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Mechanised non-puddled transplanting of boro rice following mustard conserves resources and enhances productivity

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ABSTRACT

Dry season irrigated rice (boro) can be transplanted into non-puddled soil when it follows a mustard crop in Bangladesh. However, the options for non-puddled transplanting, including reduced tillage (RT) or zero tillage (ZT) with manual or mechanised transplanting have not been evaluated in farmers' fields. Therefore, two on-farm experiments were conducted over three years to compare two transplanting methods (manual – Man, mechanical – Mech) and three tillage methods (reduced tillage - RT, zero tillage - ZT, and conventional tillage - CT (puddling)). For both transplanting methods, grain yield with CT and RT was similar. However, there was a slight (3–4%) but significant decline in grain yield with ZT in three out of four instances. Total irrigation input increased with decrease in tillage, by around 100–150 mm in RT compared with CT, and by 200–300 mm or 25–30% in ZT compared with CT. Grain yield and gross margin of mechanically transplanted rice with CT, RT and ZT were higher than or similar to that for manually transplanted rice, while the labour requirement for mechanical transplanting was 5% of that for manual transplanting. Furthermore, mechanical transplanting provides the opportunity to advance crop establishment.

1. Introduction

Double rice cropping systems play an important role in food security in Asia, occupying about 24 Mha, of which 10% is in Bangladesh (Bhuiyan et al., 2004; Dawe et al., 2004; Ladha et al., 2003). In Bangladesh, this involves growing a wet season rice crop (aman) in rotation with an irrigated dry season rice crop (boro). The aman-fallow-boro system accounts for 22% of the rice produced in Bangladesh (Elahi et al., 2001). Furthermore, this system is a source of employment, income, and livelihoods for millions of rural and urban poor people in Bangladesh.

Cultivation of boro crops became common in Bangladesh in the 1980′s following the introduction of cheap irrigation pumps, enabling the country to achieve rice self-sufficiency. However, boro rice displaced many minor but nutritionally important crops, such as oilseed mustard (BBS, 1985, 1991; BBS, 2014). The present domestic edible oilseed production in Bangladesh meets only one-third of national demand (BBS, 2013).

The current aman-fallow-boro system involves the cultivation of medium to long duration rice varieties which are transplanted in July and mature in late November, followed by a fallow period of about two months, followed by a boro crop which is transplanted during mid to late January. The soil is puddled for both crops and the rice seedlings are transplanted manually. While puddling and manual transplanting is a very reliable method of rice crop establishment, both practices bring considerable disadvantages. Manual transplanting is very cumbersome and labour intensive, requiring 30 man-days ha^{-1} in boro rice (Rashid et al., 2009). Increasing agricultural labour scarcity in Bangladesh results in delays in transplanting and increases labour costs (Munnaf et al., 2014; Saharawat et al., 2010; Ladha et al., 2009). Furthermore, plant spacing and population density are often sub-optimal with manual transplanting (Joshi et al., 2013).

Prior to transplanting of rice, the soil is typically dry-tilled and then saturated and wet tilled (puddled) in multiple passes. Irrigation is normally required to saturate the soil for the boro crop, while the aman crop is normally established on rainfall. Puddling benefits rice by reducing water percolation losses, controlling weeds, facilitating manual transplanting and seedling establishment, and creating anaerobic conditions which enhance nutrient availability (Ghildyal, 1978; Sharma and De Datta, 1985). However, puddling has adverse effects on soil

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properties for upland crops grown in rotation with rice (Tripathi et al., 2005; Sharma et al., 2003; Kirchhof et al., 2000; Hobbs and Moris, 1996), and the deterioration in soil structure also increases the energy required to achieve proper soil tilth for succeeding crops (Gill et al., 2014). Furthermore, pre-puddling and puddling tillage are costly in terms of fuel consumption, labour and machinery wear and tear, and account for about 11% of the cost of boro production (Rashid et al., 2009). Also, the water requirement for puddling is high. Puddling accounted for up to 30% of the total irrigation water application in dry season rice grown on light textured soils in Pakistan (Aslam et al., 2002).

However, puddling of the soil is not essential for rice establishment by transplanting. In Bangladesh, Haque et al. (2016) achieved similar or higher rice yields and lowered cost of production with manual transplanting into a non-puddled sandy loam soil. The soil was prepared for transplanting by shallow dry tillage (full pass or strip tillage) and soaking for 24 h. Furthermore, Ahmed et al. (2002) found similar grain yield with manual transplanting of boro rice into puddled and non-tilled (zero till, ZT) soil. However, adoption of ZT manual transplanting is constrained by the greater hardness of the non-puddled soil, making it more difficult to transplant rice at the optimum depth, and increasing the transplanting time and cost (Islam et al., 2014; Naresh et al., 2014). The use of mechanical transplanters has the potential to solve this problem. Moreover, mechanical transplanting facilitates optimum plant spacing and population (Kamboj et al., 2013). In addition, mechanical rice transplanters are becoming more common in many rice growing regions to address the problem of labour shortage (Ali et al., 2012; Dixit et al., 2007; Xianwen et al., 2014). Given rising rural labour costs and scarcity the introduction of labour saving machinery such as mechanical rice transplanters is an imperative (Karim et al., 2014).

