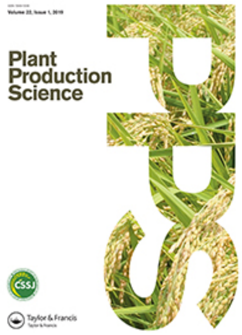

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Partially mechanized non-puddled rice establishment: on-farm performance and farmers' perceptions

Md. Enamul Haque and Richard W. Bell

School of Veterinary and Life Sciences, Murdoch University, Murdoch, WA, Australia

ABSTRACT
Transplanting rice (*Oryza sativa* L.) seedlings into non-puddled soils with minimum soil disturbance (by mechanized strip tillage) is an opportunity to expand Conservation Agriculture (CA) adoption in rice-based cropping systems. However, the farmer acceptance and on-farm profitability of this technology has not been assessed. Here, we analysed farmer-managed non-puddled transplanting (NT) of rice seedlings in paired comparisons with rice seedlings transplanted in puddled (PT) soil. Sixty-six rainfed monsoon (aman) and 84 dry-season irrigated (boro) rice crops were established by NT and compared with paired PT crops during 2013–2015 in north and north-west Bangladesh. Non-puddled fields were prepared by firstly making 40–60-mm-wide tilled strips with a Versatile Multi-crop Planter, then by 18–24-h inundation with water to soften soils in the strip, followed by transplanting seedlings into strips. The NT crops produced similar or significantly greater grain (boro season of 2015) and straw yields than paired PT crops. The minimum soil disturbance NT did not hinder seedling transplanting of rice or increase the total labour costs for transplanting and weeding compared to PT, rather it reduced the cost of production, and increased net benefit for rice in both seasons relative to PT. Under farmer management on a range of soils and in the two main rice-growing seasons, NT performed as well or better than PT suggesting that this is a feasible option for farmers planning to adopt CA in rice-based cropping systems. Over 3 years, farmers' perception of NT performance shifted from scepticism to mostly favourable.

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Aman; boro; conservation agriculture; minimum tillage; puddling; strip tillage

1. Introduction

Rice is the most important staple food for about 3 billion people (Maclean, Dawe, Hardy & Hettel, 2002) and contributes significantly to food security among millions of farms households. Rice area, production and yield increased rapidly from the 1960s to the late 1980s (Khush, 1995) due to adoption of high-yielding varieties, together with increased use of irrigation water, chemical fertilizers, herbicides, pesticides, etc. However, sustainability threats have to be addressed for the future of wetland rice cultivation. Rice seedling establishment in fully tilled and puddled saturated soils is a major source of greenhouse gas (GHG) emission, particularly methane (Pathak et al., 2011). Avoidance of puddling of soils for establishment of rice can decrease water requirements for growing rice (Mahajan, Timsina & Kuldeep-Singh, 2011; Mahmud, Bell, Vance & Haque, 2017) and decrease GHG emissions (Alam, Biswas & Bell, 2016).

Soil tillage followed by ponding of water and puddling is practised to control weeds, facilitate transplanting and reduce soil permeability for wetland rice establishment (Sharma, Ingram & Harnpichitvitaya, 1995). However, puddling of soil consumes about 200–250 mm of water, equivalent to 17% of the total water use by rice (Mahajan et al., 2011). Puddling also destroys soil aggregates, breaks capillary pores, disperses clay particles (that can form an impermeable clayey layer on the surface of coarse-textured soil) and creates a plough pan that impedes root penetration for following crops (Haque, Bell, Islam & Rahman, 2016). Soil puddling for rice cultivation results in low wheat (*Triticum aestivum* L.) grain yields in the rice–wheat system, mainly due to weakening of soil structure and the development of sub-surface hardpans and increased risk of water-logging (Fujisaka, Harrington & Hobbs, 1994). Continuation of soil puddling for rice transplanting will negate the benefits of zero tillage practised in other crops in the rotation as is reported for the rice–wheat system (Singh et al., 2011).

Conservation Agriculture (CA) helps farmers to reduce production costs while improving soil health, crop diversity and timeliness of cultivation (Johansen, Haque, Bell, Thierfelder & Esdaile, 2012). However, the adoption of CA is still low by rice-based smallholders (Johansen et al., 2012), even though two-wheel tractor (2WT)-based implements have created new avenues for the pursuit of CA in rice-based smallholder farming

CONTACT Md. Enamul Haque e.haque@murdoch.edu.au

systems (Bell et al., 2019; Haque, Bell, Islam, Sayre & Hossain, 2011). In rice-based cropping systems, implementation of CA is hampered due to the practice of soil puddling for rice seedling transplanting. Initial development of non-puddled transplanting (NT) of rice seedlings systems in Bangladesh was described in Haque (2009). Various forms of NT of rice seedling, as well as benefits and limitations of NT, were further elaborated on by Ladha et al. (2009), Saharawat et al. (2009), Johansen et al. (2012), and Haque et al. (2016). Generally, the methodology of NT of rice seedling is the same as for rice seedlings transplanting in puddled (PT) soil except for the different land preparation. Haque et al. (2016) evaluated four options of land preparation for NT of rice seedling in 2 long-term experiments and 27 on-farm sites in Rajshahi district of Bangladesh. In this study, NT establishment had no negative effect on rice yields across seasons and years, but it reduced cost of production and increased the gross margin of NT rice relative to PT, as well as decreasing the time taken for land preparation and crop establishment and decreasing the number of irrigation events required to saturate the soil prior to transplanting. However, despite these obvious benefits of NT from research on farms, the acceptance and profitability of the NT technology when managed by farmers is not well understood.

Several hundreds of farmers have adopted NT rice establishment methods where the technologies were demonstrated earlier in Bangladesh. The aim of the present study was to determine the crop growth, yield and profitability of NT rice crops managed by farmers. A total of 150 on-farm studies on NT aman (hot, monsoon season growing period July to October–November) and boro (cool, dry season growing period February to April–May) season rice were conducted in eight locations (Table 1) and compared with paired crops of conventional PT rice establishment during 2013, 2014 and 2015 in varied Agro-ecological Zones (AEZ) of Bangladesh (Figure 1). Focus group discussions (FGD) were also held over three successive years to elicit farmers' opinions about the suitability, particularly, of the mechanized strip tillage NT and how their perceptions changed over time.

