Band tillage with fertilizer application for unpuddled transplanting rice in northeast of China

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Abstract: Many technological innovations have been developed in agriculture for rice cultivation. Farmers still rely on intensive soil tillage, broadcasting fertilizer, excess irrigation water and labor for rice production. Rice cultivation under unpuddled condition in band-tillage (BT) is a new alternative rice cultivation system in the regions where rainfall, fresh water resources, fertilizers and labors are limited. Therefore, the concept of inter-row BT (T-shaped) with row fertilizer application in soils for unpuddled transplanted rice cultivation (T1) was carried out at Fangzheng, Harbin in the northeast of China. The improved system (T1) was compared with traditional practices (T2) in randomized complete block design with three replications. T2 was done with removal of crop residue, full tillage, broadcasting fertilizer and puddled soils by using the conventional machine. Test results showed that all parameters were satisfied and met the requirements of agronomic performances. The variations of fertilizing stability and evenness were 1.84% and 1.72%, respectively. Soil cone penetration resistance was less in T1 than T2 after tillage. Irrigation water was saved by 26.3% in treatment T1 as compared with T2 for wet land preparation, and wet soil resistance depth had no significant difference. Planting depth was significantly different between the treatments which was affected by intensive tillage and puddling in T2 as compared with T1. Soil temperature was nearly similar, but comparatively 0.23°C (on average) higher than traditional system throughout the crop growing season. Crop growth rate and grain yield increased by 8.5% and 5.3%, respectively in band till with fertilizer placed compared to conventional practices of puddled transplanting. The unit production cost (￥/kg of grain yield) was found lower by 12.3% in treatment T1 than T2. The output-input ratio was marginally greater in treatment T1 (1.51) as compared to T2 (1.32). Short-term findings suggest that inter-row BT system with row fertilizer application could be used in unpuddled rice farming system instead of traditional puddled rice cultivation.

Keywords: conservation agriculture, tillage system, unpuddled rice, irrigation, water saving, economics
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1 Introduction

China is the world's largest producer of rice and accounts for 26% of all world rice production. Rice is an important food crop and national economy in China and also staple food for more than a half of the world population[1]. More than 90% of the global rice cultivation and production is concentrated in Asia[2].

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Out of 1.47×10^8 hm^2 area under rice cultivation 1.30×10^8 hm^2 is in Asia that has increased by 33% in the year of 1957-2010[3,4]. In most countries in Asia like China, the food production cost increased which comes from increasing variable input cost per hectare due to constraints in expansion of land area owing to competing land uses associated with modern urbanization. So, producing more rice with less resource input is a formidable challenge to cope with the food, economic, social and water scarcities[5].

Northeast is one of the rice growing zones in China. Precipitation indices in China showed decreases in the last four decades[6,7]. Farmers still confide on traditional practices of tillage, broadcasting fertilizer, excess irrigation water and labors for rice cultivation. Most of the rice is practiced under traditional flooded irrigation. The most common and traditional rice cultivating is the usual method by flooding water, puddling and leveling after dry land plowing while or after setting the young seedlings of rice to the field, and almost 80% of the paddy in Asia is grown to puddle (wet cultivation) the soil[8]. For transplanting rice seedlings, there are three main operations, wet land preparation, preparation of rice seedlings and transplanting. Unfortunately puddling is a high energy and labor consuming practice. Surface and groundwater sources are still oppressed. Irrigation water shortage is an acute problem and major constraint for rice production which will face in severe economic water problem by 2025 in Asia[9]. Traditional cultivation systems have low water use efficiency due to huge losses by runoff, evaporation, surface flow, seepage and deep percolation, competing weeds and unwanted climatic factors. Hence, farmers are trying to cut their usage of irrigation water and input costs, also shifting to less input demanding cultivation practices for profitability and sustainability[10]. Therefore, alternative cultivation is necessary to the rice production in worldwide to reduce water consumption and produce more rice with less water[11,12]. Improvements in crop production may arise from several strategies such as conservation tillage (CT) farming[13] which can reduce evaporation, run off, soil erosion, machine requirements, farming cost, and is beneficial for controlling moisture and nutrient, rebuilding soil, optimizing crop production inputs and profits[14], and avoiding traditional practices without any penalty. The most common practice is to broadcast fertilizer and puddle the soil for rice cultivation in northeast of China and Asia. Unfortunately puddling is a high energy, labor and time consuming, unpleasant and arduous work which destroys the ecological environment and crop yields[15]. Besides this, direct seeding rice is subjected to more severe weeds, slow growth, lodging and lower yield[16]. Tillage also affects the movement of phosphorus in subsurface drainage waters. In developing countries, utilization rates of nitrogenous and phosphorous fertilizer is less than developed countries by 20%-25% and 30%-35%, respectively[17]. Traditional plowing operation system brings several problems including excess irrigation water, soil erosion, decrease in soil fertility, moisture loss, and harms on the ecological environment, soil structure, crop yields and productivity[18].

