.1	77.5	29.0
2012	170	176	29.9	88.0	30.0
2013	163	182	29.7	91.2	29.9
2014	171	172	29.5	89.8	29.9
Mean	163 b	191 a	31.0 a	86.3 a	29.6 a
LSD (0.05)	20	12	4.0	1.8	1.3

*Means of cultivation methods for each parameter with the same letters are not significantly different according to LSD at p=0.05.
** LSD values are for the comparison of years for each parameter under each cultivation method.

These results indicated that wide plant spacing decreased panicle number per m^2 but increased spikelet number per panicle; while no-tillage did not have negative effects on the two yield components.

This finding was consistent with other reports that there was no significantly difference in panicle number per m^2 and spikelet number per panicle between NTTP and CTTP (Huang et al., 2004; Dong et al., 2008; Feng et al., 2011). In addition, the result also showed that there was a strong compensation between panicle number per m^2 and spikelet number per panicle, which was further supported by the significantly negative relationship between two yield components (Figure l). In cereal crops, the compensation among yield components is always arising (Simane et al., 1993; Ying et al., 1998; Zeng and Shannon, 2000; Huang et al., 2011; Huang et al., 2013), from either the physiological competition or developmental allometry (Grafius et al., 1976; Grafius, 1978).

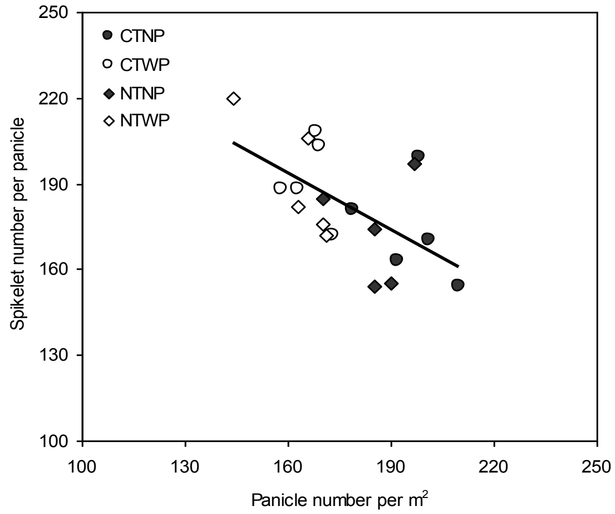

Figure 1. Relationship between spikelet number per panicle and panicle number per m^2 of hybrid rice Chuanxiangyou9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Luxian county, Sichuan province, China, in 2010-2014

In our present study, the compensation between the panicle number m^2 and spikelet number per panicle resulted in no significant difference in sink size (spikelets per m^2) among the four cultivation methods, and sink size was highly correlated with grain yield (Figure 2). In addition, the mean grain filling across years under NTNP was higher than under CTNP and that under NTWP was higher than under CTWP. This is in agreement with Feng et al. (2006), who reported that grain filling under no-tillage (NT) was equal or slightly higher than under conventional tillage (CT), since NT enhanced root properties.

At maturity, root weight, root length, root weight density and root length density in the 0-5 cm soil layer, specific root length in 5-10 cm and 10-20 cm soil layer under NT were higher than those under CT. Dong et al. (2008) stated that the better grain filling seen in NT rice than in CT rice was related to its higher root oxidizing ability during grain filling period and higher biomass production after heading and delayed leaf senescence. The difference in grain weight among the four cultivation methods was relatively small.

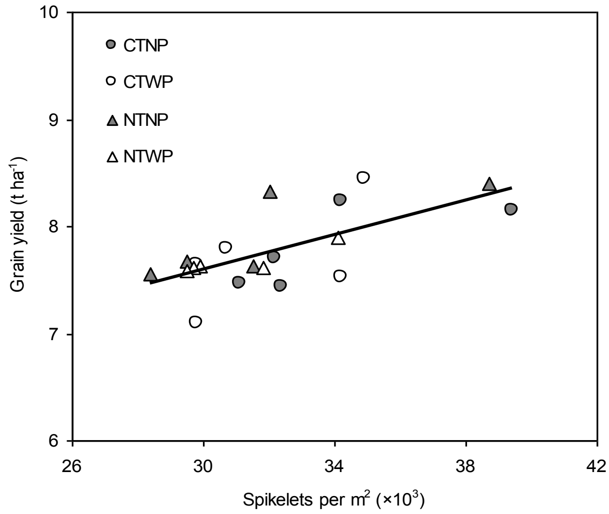

Figure 2. Relationship between grain yield and spikelet number per m^2 of hybrid rice Chuanxiang9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Luxian county, Sichuan province, China, in 2010-2014

Biomass production was significantly affected by cultivation method (Table 3). When averaged across two years, biomass production under CTNP was significantly higher than under CTWP by 9.6%, and that under NTNP was higher than under NTWP by 4.8%, while there were no significant differences observed between CTNP and NTNP, as well as between CTWP and NTWP. These indicated that no-tillage had less influence on biomass production at maturity. This is agreement with Huang et al. (2011), who reported that there was no significant difference in total biomass observed between NT and CT, while NT decreased biomass production before heading but increased biomass production after heading. On average, harvest index under CTWP and NTWP was significantly higher than CTNP and NTNP, while there were no significant differences observed between CTNP and NTNP, as well as between CTWP and NTWP. Rice yield increase can be achieved either by increasing the biomass production or harvest index or both. Peng et al. (1999) suggested that further improvement in the rice yield might come from an increase in biomass production rather than harvest index. However, in our present study, although CTNP and NTNP showed higher biomass production than CTWP and NTWP; lower harvest index under CTNP and NTNP, nullifying the advantage of biomass production under them, resulted in no significant differences observed in grain yield among the four cultivation methods.