2. Materials and methods

2.1. Experiment description

To account for the range of soils used for rice cultivation in north and northwest Bangladesh, 150 on-farm paired comparisons in the aman (Figure 2) and boro (Figure 2) seasons between NT and conventionally puddled PT rice establishment were conducted in eight locations (Table 1) during 2013, 2014 and 2015 in different AEZs of Bangladesh.

2.2. Farmer selection

Officers of the Department of Agricultural Extension (DAE), local leaders and farmers of the study locations (Table 1) were invited to field days, FGD and introduced to the past years' NT rice experiments (Haque et al., 2016). Each year, motivated farmers were provided with 1-day orientation training on NT rice production methods. From each location, six farmers were pre-selected to conduct on-farm experiments of NT of rice seedling in boro and aman seasons (Table 1). Performance of each NT rice field (Table 1) was closely supervised to compare with a paired field established by conventional PT of rice seedlings.

2.3. Experiment location characteristics

During 2013–2015, a total of 66 and 84 paired trials for aman and boro rice, respectively, were conducted in Durgapur and Godagari upazila (sub-district) under Rajshahi district; Sadar and Gouripur upazila of Mymensingh district; Sadar upazila of Thakurgaon district; and Baliakandi upazila of Rajbari district (Table 1). These locations are known as High Ganges River Floodplain, High Barind Tract, Old Himalayan Piedmont Plain and Old Brahmaputra Floodplain (FAO-UNDP, 1988) and classified as AEZ 11, 26, 1 and 9, respectively. The soil types were varied in the experimental plots from alluvial in Durgapur upazila, silty-clay loam in Godagari upazila, to light loamy in Gouripur upazila and Sadar upazilas of Thakurgaon and Mymensingh (Huq & Shoaib, 2013). Among these locations, the highest average annual rainfall (2522 mm) was recorded in Gouripur and Sadar upazilas of Mymensingh followed by Sadar upazila of Thakurgaon (2218 mm) and the lowest rainfall (1581 mm) was recorded in Godagari and Durgapur upazilas in Rajshahi district (Figure 2) but in all cases about 80% of the precipitation occurs during June–September. The minimum (in December) and maximum (in April) average temperature in Durgapur and Godagari upazilas were 11–36°C, 10–33°C in Sadar upazila of Thakurgaon and 12–32°C in Gouripur and Sadar upazilas of Mymensingh (Figure 2).

2.4. Treatments and design of on-farm trials

The study was conducted in farmers' fields with NT and PT treatments each applied to half of a field.

Table 1. General information of on-farm experiments of non-puddled aman and boro season rice.

Year	Locations	No. of paired fields	Rice varieties	Seedling age (days)	Seedling transplanting period	Total fertilizer used (kg ha^{-1})					
						Urea$^{(1)}$	DAP$^{(2)}$	MoP$^{(3)}$	Gypsum$^{(4)}$	Zinc$^{(5)}$	Boron$^{(6)}$
Aman season rice											
2013	Alipur	6	Hybrid – Tej	25 to 30	20 to 29 July	188	150	75	0	0	0
2014	Alipur	6	Local – Jirashail	25 to 32	15 to 25 July	150	150	75	0	0	0
	Digram	6	Local – Swarna	25 to 27	17 to 23 July	188	150	90	75	0	0
	Jogonnathpur	6	Hybrid -Tej	35 to 44	5 to 10 August	240	203	128	113	0	0
	Durbachor	6	HYV – BRRIdhan-48	28 to 34	10 to 17 August	203	150	113	75	7.5	0
	Sutiakhali	6	Local – Jirashail	25 to 31	12 to 18 August	188	165	98	113	0	7.5
2015	Alipur	6	Local – Jirashail	24 to 32	20 to 29 July	150	113	75	75	0	0
	Choighati	6	Local – Swarna	25 to 29	10 to 20 July	150	113	75	75	7.5	7.5
	Digram	6	Local – Swarna	25 to 33	20 to 28 July	188	150	90	75	7.5	7.5
	Jogonnathpur	6	Local – Swarna	36 to 45	6 to 14 August	225	210	135	113	0	7.5
	Durbachor	6	Hybrid – Tej	30 to 40	9 to 16 August	203	150	75	90	0	7.5
	Sub-total: Aman rice	66									
Boro season rice											
2013	Alipur	6	HYV – BRRIdhan-28	35 to 43	20 to 28 February	244	188	113	113	7.5	7.5
	Digram	6	HYV – BRRIdhan-28	45 to 50	15 to 21 February	248	225	75	75	7.5	7.5
	Durbachor	6	HYV – BRRIdhan-28	38 to 45	12 to 15 February	263	188	113	113	0	7.5
	Kalitola	6	HYV – BRRIdhan-28	45 to 54	18 to 26 February	300	248	150	150	7.5	7.5
2014	Alipur	6	HYV – BRRIdhan-28	43 to 50	15 to 22 February	225	166	88	93	7.5	7.5
	Choighati	6	HYV – BRRIdhan-28	40 to 52	10 to 15 February	225	188	113	90	7.5	7.5
	Digram	6	HYV – BRRIdhan-28	44 to 55	9 to 14 February	263	188	90	113	7.5	7.5
	Sutiakhali	6	HYV – BRRIdhan-28	40 to 51	12 to 18 February	263	188	150	113	0	7.5
	Durbachor	6	HYV – BRRIdhan-28	35 to 41	13 to 17 February	295	225	113	150	0	7.5
	Kalitola	6	HYV – BRRIdhan-28	35 to 45	23 to 28 February	263	225	150	150	7.5	7.5
2015	Alipur	6	HYV – BRRIdhan-28	39 to 44	16 to 23 February	246	156	75	75	7.5	7.5
	Choighati	6	HYV – BRRIdhan-28	45 to 52	7 to 13 February	236	150	75	100	7.5	7.5
	Digram	6	HYV – BRRIdhan-28	50 to 55	20 to 28 February	236	150	75	100	7.5	7.5
	Jogonnathpur	6	HYV – BRRIdhan-28	38 to 44	20 to 28 February	300	248	188	225	7.5	75
	Sub-total: Boro rice	84									
Total: aman and boro rice		150									