However, no-till rice transplanting systems need minimum machinery passes from three or four to down one, less irrigation water and labor than traditional rice cultivation system[19]. Puddling and levelling are not necessary for optimum rice production. Rice yield almost equal in traditional puddle transplanting and direct seeding on puddle or non-puddled under no-tillage systems[11,20,21]. Generally, farmers have a tendency to create a very fine puddle that actually may not be required. Non-puddling paddy fields with straw mulching improved the soil environment (soil oxygen) and reduced water consumption for rice cultivation[22]. Minimum tillage reduced the operations of harrowing, puddling, leveling and saved land preparation cost by 50%-60% and water by 30%-40%[23]. The areas where irrigation water is limited, reduced tillage by the combination of no-till and conventional tillage would be solved a greater extent of CT system. Some form of CT is also essential, even if crop yield is reduced to protect soil, water and fertilizer losses. Increased sustainability of CT systems can be accomplished through improved crop management strategies with favorable impact on biological, physical and chemical properties which has a direct impact on the system sustainability and crop performances[24]. The challenge to research is an urgent need for sustainable yield in CT farming. New technology can be considered for questing reduced tillage, stubble management and effective utilization of fertilizer. Band-tillage (BT) is considered in this study which is as one of the many types of CT system and modified no-till system[25]. BT system applies tillage procedures only to narrow zones of soil where the individual zones would be planted for the next crops, and the soil remains partially covered with protective residues while crop is established in the row zones. There is no wide range of research findings and machinery equipment on BT system for unpuddled rice cultivation. The idea of the improved system and developed machine was taken initiative in 2011 at the Institute of Agricultural Mechanization, Harbin Academy of Agricultural Sciences, which was only compared with traditional cultivation by experimental design factor. However, based on the sustainable agriculture and the technological core of CT farming to increase the productivity of soil, water, yield and reduce farm cost, the specific objectives of the study were to: (i) evaluate inter-row BT with fertilizer mixed in soils application for non-puddled transplanting rice cultivation using newly developed machine, and (ii) compare with traditional tillage system on soil cone penetration resistance, water saving, wet soil resistance and planting depth, crop growth rate, crop yield and economic analysis.

2 Materials and methods

2.1 Experimental site

The experiment was conducted at Fangzheng, Harbin in northeast of China during the rice growing season in 2011 and 2012. The developed machine was fabricated at the machinery workshop of Harbin Academy of Agricultural Sciences. The coordinate of the experimental site was 45º48′N and 128º52′E. Mean monthly pan evaporation and relative humidity and the highest rainfall were recorded in early and mid-stages of the crop season (Table 1), respectively. The average pan evaporation and relative humidity was found at 118.4 mm and 71.4%, respectively during the crop growing periods.

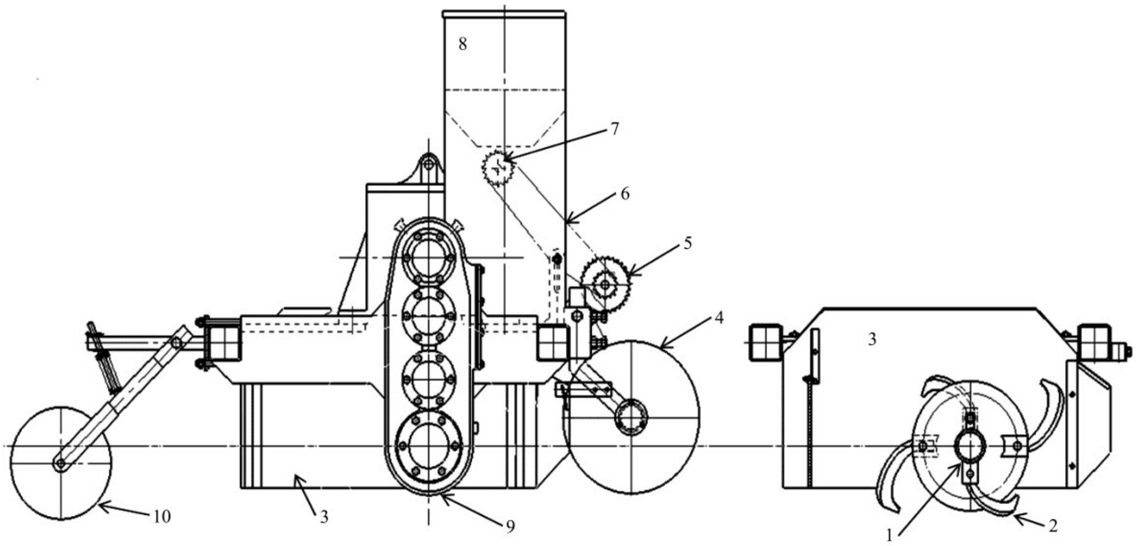
Table 1 Mean monthly pan evaporation, relative humidity, and total rainfall during the crop season of 2011 and 2012

