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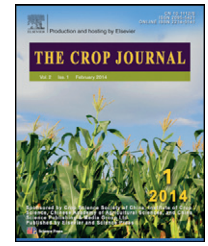

Yield and tillering response of super hybrid rice Liangyoupeijiu to tillage and establishment methods

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A B S T R A C T

Tillering is an important agronomic trait for rice grain production. To evaluate yield and tillering response, Liangyoupeijiu (super hybrid rice) was grown in Hunan, China during 2011–2012 under different methods of tillage (conventional and no-tillage system) and crop establishment methods (transplanting at a spacing of 20 cm × 20 cm with one seedling per hill and direct seeding at a seeding rate of 22.5 kg ha^{-1}). Our results revealed that, at maximum tillering (Max.) and at maturity (MA) stages, direct seeding (DS) resulted in 22% more tillers than transplanting (TP) irrespective of tillage system. Tiller mortality reached a peak between panicle initiation (PI) and booting (BT) stages, and was 16% higher under conventional tillage (CT) than under no-tillage (NT). Transplanting required 29% more time for the completion of tillering and less for DS. Tillering rate was 43% higher in DS than TP under either CT or NT. There was a positive correlation between panicle number per m^2 and maximum tiller number per m^2, but not panicle-bearing tiller rate. The panicle bearing tiller rate was higher under DS than TP and higher under NT than CT. Tiller dry weight gradually increased up to heading (HD) stage, and was 14% higher under TP than DS. Leaf area (cm^2 $tiller^{-1}$) gradually increased from Max. to HD stage and then decreased by 34% in conventional tillage transplanting (CTTP) and 45% in no-tillage transplanting (NTTP) from 12DAH–24DAH (days after heading), but was similar (35%) under DS under either CT or NT. Grain yield was higher under CTTP owing to the larger sink size (heavier panicle, more spikelets in per cm length of panicle) than under DS.

1. Introduction

Tillering in rice (*Oryza sativa* L.) is an important agronomic trait for panicle number per unit land area as well as grain production [1]. The panicle-bearing tiller rate influences the grain yield of rice [2] and excessive tillering leads to high tiller abortion, poor grain setting, small panicle size, and further reduction in grain yield [3,4]. For this reason excessive branching is often considered expensive [5], and formation of lowly productive tillers is considered an investment loss to the plant. Tillering

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Table 1 – Soil properties of the experimental field.

Treatment	Bulk density (g cm^{-3})	pH	Active organic carbon (mg g^{-1})	NaOH-N (mg kg^{-1})	Double acid P (mg kg^{-1})	Extractable K (mg kg^{-1})
0–5 cm soil depth						
CTTP	1.06	5.94	3.01	198	27.7	44.5
NTTP	1.07	5.83	3.45	197	27.1	46.1
NTDS	1.01	5.91	4.42	239	28.7	52.8
CTDS	1.04	5.81	4.02	227	29.1	52.0
6–10 cm soil depth						
CTTP	1.08	6.01	2.62	160	30.8	33.7
NTTP	1.26	5.91	2.90	160	28.3	33.3
NTDS	1.27	6.18	2.07	136	31.6	29.7
CTDS	1.06	5.99	2.11	133	33.0	30.9

CTTP: conventional tillage and transplanting; NTTP: no-tillage and transplanting; CTDS: conventional tillage and direct seeding; NTDS: no-tillage and direct seeding.

characteristics can be altered by changes in environment and agronomic practices [6] and should be considered in relation to light intensity, temperature and carbohydrate metabolism. Higher panicle numbers per m^2 of direct-seeded rice are due to higher maximum tiller number per m^2 but not to higher panicle-bearing tiller rate [7]. Tillage is considered to be the oldest and the most effective farm activity for developing a desired soil structure. Tillage improves the physical conditions of soil and favors the rooting characteristics of plants, leading to better rice yield. No-tillage was reported to lead to a reduction of rice tillering, effective panicle number, and filled kernels [8]. Grain yield under no-tillage was 13.4% lower than that under conventional tillage, and grain yields were in the order of conventional tillage (CT) > minimum tillage > no-tillage (NT) [9]. Some information is available about direct seeding and transplanting effects on tillering characteristics, but very little information is available describing the combined effect of tillage and crop establishment methods on tillering response in relation to grain yield. This study was accordingly undertaken to investigate the combined effect of tillage and crop establishment methods on tillering characteristics and their subsequent effect on grain yield of the super hybrid rice Liangyoupeijiu.