(1) CO $(NH_2)_2$ form containing 46% of nitrogen (N); (2) $(NH_4)_2HPO_4$ form containing 18% N and 20% phosphorus; (3) KC1 form with 50% of potassium (P); (4) $CaSO_4$, $2H_2O$ form with 18% sulphur (S) and 20% calcium (Ca); (5) $ZnSO_4$. H_2O form with 17.5% S and 36% Zn; (6) H_3BO_3 form containing 17% boron (B).

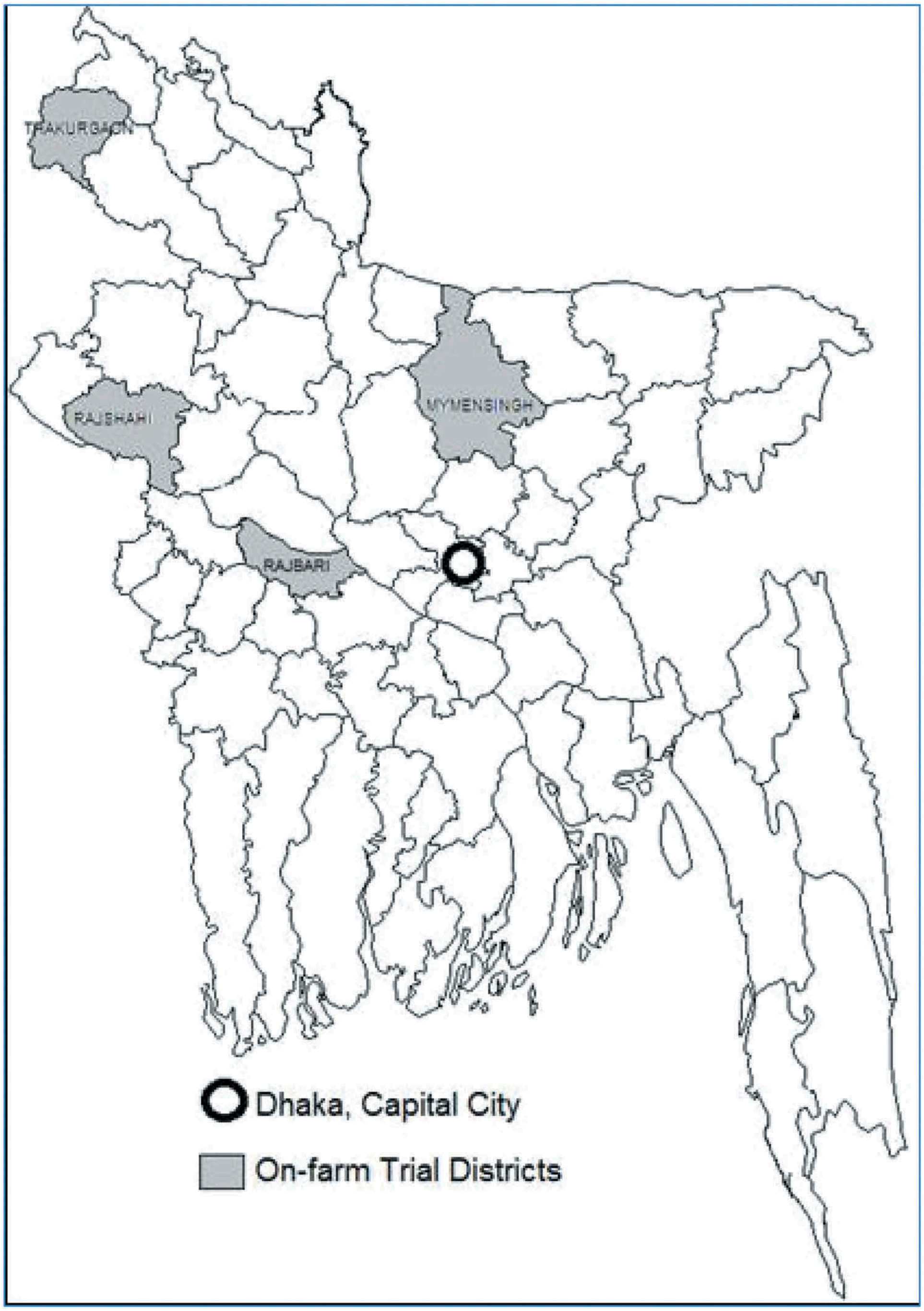

Figure 1. Map of Bangladesh showing the locations of on-farm studies of non-puddled rice.

Each farmer's field (plots size was ranging from 660 to 1330 m^2) was treated as a replicate for both methods of rice crops establishment types. Treatments consisted of two rice establishment methods: (i) puddled transplanted (PT) and (ii) non-puddled transplanted (NT) of rice seedlings. All farmers used exactly the same management for the paired fields apart from crop establishment (PT vs. NT).