Month	Pan evaporation/mm	Relative humidity/%	Rainfall/mm
March	42.8	69.0	11.6
April	112.6	57.5	29.6
May	152.5	66.5	48.3
June	145.8	75.0	94.1
July	143.5	80.5	146.8
August	123.6	81.0	77.8
September	107.7	70.0	19.0

Data source: Weather station, Fangzheng, Harbin.

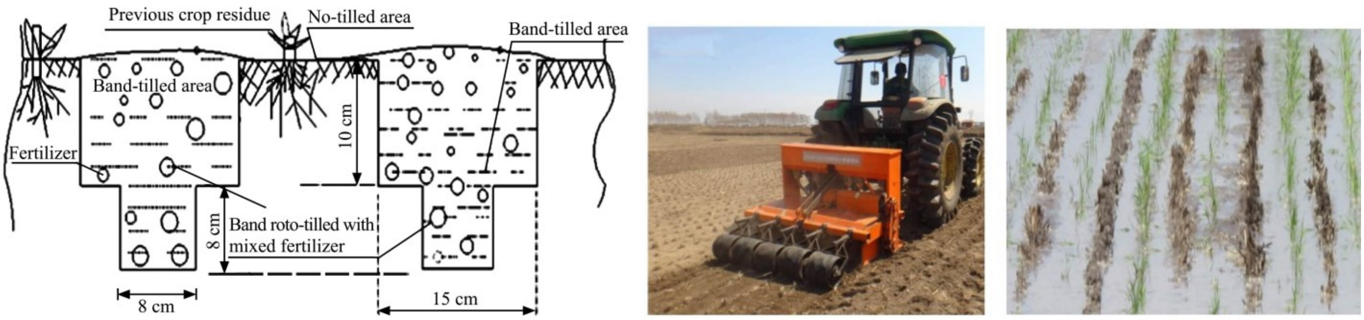
2.2 Working principles of the machine

The developed machine (Figure 1) mainly consisted of two parts: (i) blade arrangement, and (ii) fertilizer metering mechanism. Blade arrangement was designed for band roto-tilling with desired working width and depth for breaking-up and mixing fertilizer in soils for favorable of crop establishment. One combination of four rotary blades (2 L-type and 2 C-type) per flange was attached to the rotor shaft for two sections of band-tillage layers which upper section was 15 cm in width, 10 cm in depth and the lower section was 8 cm in width and 8 cm in depth (Figure 2a). The five sets of blades in one pass were implemented. Blades were one oriented at 90º apart in the plane perpendicular to the shaft. The cutting depth was controlled by the gauge lever mounted to the frame. The common fluted roller type fertilizer metering was used in this machine. The fertilizer unit consisted of fertilizer box, delivery tube, a drive wheel, roller chain, drive and driven sprocket and metering device (Figure 1). The manually metering controlled was placed to the side of fertilizer box to calibrate the fertilizer rate. The metering device was driven by a drive wheel through roller chains and sprockets. The machine was operated by a 35.3 kW tractor through three point hitch. When the machine was operated, fertilizer was placed uniformly on the soil surface and mixed into the soil during tilling at two sections of desired soil layer, which created into form of inter row BT (T-shaped), and the tilled area was pressed by the press wheel. Only the inter row zone was tilled as T-shaped and others were remained in no-tilled area with standing previous crop stubbles (Figure 2a).