2. Materials and methods

2.1. Experimental location and soil

A field experiment was conducted in a moist sub-tropical monsoon climate during 2011–2012 (May to September). The soil properties of the experimental field are presented in Table 1.

2.2. Weather conditions during crop growing period

Average maximum and minimum temperatures were similar under TP and DS in both years from SW to PI and from HD to MA but were highest at Mid.–Max. during 2012. Average sunshine hour was highest at Mid.–Max. during 2012 in TP

Table 2 – Weather data during crop growing period, Changsha, Hunan, China.

Growth stage	Maximum temp. (°C)		Minimum temp. (°C)		Rainfall (mm)		Sunshine hour (h)	
	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting (TP)								
SW–Mid.	29.02	28.96	21.34	22.26	6.63	7.38	5.67	4.54
Mid.–Max.	33.28	35.64	25.59	27.85	6.96	2.92	7.70	10.65
Max.–PI	32.86	32.51	25.35	26.24	0.70	14.61	6.90	4.72
PI–BT	34.40	31.15	26.87	30.94	1.19	2.20	7.20	9.19
BT–HD	36.03	33.84	27.40	26.44	0.02	1.51	9.96	6.47
HD–12DAH	30.73	30.09	23.97	26.01	1.73	1.18	6.76	7.05
12DAH–MA	27.61	29.03	20.91	20.47	1.07	3.50	3.94	5.89
Direct seeding (DS)								
SW–Mid.	29.48	29.79	22.33	23.09	9.05	5.19	4.69	4.62
Mid.–Max.	33.79	34.33	26.29	26.79	6.81	3.39	9.07	8.92
Max.–PI	31.50	33.86	24.48	27.39	3.74	14.24	5.09	6.98
PI–BT	34.84	32.38	27.07	29.53	0.42	1.60	8.28	9.10
BT–HD	34.85	34.22	26.72	26.86	1.34	2.77	8.78	7.49
HD–12DAH	31.48	31.77	24.28	24.09	1.08	1.13	7.19	6.74
12DAH–MA	28.18	29.43	21.39	20.93	1.22	3.21	4.23	5.84

SW: sowing; Mid.: mid tillering; Max.: maximum tillering; PI: panicle initiation; BT: booting; HD: heading; DAH: days after heading; MA: maturity.

but similar in DS in both years. Average rainfall was higher in 2012 than in 2011 under both TP and DS (Table 2).

2.3. *Experiment design and fertilizer management*

The field experiment was conducted in a factorial randomized complete block design with four replications. The unit plot size was 30 m^2. Factor A was tillage system, with levels being conventional tillage (CT) and no-tillage (NT), and factor B was crop establishment method, with levels being transplanting (TP) and direct seeding (DS). The treatment combinations were conventional tillage and transplanting (CTTP), no-tillage and transplanting (NTTP), conventional tillage and direct seeding (CTDS), and no-tillage and direct seeding (NTDS). For CT, land was prepared by animal-drawn plowing followed by harrowing, and for the plots of NT, by using a non-selective herbicide and flooding. For TP, twenty five-day old seedlings were manually transplanted at a spacing of 20 cm × 20 cm with one seedling per hill on June 8th. For DS, pre-germinated seeds were manually broadcasted on the soil surface at a seeding rate of 22.5 kg ha^{-1} on May 24th. Fertilizer (per ha) was applied as 150 kg N, 90 kg P_2O_5 and 180 kg K_2O. Fertilizer N was spit as 90, 45 and 15 kg ha^{-1} at basal, mid-tillering and panicle initiation stages, respectively. Fertilizer P_2O_5 was applied at basal stage. K_2O was split equally at basal and panicle initiation (PI) stages. Weeds, insects and diseases were controlled by recommended methods.

2.4. *Sampling*

Plants of 0.48 m^2 area (60 cm × 40 cm iron frame) from two different locations in DS plot and twelve hills for TP of each unit plot (2 × 2 hills from three locations) were selected and marked for tiller counting. Counting was performed at mid-tillering (Mid.), maximum tillering (Max.), panicle initiation (PI), booting (BT), heading (HD) and maturity (MA) stages. Plant samples were separated into stem (the vegetative parts including leaf blades, culm plus sheath and dead tissues), panicles (at BT, HD, 12DAH and MA stages) and spikelets (at maturity stage). The vegetative plant parts were oven-dried at 70 °C to constant weight and then weighed to calculate the stem dry weight of the respective stage. Panicle number was counted from the 12 hills and 0.48 m^2 sampled area at maturity stage. At MA, a 5 m^2 area was harvested for grain yield and the grain was adjusted to a 14% moisture level.