2.5. Crop management

2.5.1. Land preparation

In case of land preparation for PT, three to four rotary tillage passes and one to two land levelling passes were done by a locally hired 2WT. Initially, farmers used two rotary tillage passes by 2WT to break up the soil which was left for 7–15 days, and then inundated by irrigation

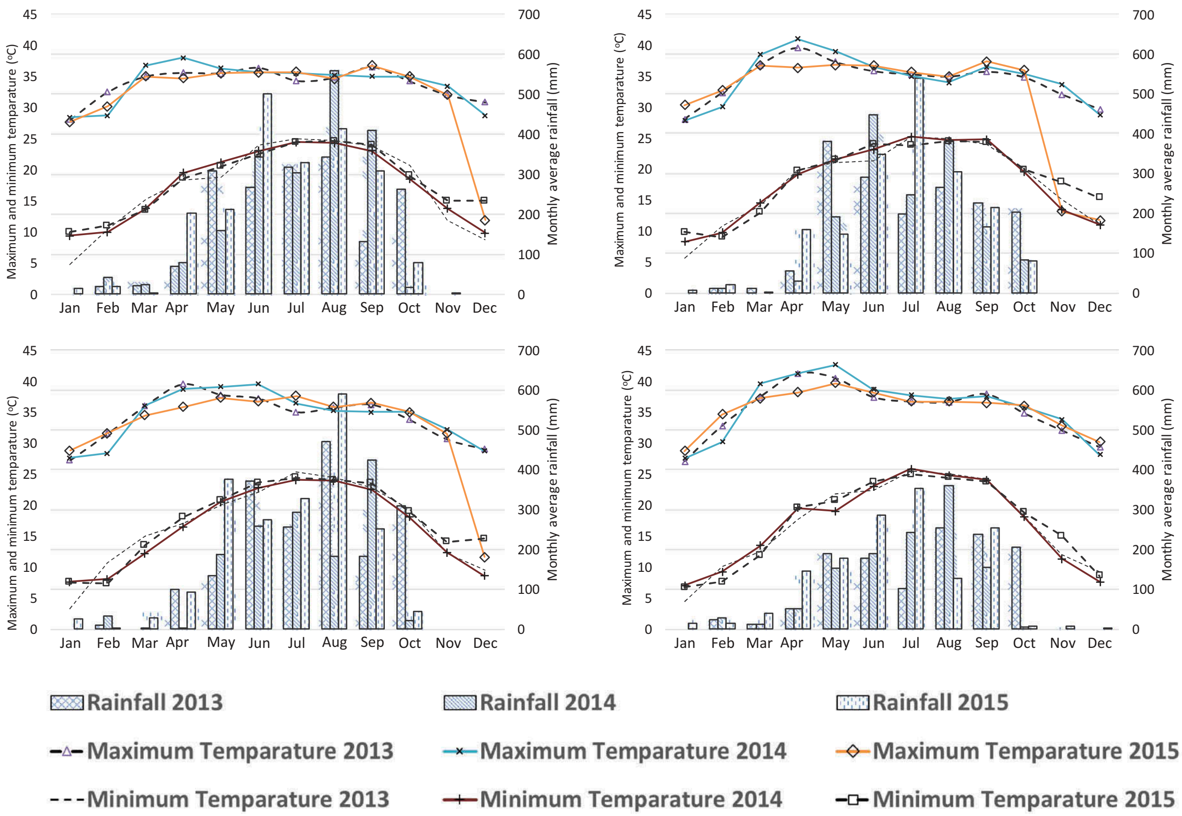

Figure 2. Monthly total rainfall (mm), average maximum and minimum temperature (°C) in study locations (called upazilas, districts). Data were collected from nearest weather stations of the Metrological Department of Bangladesh (BBS, 2016).

or rain water for 2–3 days. Initial tillage and water inundation for PT helps to kill germinated weeds and soften the soils. Finally, lands were puddled for PT with additional one to two rotary tillage operations and similar numbers of land levelling passes by 2WT in the inundated field. The lands were left for 1–3 days with standing water to allow suspended sediment to settle and to firm up the surface before manual rice seedling transplantation.

In case of NT, the land preparation was done by locally hired Versatile Mutli-crop Planter (VMP) (Haque et al., 2011). Generally, in dry land (having gravimetric soil water content from 15% to 40%), 50–70-mm-deep and 40–60-mm-wide strips (that preserved about 70–80% undisturbed soil) were made by VMP in a single pass operation. In boro season, the irrigation water was applied to the fields after strip tillage to inundate the field for 18–24 h before two to three rice seedlings hill^{-1} were transplanted manually in rows with hill spacing of 200 × 200 mm (Hossen, Hossain, Bell & Haque, 2017). In aman season, the strips were made prior to the onset of monsoon rain; however, in two cases in aman season the farmers used the VMP as single-pass shallow tillage where it was not possible to make the mechanized strip tillage due to standing water in the fields and because it was not possible to spray knock-down herbicide to control pre-germinated weeds due to standing water in the field.

2.5.2. Rice variety

In these trials, we did not influence the farmers' rice variety selection. Farmers used their preferred rice varieties in both PT and NT establishments. Farmers in aman seasons used local rice cultivars cv. Jirashail and cv. Swarna, except at Alipur in 2013, Jogonnathpur in 2015 and Durbachor in 2015, where they used hybrid rice variety cv. Tej; and only in Durbachor in 2014 where farmers used high-yielding variety (HYV) cv. BRRIdhan-48 (Table 1). During boro seasons of 2013, 2014 and 2015 in all locations, farmers used HYV rice cv. BRRIdhan-28 (Table 1). The lifespan of hybrid-Tej, local–Jirashail, local–Swarna and HYV–BRRIdhan-48 in aman season is 130–140, 125–130, 135–145 and 105–115 days, respectively, and the potential grain yield is 6.5–7.0, 6.0–6.5, 5.5–6.0, 4.5–5.0 t ha^{-1}, respectively; the lifespan of HYV–BRRIdhan-28 in boro season is 140 days, and yield potentiality is up to 6.0 t ha^{-1} (Bangladesh Rice Research Institute [BRRI], 2018).

2.5.3. Seedling age

In both aman and boro seasons of all three years, the farmers raised their own rice seedlings individually for both PT and NT establishments. Depending on rice varieties, 25- to 36-day-old seedlings were transplanted in aman seasons, whereas 35- to 55-day-old seedlings were transplanted in boro seasons (Table 1).