The recent development of short duration (115–125 day) aman varieties such as BRRI dhan33, BRRI dhan39 and BINA dhan7 that mature in late October to early November, provides farmers in Bangladesh with an opportunity to grow high yielding, short duration (85 day) mustard varieties such as BARI sarisha14 and BARI sarisha15 in the gap between the aman and boro crops (BARC, 2001; Islam, 2013). Following a mustard crop, the fields have few weeds and good soil tilth because of dry tillage for the mustard crop, and may be in a suitable condition for rice to be transplanted with reduced or no tillage. Transplanting into non-puddled soil could save time and reduce land preparation costs without hampering yield (Haque et al., 2016; Islam et al., 2014; Karim et al., 2014). Mechanical transplanting of the boro crop could further facilitate timely transplanting of the boro crop. Therefore, the present study was designed to evaluate (1) the effect of tillage method on the performance of manually and mechanically transplanted boro rice, and (2) mechanical transplanting of the boro crop in comparison with manual transplanting. The evaluation was conducted in an aman-mustard-boro rotation, and treatments were compared in terms of boro rice yield, labour requirement, irrigation water productivity and profitability.

2. Materials and methods

2.1. Experimental sites and seasons

Two on-farm participatory experiments were conducted in adjacent sections of six farmers' fields for two consecutive boro crops during 2013–16. The fields were located within a radius of 500 m in Bashghata village in Sadar Upazila, Satkhira district (22.75 °N and 89.41 °E) in Bangladesh. The area belongs to the Ganges Tidal Flood Plain agro-ecological zone (UNDP and FAO, 1988). The climate of the area is subtropical, with average annual rainfall of 1710 mm and peak rainfall in July and August, minimum monthly mean temperature of 12.5 °C in January, and maximum monthly mean temperature of 35.5 °C in April and May. The soils of the experimental fields at 0–15 cm depth were sandy loam in texture, having 51.0% sand, 45.8 to 46.3% silt and 2.6 to 3.2% clay, a bulk density of 1.35 to 1.38 Mg m^{-3}, pH of 6.8–7.2 (1:2.5 soil: water), organic C of 7.6–9.0 g kg^{-1} (Walkley and Black method; Allison, 1965), total N of 0.8–0.9 g kg^{-1} (Yoshida et al., 1976), available P of 40– 57 mg kg^{-1} (Olsen et al., 1982), exchangeable K of 0.22–0.26 mmol kg^{-1} (Page et al., 1982), available S of 9.8–12.5 mg kg^{-1} (Fox et al., 1964), and extractable Zn of 0.83–0.98 mg kg^{-1} (Page et al., 1982). Gravimetric soil moisture content of the topsoil prior to dry tillage for the boro crops ranged from 22.7 to 26.4, 21.0 to 27.9 and 16.9 to 23.1% in 2013–14, 2014–15 and 2015–16, respectively (Black, 1965).

The experimental area in each farmer's field had a similar crop management history and uniform soil type. The t. aman-mustard-boro cropping sequence had been practised in the experimental fields for five years prior to the commencement of the experiment, with the soil puddled prior to manual transplanting of each rice crop.

2.2. Experimental design

Both experiments tested three tillage methods for establishment of transplanted boro rice: conventional wet tillage (puddling) (CT), reduced tillage by single pass shallow dry tillage (RT), and zero tillage (ZT) (Table 1). Experiment 1 was conducted during the boro 2013–14 and 2014–15 seasons, and all tillage treatments were manually transplanted. Experiment 2 was conducted in 2014–15 and 2015–16 and all tillage treatments were mechanically transplanted. In addition, there was a manually transplanted CT treatment. The four treatments in this experiment are referred to hereafter as "establishment methods"

The details of the tillage treatments are as follows:

1) CT: Within 2–3 days of mustard harvest the land was irrigated and ploughed twice to a depth of 12–15 cm, left for 2–3 days and then ploughed once again with 2–3 cm standing water depth followed by two levelling operations. All tillage operations were done with a rotary tiller powered and drawn by a 2-wheel tractor (2WT). The rice was transplanted 2 days after land preparation was completed.
2) RT: The soil was dry tilled to a depth of 8–10 cm using a rotary tiller/2WT in a single pass, and then irrigation was applied to achieve a water depth of 2–3 cm above the surface. Rice was transplanted 2 days after irrigation.
3) ZT: The land was not ploughed. Irrigation was applied to achieve a water depth of 2–3 cm above the surface two days before transplanting, and again on the day of transplanting.

Both experiments used a randomized complete block design, with six replicates (one replicate in each farmer's field). The unit plot size was 100 m^2 for each treatment in both experiments, and the same treatments were implemented in the same location each year within each experiment.

Table 1
Establishment methods in Experiments 1 and 2.

Experiment #	Years	Treatment ID	Tillage treatment	Transplanting method
1	2013-14, 2014-15	CT-Man	Conventional	Manual
		RT-Man	Reduced	Manual
		ZT-Man	Zero	Manual
2	2014-15, 2015-16	CT-Man	Conventional	Manual
		CT-Mech	Conventional	Mechanical
		RT-Mech	Reduced	Mechanical
		ZT-Mech	Zero	Mechanical