2.5. *Measurements and methods*

Tillering duration (TD) was calculated from sowing to the date of maximum tiller number. Tillering rate (TR) = the maximum number tillers / TD. Panicle bearing tiller rate (PBTR) = (number of panicles per m^2 / number of maximum tillers per m^2) × 100. Tiller mortality at different growth stages = (TL_1 − TL_2) / TL_1 × 100, where TL_1 is the total tiller number at time T_1, and TL_2 is the total tiller number at time T_2.

Mid. is defined as the midpoint between TP and PI. The PI stage was determined by dissecting five main stems starting from 40 DAT. BT was measured at 20 days after PI. HD was taken as the time when 80% of stems had more than 50% of panicle exerted. The crop reached maturity when 90% of the spikelets turned from green to yellow. Canopy height was measured from the soil surface to the top level of the canopy at every growth stages.

2.6. *Data analysis*

Statistical analyses were performed using Statistix 9, analytical software, Tallahassee, FL, USA. Means of cultivation methods were compared according to the least significant difference (LSD) test at the 0.05 probability level. Figures were constructed using Microsoft Excel 2003.

Although the results were higher in 2012, all parameters showed similar trends among treatments in both years. For this reason, analyses were performed using the combined results of the two years.

3. Results

3.1. *Canopy height dynamics*

Canopy height (cm) varied significantly among the treatments at all crop growth stages except BT. Canopy height increased with time from Mid. to HD stage. At every sampling date, TP rice had higher canopy height than DS rice. At HD, the highest canopy height (127.1 cm) was found under the CTTP

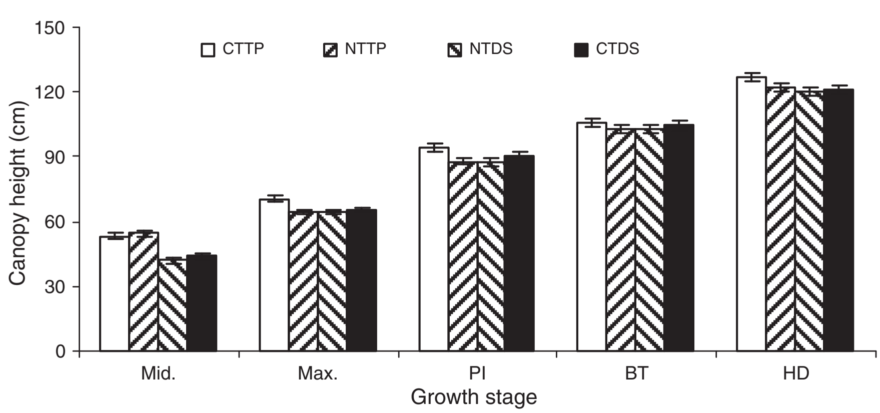

Fig. 1 – Canopy height dynamics at different growth stage, bar represents SE.

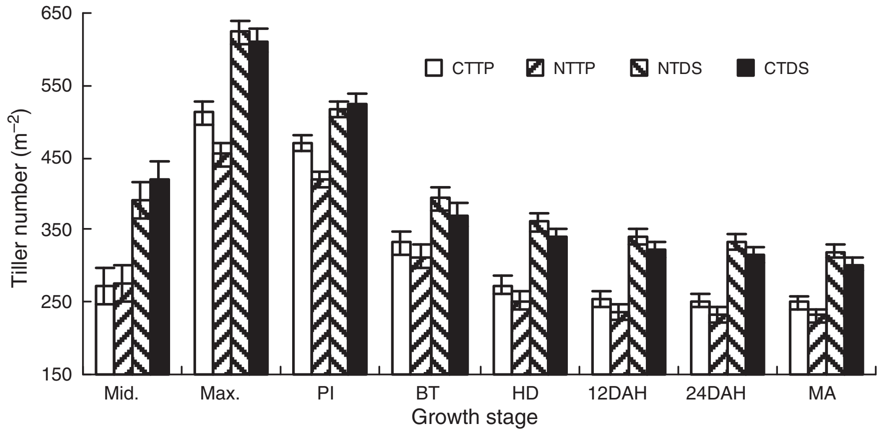

Fig. 2 – Tillering pattern at different growth stage, bar represents SE.

treatment and NTTP, CTDS and NTDS resulted in lower and statistically identical canopy heights (Fig. 1).