2.5.4. Time of seedling transplanting

Seedling transplanting in on-farm experiments for aman season rice of 2013, 2014 and 2015 was done during July in the cases of Alipur, Digram and Choighati locations; at Jogonnathpur, Sutiakhali and Durbachor locations, the seedling transplanting was delayed until mid-August in 2014 and 2015 (Table 1). However, the land preparation and seedling transplantation for boro season rice in on-farm experiments were completed within February in each year at all locations (Table 1). The seedling numbers hill^{-1} were one, two to three, and three to five for hybrid, HYV and local varieties, respectively; and seedlings were transplanted manually at the row and hill spacing of 200 mm. Both PT and NT on each farm took place on the same day.

2.5.5. Nutrient management

The farmers were instructed to apply locally practised doses of fertilizers and apply the same rates on the paired PT and NT plots. The sources of added nutrients were urea for N, diammonium phosphate (DAP) for N and P, muriate of potash (MoP) for K, gypsum for S, zinc oxide (ZnO) for Zn and boric acid (H_3BO_3) for B. In all aman seasons, the use of urea fertilizer was varied 150 kg ha^{-1} (in Choighati and Alipur during 2015) and more than 200 kg ha^{-1} in Jogonnathpur for 2014 and 2015 and Durbachor in 2015 (Table 1). The use of DAP and MoP fertilizers were higher in case of Jogonnathpur during 2014 and 2015 aman seasons (Table 1). Urea fertilizer rate varied from 150 to 240 kg ha^{-1}, DAP from 113 to 210 kg ha^{-1}, MoP from 75 to 113 kg ha^{-1} in boro seasons (Table 1). The dose of Zn and B fertilizers was 7.5 kg ha^{-1} but was not commonly used in all locations and years for aman season rice; by contrast, farmers commonly used the Zn and B fertilizers for boro season rice (Table 1). Except urea, all fertilizers were applied basally. The total urea was applied as three splits – 50% at 3–5 days after transplanting (DAT), 25% at 30–40 DAT and 25% at 50–60 DAT (panicle initiation stage) in both seasons of all three years for on-farm experiments. The full amount of basal fertilizers, viz., DAP, MoP, gypsum, Zn and B, were hand broadcast for PT during final land preparation. For the NT plots, only DAP fertilizer was banded in strips during preparation of strip tillage by VMP; and other fertilizers, viz., MoP, gypsum, Zn and B, were hand broadcast for 4–24 h prior to rice seedling transplanting, when there was 2–3 cm of standing water in the fields.

2.6. Crop protection

In each season, two insecticides, viz., Virtako 40 WG (Thiamethoxam + Chlorantraniliprole), were applied at the rate of 75 g ha^{-1} to control brown plant hopper; and Imidacloprid to control aphid at the rate of 450 ml ha^{-1}.

2.7. Weed control

Non-selective herbicide glyphosate (3.5 l ha^{-1}) was sprayed at 1.85 kg a.i. ha^{-1} for NT treatment in most of the on-farm experiments 1–7 days prior to preparing fields for strip tillage. However, as primary tillage and standing water in the field during puddling operation in PT helps to control exposed weeds, non-selective herbicide was used in PT plots. Most of the farmers used herbicide for both PT and NT to control post-transplanting weeds followed by a hand weeding at 25–30 and 35–40 days, in the case of aman and boro season rice, respectively. The pre-emergence herbicides, Pretilachlor, at the rate of 450 g ha^{-1}, and Pyrazosulfuron ethyl 20 WP, at the rate of 200–375 g ha^{-1}, were applied at 4–7 DAT and 15–20 DAT, respectively, for most of the plots.

2.8. Irrigation water management

The aman season rice was mostly dependent on rain water; however, supplementary irrigation water was applied if necessary to keep at least 2–3 cm ponding water during the rice-growing season. The lands were irrigated 1 day prior to final land preparation if there was not sufficient rain water for land preparation and transplanting of rice seedling. The boro season rice was grown in fully irrigated condition. In boro season, the irrigations were applied from land preparation and transplanting to grain-filling stage. The plots were initially supplied with 30–50 mm standing water at each of the irrigation events, and at the later stage 50–70 mm cm of standing water was supplied up to grain-filling stage. The lands were re-irrigated after disappearance of standing water.

2.9. Crop harvest

In the boro and aman seasons, rice was harvested during the second week to end of May, and during mid-October to mid-November, respectively.

2.10. Data collection

At the beginning of each season, project field staff (PFS) were trained on the data collection methodology and provided an individual structured proforma for each on-farm experimental plots to collect the following details: general information of the location, crop establishment and management, various crop economic data, etc. The inputs and economic data were recorded based on the whole experimental plots, whereas the grain and straw yields were recorded from randomly pre-marked quadrats; and data on yield contributing characters were collected from randomly pre-selected hills. Within 3–5 DAT, the PFS randomly selected three quadrats of 1 m^{-2} from both NT and PT treatments of each plot and pre-marked them with pegs and strings. At the same time, three hills were tagged from each quadrat to collect yield contribution characters, e.g. effective and non-effective tiller number per hill, average plant height (cm) before harvest, panicle length (cm) and thousand grain mass (g). Grain yield at 14% moisture and sun-dried straw yields were collected from three pre-marked quadrats and converted to ha^{-1} basis.

At the end of each season, the farmers were invited in FGD to collect the filled-up proforma, and to validate the recorded data; and compile farmers' feedback, experiences and perceptions about the NT rice crop performance. The FGD collected overall responses from each group and hence the information could not be dis-aggregated into individual responses.

2.11. Crop economic data

Total production cost was calculated considering all input costs, e.g. tillage and land levelling; seedling; fertilizers; irrigation; herbicide (knockdown, pre- and post-emergence) and pesticides; labour (hired and family) for transplanting, weeding, irrigation, harvesting; and rent of land (Table 10). The gross production cost and gross income were calculated considering the estimated sale price of grain and straw (Table 10). Net return or net loss was calculated as gross income – gross production cost.