1. Blade rotor shaft 2. C-type blade 3. Soil shield 4. Fertilizer drive wheel 5,7. Driven and drive sprocket 6. Chain 8. Fertilizer hopper 9. Power transmission system 10. Press wheel

Figure 1 Schematic diagram of developed band-tilled machine with fertilizer metering mechanism



(a) (b) (c)

Figure 2 (a) Schematic diagram and working principle of band-till (T-shaped) with row fertilizer incorporated into soil for unpuddled transplanted rice cultivation where 50% of the field area is no-tilled and previous crop residue while the planting zone is band tilled. (b) Photographic view of band-till cum fertilizer applicator working at field condition. (c) Photographic view of transplaned young plants at unpuddled field condition in CT system of treatment T1

(a) (b)

Figure 3 (a) Photographic view of locally available rotavator for full tillage dry land preparation. (b) Young plants transplanted by conventional mechanization systems in treatment T2

2.3 Layout of the experiment and treatment

The experimental design was laid out by randomized complete block with two treatments by three replications, where the treatment T1 consisted of inter-row band-tillage (T-shaped) (Figure 2a) in upper portion of 15 cm width and 10 cm depth and the lower portion of 8 cm width and 8 cm depth of roto-tilling with mixed fertilizer using the developed machine (Figure 2b). The previous crop residues were remained in the no-tilled area. After BT with applied fertilizer, irrigation water was applied.

After disappearing of standing water, rice transplanter (made by Agricultural Mechanization Institute, Harbin Academy of Agricultural Sciences, Harbin) was used for transplanting the young plants into the middle of the BT. Row to row and plant to plant spacing was 30 cm and 15 cm, respectively. Treatment T2 consisted of traditional dry tillage with locally available rotavator to a depth of about 12-14 cm, followed by flood irrigation, manual fertilizer application broadcasting. After that two passes puddling and leveling and transplanting was done by the same transplanter. The unit plot size was 59 m × 9 m, and separated by plastic sheet with a height of 35 cm of which 20 cm was placed below the soil surface and 15 cm was above the ground. Local recommended dose (300 kg/hm^2) of Chinese brand compound fertilizer was used as basal fertilizer for both treatments during land preparation. Using fertilizer was ≤46% N-P_2O_5-K_2O: 13-18-15. Two split broadcast fertilizer of prilled urea (60 kg/hm^2) applied at 7 d and 30 d after transplanting (DAT) for all treatments. Intermittent irrigation with alternative wetting and drying method was followed for both treatments. Rice seedlings were developed under artificial controlled environment before the outside growing season starts. The variety of Chinese rice was Jiahe No.1. Seedlings age and average height at transplanting were 30 d and 11.89 cm, respectively. During transplanting, average transplanted seedling rate was 4.3 per hill. After transplanting, all inter cultural practices were similar for both treatments.

2.4 Evaluation tests method

2.4.1 Stability and evenness of fertilizer application

The machine was tested in the workshop to examine the uniformity and stability of fertilizer application in each opener. Standard deviation (SD) and degree of variation (CV) were followed by the review of Jia et al.[26] and Karayel et al.[27]

2.4.2 Soil penetration resistance

Soil compaction was measured to quantify the soil compaction by digital cone penetrometer (Field Scout™ SC900, Model: 6110FS, Spectrum Technologies Inc). It consisted of a 30° circular cone with a 1.28 cm base diameter and 10 mm shaft. Measurements were made at random locations for each plot, 4 times before carrying out the tillage practices from each plot. The wet soil resistance depth was measured after the wet land preparation using a drop cone penetrometer specially designed for use in paddy fields[28]. It was measured randomly at 4 locations over each plot.

2.4.3 Irrigation water saving

Irrigation water was applied to each plot according to the requirements of wet land preparation for all treatments and measured by digital water flow meter. Water savings was computed by the following equations:

$$\text{Water saving (\%)} = \frac{\text{Water consumed in T2 plot} - \text{water consumed in T1 plot}}{\text{Water consumed in T2 plot}} \times 100 \tag{1}$$

2.4.4 Planting depth

Transplanted rice planting depth was evaluated by the following equation:

$$P_d = \frac{\sum P_t - P_h}{n} \tag{2}$$

where, P_d is the average planting depth, cm; P_h is the protruding height above the soil, cm; P_t is the total seedling length, cm; n is the total number of measurement. Measurements were made 5 times from 3 random locations from each plot.

2.4.5 Soil temperature

Soil temperature (ST) was measured by long stem digital thermometer (Measuring range: −50°C to +150°C, Spectrum Technologies Inc). Nine thermometers were installed at different depths of soil in each treatment. ST was recorded on 33, 63, 98 and 124 DAT in each 2 h interval from morning to evening (12 h) at the depth of 0-5 cm, 5-10 cm and 10-15 cm from each plot with 3 replications.