3.2. *Tillering pattern*

Tiller number varied significantly among the treatments at all crop growth stages. Tiller number under DS was always higher than under TP irrespective of tillage system at all growth stages and was higher under CTTP than under NTTP except at the Mid. stage. At Max. stage, CTTP showed a significantly higher tiller number (512 per m^2) than NTTP (454 per m^2) but both NTDS and CTDS showed statistically identical tiller numbers (624 and 612 per m^2 respectively). NTTP showed the lowest tiller number among the treatments (Fig. 2).

3.3. *Tiller mortality pattern*

Tiller mortality varied significantly among the treatments at all growth stages except PI–BT, HD, 12DAH and Max.–MA. Tiller mortality began at PI, reached a peak in the PI–BT stage, and then gradually decreased with time until maturity. At the Max.–PI stage, DS rice showed higher tiller mortality than TP rice but lower at BT–HD and HD–12DAH under either CT or NT. At PI–BT, higher tiller mortality was observed for CTTP (29.1%) and CTDS (29.4%) and NTDS showed lower tiller mortality than NTTP but with no significant difference. At the Max.–MA stage, the difference in tiller mortality between DS and TP was the smallest (Fig. 3).

3.4. *Tillering duration and tillering rate*

Both tillering duration (TD) and tillering rate (TR) varied significantly among the treatments. The TD was longer under TP than DS but TR was higher under DS than TP in either CT or NT. TD was longer in CTTP (59 days) followed by NTTP and lower duration was observed for NTDS and CTDS methods. NTDS had higher TR (15.3 m^{-2} day^{-1}) followed by CTDS. There was no significant difference in TR between CTTP and NTTP (8.8 and 8.0 m^{-2} day^{-1}) respectively (Fig. 4).

3.5. *Relationship of maximum tiller number with panicle number and bearing tiller rate (PBTR)*

There was a significant correlation between panicle number per m^2 and maximum tiller number per m^2, but not between maximum tiller number and panicle-bearing tiller rate (Fig. 5).

3.6. *Dry weight of tiller*

The dry weight of the vegetative part of tillers varied significantly among the treatments at all crop growth stages. The tiller dry weight gradually increased until HD and decreased at

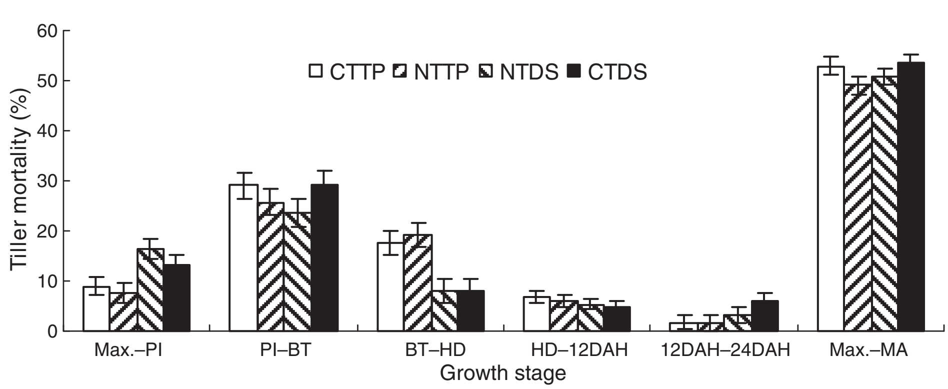

Fig. 3 – Tiller mortality (%) at different growth stage, bar represents SE.