2.12. Data analysis

All statistical analysis on grain, straw and yield components, and input use were carried out by MSTAT-C statistical software (Michigan State University, U.S.A.) and Statistics 10. For each year and season, a one-way analysis of variance was carried out, treating each field (with paired NT and PT crops) as a replicate. Duncan's multiple range test (DMRT) was applied using the same programs and was used at the $p < 0.01$, $p < 0.05$ and $p < 0.10$ level to test the differences among the treatment means.

3. Results

3.1. Crop production inputs

3.1.1. Number of tillage passes and cost for land preparation

Across all years, seasons and locations, a single-pass operation was used for NT, but 3–5 tillage (average 3.94) passes and 1–2 levelling operations by 2WT were reported (Figure 3) for land preparation in the case of PT. In aman seasons of 2013, 2014 and 2015, across all locations on average US$ 84, US$ 91, and US$ 93 ha^{-1}, respectively, were reported for land preparation cost for PT which were 65%, 63%, 61%, respectively, lower than for NT. Across all the locations, in aman season of 2014 and 2015, the highest land preparation cost was US$ 72 ha^{-1} for PT at Digram in 2014.

3.1.2. Labour use

The average total labour use in aman seasons of 2013 and 2015 for transplanting and weeding was higher ($p < 0.01$) for PT than NT (Table 2). Similarly, total labour use for transplanting and weeding in boro season of 2013, 2014 and 2015 was also higher ($p < 0.01$) for PT than NT (Table 3). Farmers in the experimental locations hired on an average 23–37 person-day ha^{-1} of labour for aman season rice cultivation during all three years (Figure 4). On an average, 17, 24 and 22 person-days ha^{-1} of family labour were recorded for aman season rice cultivation in 2013, 2014 and 2015, respectively. On average, about 15–20 person-days ha^{-1} of family labour was reported for cultivation of boro rice during 2013–2015 (Figure 4). In comparison with NT, greater numbers of hired labour for PT were reported in the boro season rice cultivation during 2013 and 2015 ($p < 0.01$) (Figure 4).

Between NT and PT, no differences were observed for the total labour cost of aman season rice cultivation during 2013 and 2014; but higher ($p < 0.01$) cost for total labour use was recorded in 2015 in PT than NT (Table 2). Total labour cost for boro season rice cultivation was reported higher for PT than NT during 2013, 2014 and 2015 (Table 3).

3.2. Crop growth and biomass yield

3.2.1. Plant height

Taller ($p < 0.01$) plants were recorded for aman season rice in 2015 for NT than PT (Tables 4 and 5). The plant

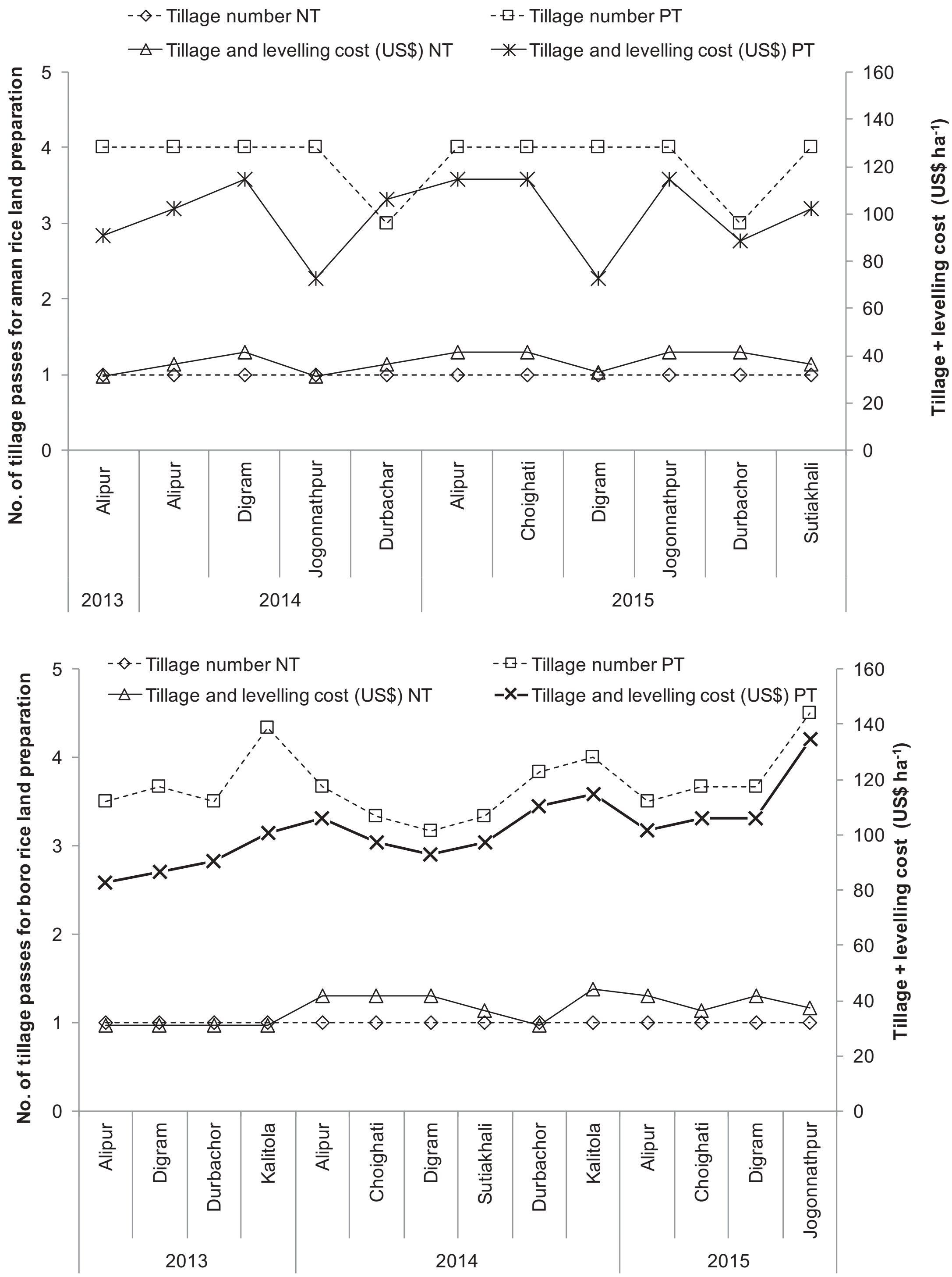

Figure 3. Number of tillage passes and cost of tillage and levelling for land preparation in aman (upper) and boro (lower) season rice cultivation at different locations in Bangladesh.

height of boro season rice significantly varied only among locations within each year of 2013, 2014 and 2015 (Table 5).