Table 3. Biomass, harvest index and spikelet production efficiency per unit biomass (SPE) of hybrid rice Chuanxiang9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Southwest China in 2013-2014

Year	Biomass (g m^{-2})	Harvest index (%)	SPE (spikelets per g^{-1} biomass)
CTNP			
2013	1514	55.0	22.6
2014	1341	48.3	24.0
Mean*	1428 a	51.7 b	23.3 a
LSD (0.05) **	263	3.4	4.4
CTWP			
2013	1362	58.5	22.6
2014	1244	52.7	23.9
Mean	1303 b	55.6 a	23.3 a
LSD (0.05)	104	1.9	2.0
NTNP			
2013	1380	51.6	23.2
2014	1357	48.3	21.7
Mean	1369 ab	50.0 b	22.5 a
LSD (0.05)	88	1.0	3.2
NTWP			
2013	1376	57.4	21.5
2014	1235	54.5	23.9
Mean	1306 b	56.0 a	22.7 a
LSD (0.05)	210	1.7	3.5

* Means of cultivation methods for each parameter with the same letters are not significantly different according to LSD at p=0.05.

** LSD values are for the comparison of years for each parameter under each cultivation method.

Spikelet production efficiency has a large influence on sink size. Spikelet production efficiency in hybrid rice Chuanxiang9838 was 22.6 to 24.0 spikelets per g^{-1} biomass under CTNP, 22.6 to 23.9 spikelets per g^{-1} biomass under CTWP, 21.7 to 23.2 spikelets per g^{-1} biomass under NTNP, and 21.5 to 23.9 spikelets per g^{-1} biomass under NTWP during growing seasons in 2013-2014 (Table 3). On average, the difference in spikelet production efficiency was not significant among the four cultivation methods. When averaged across five years, spikelet production efficiency under CTNP, CTWP, NTNP and NTWP was 23.3, 23.3, 22.5 and 22.7 spikelets per g^{-1} biomass, respectively.

The maximum number of tillers per m^2 across five years under CTNP was significantly higher than under CTWP by 16.5% and that under NTNP was significantly higher than under NTWP by 24.1% (Table 4). There was no significant difference in panicle-bearing rate observed among the four cultivation methods. These revealed that the higher panicle number per m^2 of CTNP and NTNP were derived from the higher maximum number of tillers per m^2 rather than from a higher rate of panicle-bearing tiller. This finding suggested that selection of genotypes with strong tillering ability in the breeding program is an effective approach to achieve higher panicle number per m^2.

Table 4. Maximum tillers per m^2 and panicle-bearing rate (%) of hybrid rice Chuanxiang9838 grown under conventional tillage and normal plant spacing (CTNP), conventional tillage and wide plant spacing (CTWP), no-tillage and normal plant spacing (NTNP), and no-tillage and wide plant spacing (NTWP) in Southwest China in 2010-2014

Cultivation method	Year					Mean*	LSD(0.05)**
	2010	2011	2012	2013	2014		
Maximum tillers per m^2							
CTNP	255	267	249	256	389	283 a	18
CTWP	229	262	222	209	293	243 b	29
NTNP	248	280	259	272	359	283 a	38
NTWP	210	257	202	202	269	228 b	34
Panicle-bearing rate (%)							
CTNP	70.4	74.2	77.6	78.4	53.9	70.9 a	8.3
CTWP	68.9	64.3	75.9	77.9	59.3	69.3 a	6.1
NTNP	68.8	70.4	71.6	68.1	53.0	66.4 a	3.8
NTWP	68.9	64.7	84.3	81.1	63.7	72.6 a	5.5

* Means of cultivation methods for each parameter with the same letters are not significantly different according to LSD at p=0.05.
** LSD values are for the comparison of years for each parameter under each cultivation method.

CONCLUSIONS

Our study shows that grain yield of hybrid rice under no-tillage and wide plant spacing (NTWP) and conventional tillage and normal plant spacing (CTNP) were equal. Hybrid rice under NTWP had more spikelet number per panicle than CTNP, but there was less panicle number per m^2 under NTWP than under CTNP. Lower maximum tillers per m^2 were partially responsible for difference in panicle number per m^2 between NTWP and CTNP. Compare to CTNP, NTWP had lower biomass production but higher harvest index. The differences in grain filling and grain weight between NTWP and CTNP were relatively small.

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