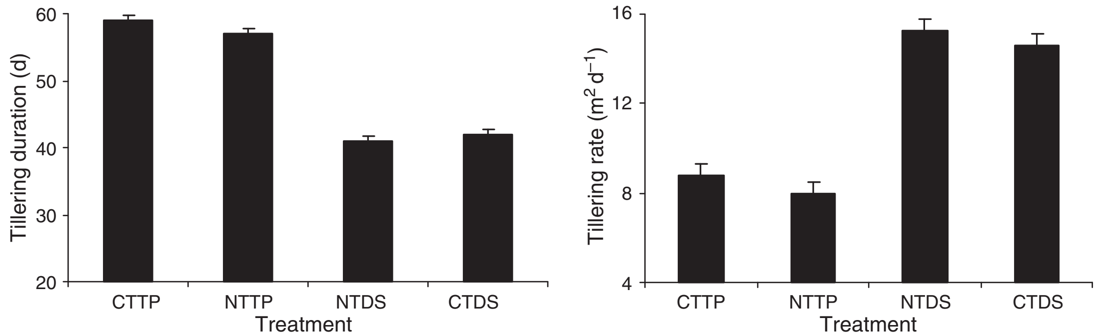

Fig. 4 – Effect of treatments on tillering duration and tillering rate, bar represents SE.

the MA stage. TP under either CT or NT had higher tiller dry weight than DS except at the tillering stage. NTTP had higher tiller dry weight than CTTP at all growth stages except the tillering and MA stages. However, CTDS produced higher tiller dry weight than NTDS at all growth stages except the tillering and HD stages. Tiller dry weight was higher at the HD stage in all treatments and NTTP had higher (4.3 g) tiller dry weight which was statistically not different from that of CTTP. Also there was no significant difference in tiller dry weight between NTDS and CTDS at the HD stage (Fig. 6).

3.7. *Leaf area per tiller*

Leaf area (cm^2 $tiller^{-1}$) varied significantly among the treatments at all growth stages of the crop. There were significant differences among establishment methods on all sampling dates. Leaf area increased sharply from the Max. to the BT stage, then slightly increased at the HD stage, and then gradually decreased with time. Leaf area per tiller was always higher under TP than DS at all growth stages. CTTP always had higher leaf area than NTTP, and CTDS than NTDS (Fig. 7).

3.8. *Spikelet per cm panicle, panicle dry weight, bearing tiller rate (PBTR) and grain yield*

Number of spikelet per cm of panicle varied significantly among the treatments. CTTP and NTTP had significantly higher numbers of spikelet per cm of panicle than CTDS and NTDS. Panicle dry weight at maturity varied significantly among the treatments. Panicle dry weight under TP was higher than that under DS under either CT or NT. CTTP had heavier panicles (4.3 g) than NTTP. NTDS and CTDS were similar in panicle dry weight. The TP method resulted in 12% longer and heavier panicles than DS. The panicle bearing tiller rate (PBTR) varied significantly among treatments and was higher under DS than under TP and higher under NT than under CT for either TP or DS. PBTR was higher in NTDS (53.2%) which was statistically identical to NTTP and was lowest in CTTP. Grain yield differences were significant among the treatments. CTTP method produced the highest grain yield (9.54 t ha^{-1}) among the treatments and the remaining treatments produced identical grain yield (Table 3).

4. Discussion

Canopy height is influenced by plant population density, and was always higher under TP at all growth stages. At HD, TP had the highest canopy height in both years owing to higher maximum and minimum temperatures and more sunshine hours at the BT–HD stage (Table 2). Canopy height was lower under DS on all sampling dates owing to lower maximum and minimum temperatures and sunshine hours at the BT–HD stage than under TP (Table 2) as well as a crowding effect (Ali [10]). At Max. and MA stages, DS showed 22% more tillers than TP irrespective of tillage system owing to a higher number of

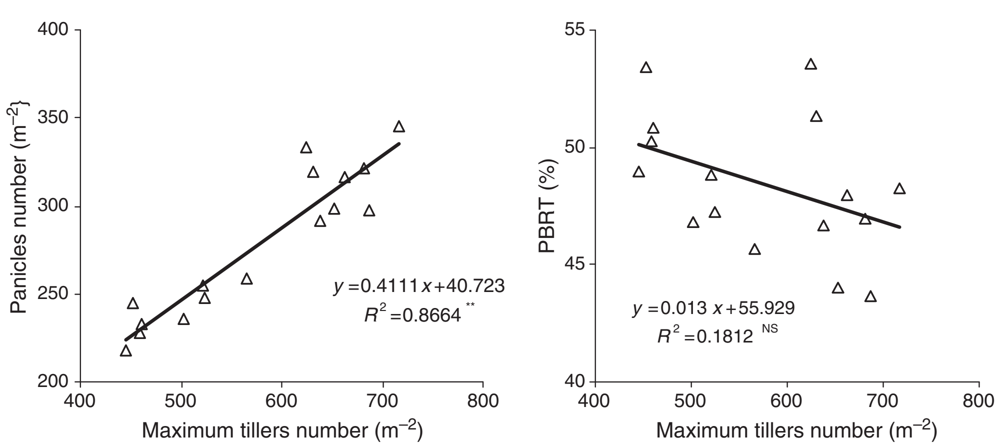

Fig. 5 – Relationship between maximum tiller number with panicles and panicle bearing tiller rate.

