Development and validation of unpuddled riding-type rice transplanter for wet land rice establishment

M. A. Hossen[1], M. M. Hossain[2], R. W. Bell[3], M. E. Haque[4] and M. A. Rahman[5]

[1]Senior Scientific Officer (SSO), Farm Machinery and Postharvest Technology Division (FMPHTD), Bangladesh Rice Research Institute (BRRI), Gazipur, Email ahossenbrri@gmail.com; [2]Professor, Department of FPM, BAU, Mymensingh, Email mosharraf53@yahoo.com; [3]Professor, School of Veterinary and Life Sciences, Murdoch University, Australia, Email r.bell@murdoch.edu.au; [4]Adjunct Associate Professor, Murdoch University Project Implementation Office, Uttara, Dhaka, angladesh, Email e.haque@murdoch.edu.au; [5]Chief Scientific Officer, FMPHTD, BRRI, Gazipur, Enail abrahman42@gmail.com

Introduction

Manual transplanting is tedious and time consuming which often the causes of delayed planting resulting yield loss of rice in Bangladesh. Mechanized rice transplanting is seen as a solution of labor problems. Likewise, using mechanized rice transplanting ensures uniform plant spacing as well as fast and efficient planting that contributes to high productivity (Manjunatha et al., 2009). Transplanters have been developed for rice seedling planting into puddled soils to alleviate labour shortages and reduce costs of rice establishment (Adhikari *et al.,* 2006). Although, tillage for rice establishment has significantly mechanized in Bangladesh, 16-18 % of total production cost are involved in tillage and land leveling (BRRI, 2013). Development of a rice transplanter suitable for unpuddled transplanting under minimum tillage conditions could further minimize the land preparation cost, which will be of interest to the farmers. No significant work to date has been conducted in Bangladesh to develop a rice transplanter for minimum tillage unpuddled soil conditions. Therefore, the following development and validation study was conducted during 2013-15 with modifying and evaluating a riding-type, 6-row mechanical rice transplanter for unpuddled soil conditions.

Materials and Methods

A strip tillage mechanism was attached in front of and in line with the rotary picker for transplanting rice seedlings (Figure 1). Fabrication was conducted according to a design made at the FMPHT Division, BRRI. Engine power available at a 3600-rpm speed was conveyed to the strip tillage rotary shaft with the arrangement of a belt-pulley, worm gearing, shaft-universal joint, involutes spline shaft and bevel gear resulting in a 450-rpm rotary blade speed. A lever-operated tensioning pulley was included into the belt drive to engage and disengage the power to the strip tillage shaft. B-section V belt (38^0 groove angle) was used based on design power and rpm of the engine shaft pulley. A straight-face worm gear was designed to reduce main shaft speed to 450 rpm from a secondary shaft speed of 2250 rpm considering transmitted power 1.0 kW. The tine was designed in such way that depth of strip should not more than 25-50 mm and width 20-25 mm (Figure 1). Specific draft of soils for making strip was taken as design force for strip tillage arrangement. The developed rice transplanter was evaluated for transplanting seedlings under unpuddled minimum tillage condition and compared with mechanized and manual transplanting on puddled soil at BRRI research farm during Boro/2014-15 season.

Results and discussion

Development of the riding type rice transplanter as unpuddled transplanter (URRT)

The values of specific draft of the soil was assumed as force 5.2 N cm^{-2} for torque calculation considering a soil specific draft for clay loam and heavy clay soil 8 Ncm^{-2} and 35% reduction for saturated condition (Kepner *et al.,* 1978). It was calculated that about 1.0 kW power is required to cut strips simultaneously across the width of the rice transplanter in operation considering all losses in power transmission from engine to strip tillage rotary shaft. A double-groove pulley of 125 mm diameter was attached to the engine shaft to replace the single-groove pulley and to share the engine power for strip tillage by transmission to the secondary shaft attached below the engine shaft. A pulley (200 mm diameter) was attached to the secondary shaft to reduce the engine rpm from 3600 to 2250. Diameter of the secondary shaft was critically designed to be 20 mm considering the combined twisting and bending moments. The maximum shear stress induced in the shaft was found less than the allowable stress in calculation (16.15 <41.4 Mpa). Input shaft of the worm gear was coupled with the secondary shaft because of equal speed of the worm and the secondary shaft. Tangential load acting on the gear was calculated as 622 N and design tangential load was calculated as 2007 N. However, the dynamic load (W_D), static load or endurance strength (W_s) and maximum load for wear (W_W) were found in calculation 2540 N, 5082 N and 2841 N, respectively. Therefore, the design is safe from the stand point of tangential load, dynamic load, static load and maximum load for wear, respectively. Bevel gears were used to connect the 90 degree intersecting shafts to transmit main shaft power to the rotary shaft of the strip tillage tine. Equal bevel gear having equal teeth and equal pitch angle was connected two shafts whose axes intersected at right angle. Because of same teeth, pitch angle for pinion and gear is same of 45 degree. An involutes spline shaft was used in the developed transplanter in between bevel gear and main shaft with hub to slide along the shaft. Total length of the shaft is 233 mm along with 175 mm spline shaft and hub. Torque of the spline shaft is same as the main shaft torque of 21.23 N-m for same rpm and power carried which is less than the allowable torque of 49.22 N-m to the resistance of the shaft. The shear stress under roots of external teeth of an external spline was found 14.68 Mpa. However, the shear stress at the pitch diameter of teeth was found 10.35 Mpa. The compressive stress on sides of spline teeth for flexible splines was also found in calculation 9.05 Mpa. The estimated value is also less than allowable shear and compressive stress.