2.4.6 Crop growth rate and yields

Crop growth rate (CGR) was measured by the following equation[29]:

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \tag{3}$$

where, W_1 is the first dry weight, g; W_2 is the second dry weight, g; t_1 and t_2 is the time of first and second sampling, d. Crop dry matter including dry root was sampled during the same date as of soil temperature measured by sampling 9 hills in an area of 90 cm×45 cm. Root samples were collected by the core sampler (8 cm diameter) to a depth of 0-15 cm. Roots were cleaned and washed by clean water and sieved using 2 mm and 0.5 mm sieves. Straw and root samples were dried untill constant weight. Yield contributing characters like effective tillers per hill, grain per spike, 1000 grain weight (TGW) was recorded in 9 hills (randomly selected) from 18 hills in each plot and grain yield was adjusted to 12% moisture content. Demonstration plots results of the crop yields were also recorded and compared with the traditional practices from 2011 to 2012.

2.4.7 Economic analysis

The comparative economic analysis was counted for both treatments. The cost analysis included the operating cost of machinery, chemicals, fertilizer, irrigation, human labor, transportation and storage. The unit production cost of the treatments was calculated by the ratio of the sum of all input production cost per hectare to the total grain yield per hectare[30]. It was expressed in Chinese Yuan (￥) per kg of grain yield. In this study, based on the local variable inputs and outputs information, the economic output-input ratio was evaluated by the review of Regalado et al.[30].

2.5 Statistical analysis

Data were analyzed using SPSS Statistics 17.0 to compare the treatment means. Treatment means were compared using Duncan's multiple range tests (DMRT) to identify significantly different means with dependent variable at p≤0.05.

3 Results and discussion

3.1 Stability and evenness of fertilizer application

The uniformity of variation of fertilizer stability and evenness between rows are presented in Tables 2 and 3. The mean difference was insignificant (p>0.05). The average degree of variation of fertilizing stability was 1.84% and varied from 1.51% to 2.1% (Table 2). The average degree of variation of fertilizing evenness between rows was 1.72% and ranged of 0.63% to 2.45% (Table 3). The combined effect of speed and row had no significant difference for fertilizer distribution (p>0.05).

Table 2 Degree of variation of fertilizer stability between rows

Measurement (No.)	Speed /km·h^{-1}	Mean/g	Standard deviation	Degree of variation/%	Fertilizer distribution rate/kg·hm^{-2}
1	2.75	181.98^{a*}	3.83	2.10	303.30
2	3.23	181.28^{a}	3.55	1.96	302.10
3	3.71	183.62^{a}	2.84	1.55	306.0
4	3.45	178.52^{a}	3.10	1.73	297.50
Average	3.29	181.35	3.61	1.84	302.20

Note: *The same letter has no significant difference in values at P<0.05 level within the treatments. 20 m distance was taken to determine the distribution rate of fertilizer. Chinese brand compound fertilizer (N-P_2O_5 -K_2O: 13-18-15) was used.

Table 3 Evenness of fertilizer rate between rows

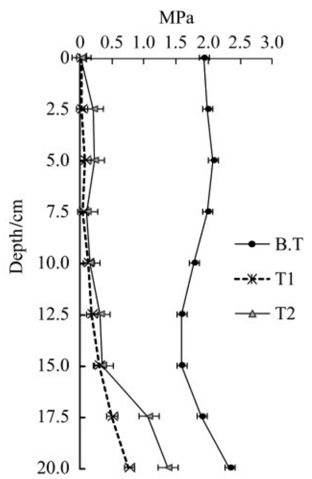
Row No.	N	Mean/g	Std. Deviation	Degree of variation/%
1	4	180.1^{a*}	4.06	2.25
2	4	181.42^{a}	4.45	2.45
3	4	183.98^{a}	1.16	0.63
4	4	178.27^{a}	2.99	1.68
5	4	182.98^{a}	2.91	1.58
Average	4	181.35	3.61	1.72

Note: *Data with the same letter has no significant difference in values at p<0.05 level within the treatments.