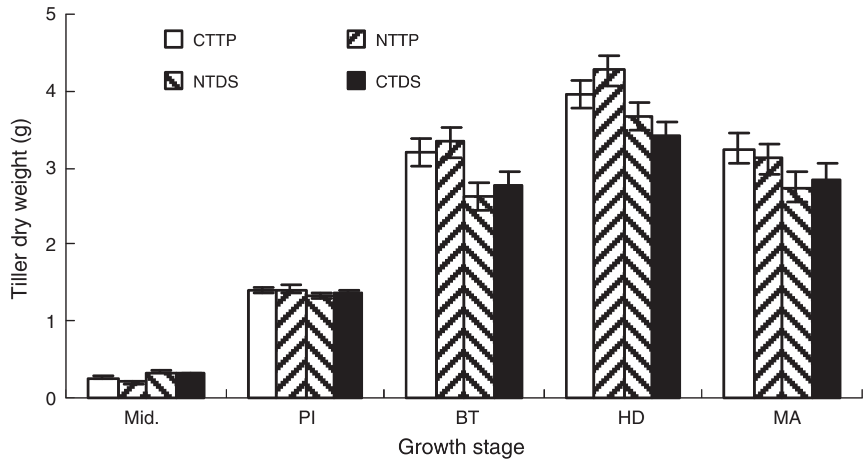

Fig. 6 – Tiller dry weight (vegetative part), bar represents SE.

plants per unit land area. At early growth stage of rice, NTTP had higher number of tillers than CTTP. Thereafter, tiller number was always higher in CTTP than NTTP owing to deeper root penetration and uptake of more nutrients. Huang et al., [7] reported that NT leads to root accumulation on the surface of soil layer under both TP and DS conditions. Tiller mortality reached a peak in the PI–BT stages, was 16% higher in CT than NT, and then gradually decreased with time up to 24DAH. Treatment differences were reduced because of tiller abortion, intra-plant competition and partial lodging, under DS. Excessive tillering leads to high tiller abortion, poor grain setting, small panicle size, and further reduced grain yield [3,4]. At Max. to MA stage, difference of tiller mortality between DS and TP was smaller (<3%). Transplanting required 29% more time for the completion of tillering and a lower time was required for DS owing to early sowing in seed bed as well as elimination of transplanting shock. Tillering rate was 43% higher under DS under either CT or NT owing to a higher number of plants per unit land area. Maximum tiller number made the largest contribution to panicle number. There was no significant correlation between maximum tiller number and bearing tiller rate, indicating that the higher the tiller number, the higher the senescence. Our study showed that maximum tiller number (per m^2) was lower in TP and that panicle number per m^2 was positively related to maximum tiller number per m^2, but not to panicle-bearing tiller rate. This result supports the findings of Huang et al. [7], but excessive tillering leads to high tiller abortion, poor grain setting, small panicle size, and further reduced grain yield [3,4]. The tiller dry weight gradually increased up to the HD stage and then decreased at the MA stage owing to translocation of dry matter from vegetative organs to sinks. Transplanting under either CT or NT resulted in higher tiller dry weight than did DS at all growth stages owing to lower inter-plant competition for light, space and nutrients but total above ground biomass was higher under DS than under TP owing to a higher number of tillers per unit land area. Badshah et al. [11] reported that, DS produced more above ground biomass than TP but that at maturity, both CTTP and NTDS had higher above ground biomass and NTTP was the lowest. Leaf area per tiller varied significantly among the treatments at all growth stages of the crop. It also varied significantly among the establishment methods at all sampling dates owing to high population density under DS resulting in increased mutual shading of plants [12] and a consequent acceleration in leaf senescence [13]. Leaf area gradually increased from Max. to HD stage and then decreased by 34% in