3.2.2. Yield attributes

No variation between NT and PT was observed on the number of effective tiller hill^{-1} during the aman seasons of 2013, 2014 and 2015. However, in the boro season of 2014 and 2015, higher (p < 0.01) numbers of effective tillers hill^{-1} were counted for NT compared to PT (Table 5). No difference was found in the panicle length irrespective of NT and PT treatments during the aman seasons of 2013 and 2014; however, longer (p < 0.05) panicles were

Table 2. Labour uses and cost for labour (hired and family) on non-puddled transplanting (NT) vs. puddled transplanting (PT) for on-farm aman rice cultivation in Bangladesh.

		Labour (person-day ha^{-1})									Total labour cost (hired + family labour) US$ ha^{-1}		
		Transplanting			Weeding			Total (Transplanting + weeding)					
Year	Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	31.7	30.0	30.9	15.3b	20.0a	17.7	47.0b	50.0a	48.5	181	192	187
	LS		NS			**			**			NS	
	CV %		5.9			6.3			6.3			5.3	
2014	Alipur	34.2	31.7	32.9	16.3	20.2	18.3B	50.5	51.8	51.2B	271	285	278B
	Digram	34.7	33.0	33.8	21.2	23.3	22.3A	56.3	56.3	56.3A	315	299	307A
	Jogonnathpur	34.7	32.7	33.7	15.7	18.8	17.3BC	50.3	51.5	50.9B	285	289	288AB
	Durbachor	35.7	33.3	34.5	14.5	15.3	14.9C	50.2	48.7	49.4B	231	238	235C
	Mean	34.8a	32.7b		16.9b	19.4a		51.8	52.1		276	278	
	LS		L = NS, T = * Lx T = NS			L = **, T = **, LxT = NS			L = **, T = NS, Lx T = NS			L = **, T = NS, L x T = NS	
	CV%		6.2			16.0			6.3			10.2	
2015	Alipur	31.7	30.0	30.8C	13.2	21.0	17.1BC	44.8	51.0	47.9D	155	176	166C
	Choighati	34.7	33.5	34.1A	14.8	21.7	18.3B	49.5	55.2	52.3AB	190	212	201A
	Digram	33.3	33.2	33.3AB	15.7	19.87	17.8ABC	49.0	53.0	51.0BC	138	149	144D
	Jogonnathpur	33.2	32.3	32.8B	15.7	19.7	17.7ABC	48.8	52.0	50.4BC	156	167	162C
	Durbachor	34.2	33.3	33.8A	13.8	18.2	16.0C	48.0	51.5	49.8CD	172	185	179B
	Sutiakhali	35.2	33.0	34.1A	15.8	23.5	19.7A	51.0	56.5	53.8A	196	217	207A
	Mean	33.7a	32.6b		14.8b	20.6a		48.5b	53.2a		168b	184a	
	LS		L = **, T = ** L x T = NS			L = *, T = ** L x T = NS			L = **, T = ** L x T = NS			L = **, T = **, L x T = NS	
	CV%		3.3			14.5			5.8			5.5	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values with the same capital letter in a column for location means and a small letter in a row for means of the transplanting methods are not significantly different by DMRT.

Table 3. Tillage and labour cost for on-farm experiments with non-puddled transplanting (NT) vs. puddled transplanting (PT) on boro rice.

		Labour (person-day ha^{-1})											
		Transplanting			Weeding			Total (Transplanting + weeding)			Total labour cost (hired + family labour) US$ ha^{-1}		
	Year/Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	32.0	30.0	31.0B	14.2	20.0	17.1	46.2	50.0	48.1B	178	192	185B
	Digram	32.3	30.0	31.2B	15.5	20.7	18.1	47.8	50.7	49.3B	183	195	189A
	Durbachor	32.5	30.5	31.5B	13.5	19.7	16.5	46.0	50.2	48.1B	177	193	185B
	Kalitola	35.0	33.7	34.3A	15.7	20.0	17.8	50.7	53.7	52.2A	130	138	134C
	Mean	33.0a	31.0b		17.7b	20.1a		47.7b	51.1a		167b	179a	
	LS	L = **, T = **, L x T = NS			L = NS, T = **, L x T = NS			L = **, T = **, L x T = NS			L = **, T = **, L x T = NS		
	CV%	13.0			11.4			5.2			5.03		
2014	Alipur	32.0a	30.0c	31.0C	14.2	20.0	17.1	46.2	50.0	48.1	178c	192b	185B
	Choighati	32.0a	32.0a	32.0A	14.2	20.0	17.1	46.2	52.0	49.1	178c	200a	189A
	Digram	32.0a	30.0c	31.0C	14.2	20.0	17.1	46.2	50.0	48.1	178c	192b	185B
	Sutiakhali	32.0a	30.8b	31.4B	14.2	19.2	16.6	46.0	50.0	48.0	177c	192b	185B
	Durbachor	32.5a	30.3bc	31.4B	13.8	20.0	16.9	46.3	50.3	48.3	148e	161d	154C
	Kalitola	32.0a	30.0c	31.0C	14.2	20.0	17.1	46.2	50.0	48.1	118g	128f	123D
	Mean	32.1a	30.5b		14.1b	19.9a		46.2b	50.4a		163b	178a	
	LS	L = **, T = **, L x T = *			L = NS, T = **, L x T = NS			L = NS, T = **, L x T = NS			L = **, T = **, L x T = **		
	CV%	5.6			6.7			6.5			7.66		
2015	Alipur	33.3	28.7	31.0	14.2	20.0	17.1	46.2	50.0	48.1	178	192	185A
	Choighati	32.3	30.7	31.5	14.2	20.0	17.1	46.2	50.0	48.1	178	192	189A
	Digram	32.0	32.5	32.3	14.2	20.0	17.1	46.2	50.0	48.1	178	192	185A
	Jogonnathpur	32.3	30.0	31.2	14.2	20.0	17.1	46.2	50.0	48.1	148	160	154B
	Mean	32.5a	30.5b		14.2b	20.0a		46.2b	50.0a		170b	184a	
	LS	L = NS, T = **, L x T = NS			L = NS, T = **, L x T = NS			L = NS, T = **, L x T = NS			L = *, T = **, L x T = NS		
	CV%	8.4			6.7			6.4			5.4		