The non-significance of variation in the uniformity fertilizer stability and evenness was due to improper and non-uniform granular sizes of fertilizers and speed of the machine. The results are in agreement with the report of Walker[31]. The adjusting of forward speed had little difference on fertilizer drilling to BT area. Jia et al.[26] reported that average standard deviation and degree of variation of evenness of fertilizing rate for the combined roto-tilling-stubble breaking-planting machine was 20.95 cm and 2.09%, respectively. The metering mechanism was also responsible for non-uniformity of application along the path of the machine. Mandal et al.[32] designed a sub-soiler-cum differential rate of fertilizer applicator and tested at laboratory conditions, and found that the coefficient of uniformity of all the application rates over 90% with a range of 93.7%-98.8%. The mechanical control system of variable rated fertilizers consisted of ground speed acquisition unit. The speed of the discharging unit had no direct corresponding to the speed of the machine, and statistically the speed of the machine did not affect the discharge rate of fertilizer per unit area. The rate of fertilizer was controlled by the movement of exposure of the fluted roller to the fertilizer within the metering cup. The fertilizer shafts was operated at a constant speed and therefore operated at the appropriate speed as it was connected by chain.

3.2 Soil resistance and planting depth

The tillage significantly affected cone penetration resistance (CPR) (p<0.01) at lower soil depth of 15-20 cm (Figure 4). CPR was observed lower in T1 as compared with T2 in the upper soil layer. Cone penetration resistance was more sensitive indicator of soil compaction and related to root growth of the crop[33]. The lower value in upper BT soil layers may be attributed to lower soil density, better degree of soil loosening and higher soil moisture content than traditional[34]. It was also suspected that the compacted soil existed at deeper depth for both treatments that caused higher penetration.



Note: T1 and T2: 4 hours after dry land tillage preparation. B.T means before tillage. Data with the following same ns means no significant difference (p<0.05) and asterisk (*) denotes significant difference (p<0.01) within the treatments.

Figure 4 Effect of tillage and depth on soil cone penetration resistance between the treatments T1 and T2

Wet soil resistance depth was not significant (p>0.05) (Table 4). The mean wet soil resistances of this study was almost similar and is in line with Weise et al.[28] The negligible variable resistance was observed in treatment T1 for better arrangement of rotary blades. On the other hand, in treatment T2 more passes of field machinery led to form soil compaction and affected soil resistance[35]. One pass of the rotary tiller is equivalent to several operations of conventional tillage[36]. The effect of puddling reduced soil structure, especially stable soil aggregates, and led to formation of compacted layers. The transplanted rice planting depth is monumental for rice crop establishment. Tillage system did significantly affect the seedling depth (Table 4). The better planting depth observed in T1 as compared T2 was due to less flowable slurry soil that reduced soil disturbed disturbance, non-puddling and leveling, and led to retention of previous crop stubbles on soil surface[37].

Table 4 Water saving for wet land preparation, wet soil resistance and transplanted rice planting depth for crop establishment

Treatment	Water use for land preparation/mm	Water saving/%	Wet soil resistance depth/cm	Planting depth/cm
T1	108.3	26.3	12.7^a (2.21*)	2.35^a (0.78*)
T2	146.9	--	12.8^a (2.72*)	3.51^b (1.29*)

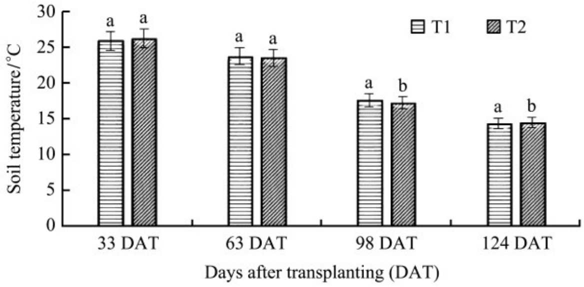
Note: Data with the same letter has no significant difference (p≤0.05) within the treatments. The values in parenthesis indicate the standard deviation.

3.3 Irrigation water saving

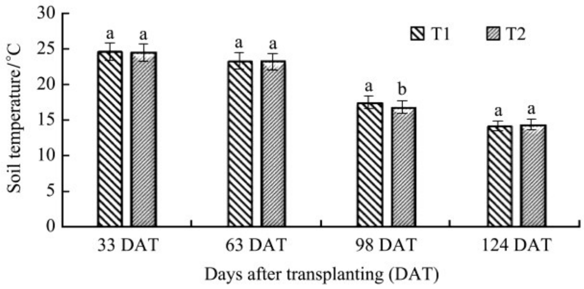
Water use for wet land preparation was greater by 26.3% (Table 4) in traditional puddling system (T2) than improved system of unpuddled rice cultivation systems (T1) due to more soil puddling and leveling, run off, evaporation and no crop stubbles in the field. Rice cultivation under non-flooded condition with straw mulching reduced water consumption[22] and reduced tillage with crop residue for unpuddled transplanted rice cultivation system as compared to traditional system[23]. In China, CT fields contained more soil moisture than the traditional fields[20].