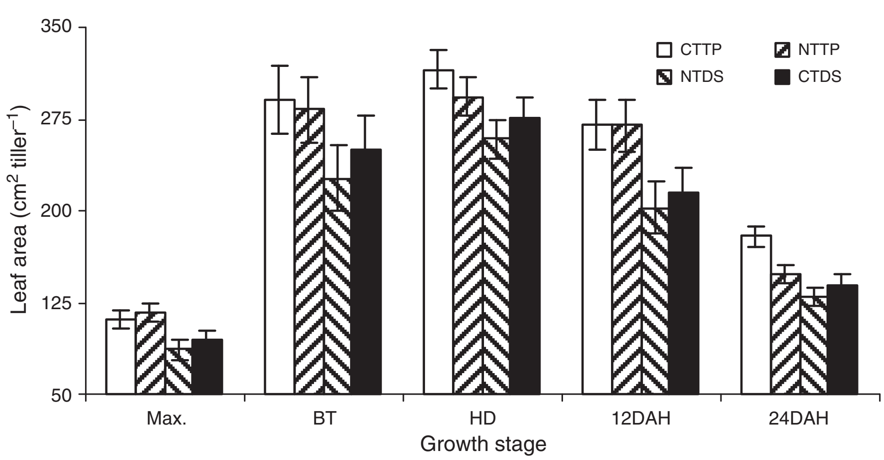

Fig. 7 – Leaf area (cm^2) per tiller, bar represents SE.

Table 3 – Spikelet per cm panicle, panicle dry weight, bearing tiller rate (PBTR) and grain yield.

Rice establishment method	Soil tillage method	Spikelet per cm of panicle	Panicle weight (g)	PBTR (%)	Grain yield (t ha^{-1})
Transplanting	Conventional tillage	8.3 a	4.26 a	48.4 b	9.54 a
Transplanting	No-tillage	8.0 a	3.76 b	50.9 ab	8.83 b
Direct seeding	No-tillage	6.0 b	3.46 bc	53.2 a	8.99 b
Direct seeding	Conventional tillage	6.8 b	3.24 c	50.2 b	8.87 b
Tillage	Factor A	NS	NS	*	NS
Establishment method	Factor B	*	*	*	NS
A × B		*	*	*	*
SE		0.4082	0.2117	1.2458	0.2288

* Significant at $P = 0.05$; NS: not significant at $P = 0.05$. Values followed by the different lowercases are significantly different at 0.05 probability level.

CTTP and 45% in NTTP from 12DAH–24DAH but was similar (35%) for DS under either CT or NT. Leaf area was reduced more in NTTP than CTTP owing to early drying of plants resulting from the shallower root system under NT. This result agrees with that of Huang et al. [7]. Badshah et al. [11] reported that, LAI increased up to the BT stage under TP and the HD stage under DS under both CT and NT and then gradually declined up to 24DAH. CTTP had higher LAI than NTTP at all crop growth stages. Similarly, CTDS had higher LAI than NTDS. Grain yield is a function of biomass accumulation from heading to maturity and translocation to kernels of reserve pre-stored before heading [14]. It has often been suggested that rice yield increase depends more on translocation to kernels of biomass accumulated before heading than on biomass accumulation from heading to maturity [15,16]. CTTP and NTTP showed significantly higher number of spikelets per cm of panicle than CTDS and NTDS owing to excessive tillering leading to small panicle size and further reduced grain yield [3,4]. Panicle dry weight at MA was higher under TP than DS under either CT or NT owing to the sink/source relationship. TP had an approximately 12% longer and larger sink (heavier panicle) than DS. Increasing spikelet number per panicle may be a better approach to increase sink size [17,18] and sink size (spikelet number per unit land area) is the primary determinant of the rice yield [19]. Grain yield was higher in CTTP owing to a larger sink size (heavier panicle, more spikelets in per cm length of panicle) than under DS although weather parameters (temperature, sunshine hours and rainfall) were similar both in TP and in DS (Table 2).

5. Conclusions

There was a positive correlation between panicle number and maximum tillers and NTTP always produced lower numbers of tillers than CTTP. However, PBTR was higher in NTTP than in CTTP, and both NTTP and CTTP had similar sinks (number of spikelet per cm of panicle). Increasing maximum tiller number in NTTP by increasing plant populations may increase rice yield.

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