Field evaluation of the developed riding type rice transplanter (URRT)

Transplanter performance

Fuel consumption of the URRT (4.8 hrs. ha^{-1} and 10.3 l ha^{-1}) did not vary significantly with the riding type rice transplanter (RRT) (4.4 hrs. ha^{-1} and 9.2 l ha^{-1}) whereas manual hand transplanting (MHT) take significantly higher time (206 hrs. ha^{-1}). Rate of area coverage in unpuddled and puddled conditions was not also varied significantly between URRT (4.78 man-hr. ha^{-1}) and RRT (4.44 man-hr. ha^{-1}), respectively whereas rate of area coverage of MHT was found 205.6 man-hr. ha^{-1} (Table 1). Planting depth varied significantly with transplanting methods. Plant to plant spacing was found identical between URRT (155) and RRT (152). URRT gave more accurate spacing compared to RRT. Contrary to, number of seedling per hill also varied with the transplanting methods (Table 1).

Percentage of missing hills

Floating, damage and total missing hills varied significantly with the transplanting methods (Table 2). MHT (2.2%) demonstrated significantly higher floating hills followed by URRT (0.7%). Contrary to, RRT (1.3%) demonstrated significantly higher buried hills whereas it was zero in MHT.

Yield and economic performance

URRT gave significantly higher yield (6.97 t ha^{-1}) which was identical with RRT (6.80 t ha^{-1}) whereas significantly lower for MHT (5.66 t ha^{-1}). Contrary to, URRT gave significantly lower straw yield (5.56 t ha^{-1}) followed by RRT (5.71 t ha^{-1}). However, URRT gave higher BCR (1.78) followed by RRT (1.66) whereas MHT gave lower BCR (1.33)**.** Variation of BCR was observed due to the effect of yield on gross margin and to some extent from input costs (Table 2).

Conclusion

A commercial riding type mechanical rice transplanter was modified to operate under minimum tillage unpuddled transplanting with the capability of making strips concurrently with rice transplanting, in a one pass operation following basic land preparation without puddling. Collectively, field performance results suggest that farmers can establish rice in unpuddled conditions to save fuel and labor costs while also achieving increased yield over RRT and MHT using URRT.

References

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Table 1. Unpuddled transplanter performance as affected under different mode of transplanting

Treatments	Fuel (l ha^{-1})	Rate of area coverage (Man-hrs ha^{-1})	Depth of planting (mm)	Plant to plant distance (mm)	[1]Deviation %	Seedlings $hill^{-1}$ (nos.)
T_1	10.27	4.78	16	155	3.13	3.33
T_2	9.2	4.44	19	152	5	3
T_3	0	205.6	13.67	200	0	4.67
LoS	**	**	*	**	NS	*
$LSD_{0.05}$	3.33	15.48	3.02	7.63	-	1.31

Table 2. Percentage of missing hills and yield performance as affected under different mode of transplanting

Treatments	Picker missing hills (%)	Floating hills (%)	Damaged hills (%)	Buried hills (%)	Total % missing hills	Yield (t ha^{-1})	Straw yield (t ha^{-1})	BCR
T_1	1.33	0.67	1.33	0.33	3.67	6.97	5.56	1.78
T_2	1.33	0.33	1.67	1.33	4.67	6.80	5.71	1.66
T_3	0.00	2.17	0.00	0.00	2.17	5.66	7.02	1.33
LoS	NS	*	*	NS	*	**	*	**
$LSD_{0.05}$	-	0.76	0.93	-	1.31	0.61	0.97	0.17

Note: NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance and T_1= Unpuddled transplanting using the 6-row developed unpuddled riding type rice transplanter (URRT), T_2= Puddled transplanting using the 6-row riding type rice transplanter (RRT) and T_3= Puddled manual hand transplanting (MHT).

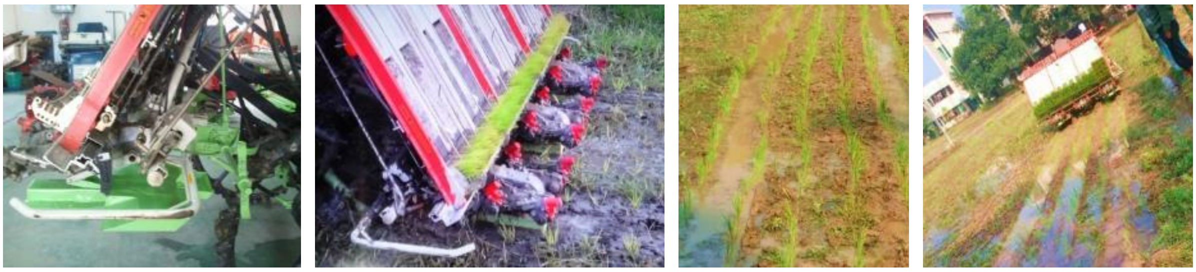

Figure 1. Unpuddled strip transplanting unsing developed rice transplanter