3.4 Soil temperature

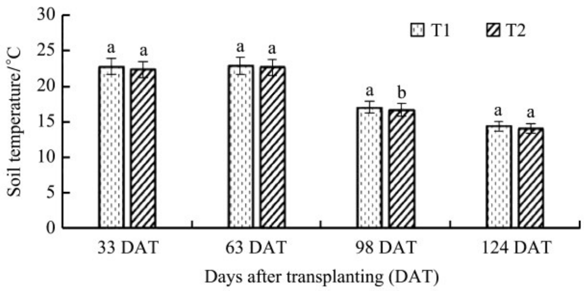
The treatments effect on soil temperature is shown in Figure 5. Soil temperature (ST) had no significant (p>0.05) difference with depth (0-5 cm, 5-10 cm and 10-15 cm) at early and late growth stages. ST was observed significantly (p=0.01) different at the growth stage of 98 DAT (Figure 5). ST was higher by 0.3°C (on average) in T1 than T2 during the crop growth periods. At grain filling stage, soil temperature was more 0.5°C in T1 than T2. At harvesting stage, soil temperature was nearly similar. The variations of the ST were consistent with the reports of Sidhu et al.[38]. In T1, ST was slightly higher due to desired soil loosening and less compact soil in band-tilled area which increases air pockets and exchange the air to soil particles, and heating air can quickly enter to the soil that enhance the heating process. The porous soil band-tilled area contains more air than compact soil, and tends to flow and retain more heat than traditional systems[39]. Soil temperature was lower at deeper depth (10-15 cm) in untilled soil and attributed to thermal admittance and heat flux which produced lower ST profile[40].



a. 0-5 cm



b. 5-10 cm



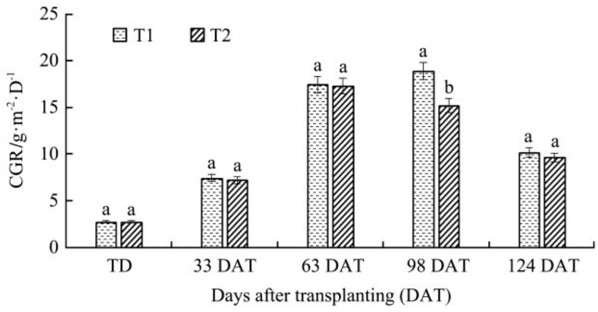
c. 10-15 cm

Note: Data with the same letters has no significant difference at the values of $p\leq0.05$ level within the treatments.

Figure 5 Effects of tillage on soil temperatures at different crop growth stages in different depths

3.5 Crop growth rate and crop yields

Crop growth rate (CGR) had no significant effect ($p>0.05$) at early growth stages and harvesting period (Figure 6). However, it was significantly different ($p\leq0.05$) on 98 DAT. Crop growth rate was observed higher by 19.6% in treatment T1 than T2 at the growth stage of 98 DAT. Average 8.5% CGR was found more in treatment T1 than T2 which might have been affected by improved tillage and fertilizer placement. Changes in soil temperature in relation to root growth[41], tillage and puddling, crop lodging in grain maturity stages also are reported to affect the CGR in traditional rice cultivation[42].



Note: Same letters means no significant ($p<0.05$) and TD means transplanting date.

Figure 6 Effect of tillage and fertilizer placement on CGR during different growth stages of rice

Table 5 Effect of tillage and fertilizer placement on yield attributing characteristics

Treatment	Effective spike per hill	Effective grain per spike	Thousand grain weight/g	Yield /kg·hm^{-2}
T1	20.7a*	83.6a	26.2a	10118a
T2	19.3b	74.6a	25.9a	9581a

Note: *Data with the same letter had no significantly different ($p\leq0.05$) within the treatments.

The treatment had no significant effect on crop yield ($p>0.05$) (Table 5). Total yield was greater by 5.3% in T1 than in T2. However under intensive tillage, puddled soils prone to more cracking and lodging and lower soil temperature in grain filling stage ultimately causes to decline crop yield[43,44]. Efficient use of fertilizer and water saving practices improve crop performances and increase yield and biomass (18 t/hm^2) compared with traditional rice cultivation practices[45]. Higher grain yield probably was influenced by the water application method[46]. Reduced tillage with straw mulching and non-flooded rice cultivation technique can keep the production more stable[21,44]. Results clearly suggest that improved tillage with previous crop residues and fertilizer placement which presumably favorable conditions for rice crop establishment[47,48].

3.6 Economic analysis

Economic analysis is exigent to recommendation of any technique. Table 6 suggests that the treatment had an effect on the unit production cost and output-input ratio in rice cultivation under conservation tillage systems. The variable input cost on land preparation was saved 60% in treatment T1 as compared to T2 (Table 6). In this study, the unit production cost was found less by 12.3% in treatment T1 than that in T2. The output-input ratio was found more in treatment T1 (1.51) than in T2 (1.32) as shown in Table 6.

Table 6 Comparison of unit production cost and output-input ratio for both treatments

Parameters	Comparative cost/￥·hm^{-2}	
Inputs	T1	T2
Machinery (Contract basis):		
Land preparation	600	1500
Mechanical transplanting	1200	1200
Harvesting	1500	1500
Chemicals:		
Herbicides	300	300
Pesticides	615	615
Human labor:		
Cultural practices	3720	4090
Harvesting	1567	1567
Others:		
Rice seedling	3300	3300
Fertilizers	1056	1056
Irrigation	1710	1900
Transportation & storage	2500	2500
Total variable input cost/￥·hm^{-2}	18 068	19 528
Grain yield/kg·hm^{-2}	10 118	9581
Unit production cost/￥ per kg of grain	1.79	2.04
Output/￥·hm^{-2} (2.7￥·kg^{-1})	27 318	25 869
Output-input ratio	1.51	1.32

Data source: Local data during the year of 2011 and 2012 from local office of Fangzheng Agriculture Mechanization Department Extension, and Farmers of Fangzheng County, Harbin. Here, fixed cost was not considered. 6.24 ￥ is equal to $1 (US dollar) during the experimental period of 2011 and 2012.

Operating BT with row fertilizer application was found lower unit production cost due to decrease of the machinery passes, reduction of field operation, less consumption of fuel and power, less soil working allowing greater timeliness for the rice cultivation and potentially reduction of farming costs, advantages of retaining crop stubble, and it is beneficial for more sustainable than traditional rice cultivation system[19,44,49]. Land preparation was greatly reduced in irrigation service unit compared with irrigation service units of traditional rice cultivation[50]. Less fuel consumption (65%) was incurred for strip tillage system compared to conventional tillage and could reduce the production cost of rice[44]. The results indicated that land preparation cost of the traditional rice cultivation system in northeastern China was more than that of minimum tillage. However, there was no extra time and cost requirement for tilling, fertilizing, excess irrigation for puddling and leveling in reduced tillage with proper placement of fertilizer in CT systems[23,47]. Saving in fuel cost and the benefit of the improved system through the existing use of farm inputs may resolve the existing traditional practices[51].

4 Conclusions

On the basis of this study, the following conclusions can be drawn.

(1) The performance of the band-till cum fertilizer applicator and the system was satiated for non-puddled transplanted rice cultivation.

(2) The variation of fertilizing stability and evenness between the rows was 1.84% ranged from 1.55% to 2.1%, and 1.72% with ranged of 0.63% to 2.45%, respectively.

(3) The field evaluated test indicated that cone penetration resistance was greatly affected by the tillage treatments, puddling water saved 26.3%, wet soil resistance was similar and planting depth was found better with machine for non-puddled transplanted rice cultivation.

(4) Soil temperature was nearly similar, but comparatively 0.23°C (on average) was higher than traditional system

(5) Crop growth rate and grain yield had no significantly differences but greater crop growth rate (8.5%) and yield (5.3%) were found in band tillage with fertilizer placement than conventional practices of puddled transplanting rice.

(6) Inter-row BT with row fertilizer application for unpuddled transplanted rice cultivation system (T1) could save 60% land preparation cost compared to traditional puddled rice cultivation practice (T2). The unit production cost was found 12.3% less in treatment T1 than in T2. The output-input ratio was found greater in treatment T1 (1.51) as compared to the treatment of T2 (1.32).

Based on short-term results, the field performance of the applicator and the system of band-tillage with fertilizer incorporated in soils for unpuddled rice cultivation was satisfactory, and can offer an alternative and suggestive future pattern to change the old paradigm of traditional puddled rice cultivation system.

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