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values with the same capital letter in column for location means and a small letter in a row for means of the transplanting methods are not significantly different by DMRT.

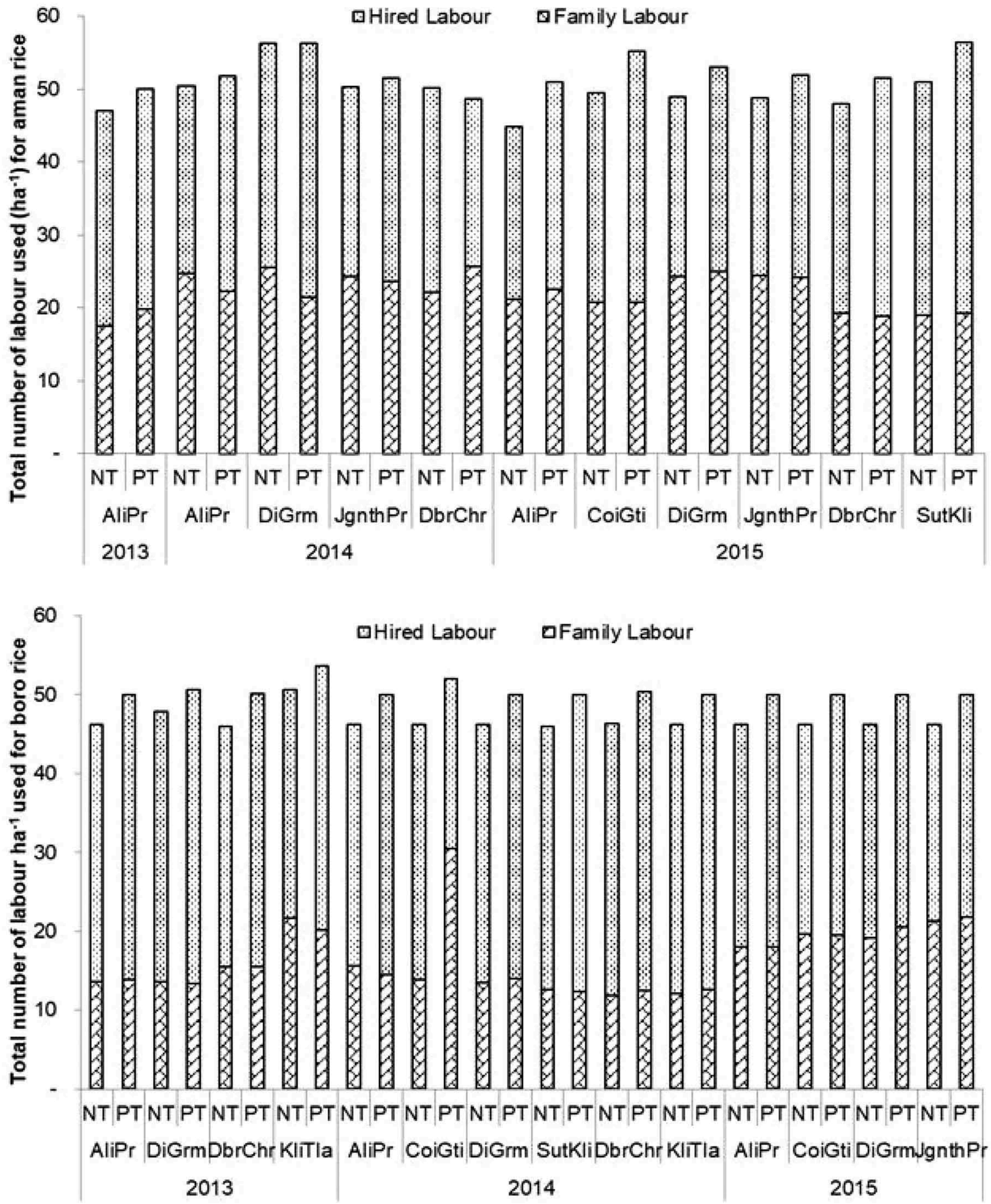

Figure 4. Source of labour for aman (upper) and boro (lower) season rice cultivation. Dots and diagonal bricks in the bars represent the family and hired labour (person-days ha^{-1}), respectively. NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; AliPr = Alipur, DiGrm = Digram, JgnthPr = Jogonnathpur, DbrChr = Durbachor, ChoGti = Choighati, KliTla = Kalitola, SutKli = Sutiakhali.

recorded for NT in aman season of 2015 over PT (Table 4).

Thousand grains mass was similar for NT and PT during aman season of 2013. In the aman season of 2014, the thousand-grain mass was higher with NT in some locations but lower in others (Table 6). During aman season on 2015, heavier thousand grain mass was recorded after NT (Table 6 and Figure 5).

3.2.3. Grain and straw yield

In aman seasons, there was no effect of NT on grain yield of rice (Table 6). Similarly, in the 2013 and 2014 seasons, NT

Table 4. Yield attributing characters of on-farm experiments of aman season rice.

		No. of effective tillers hill^{-1}			Panicle length (cm)		
Year	Location (L)	NT	PT	Mean	NT	PT	Mean
2013	Alipur	15.5	13.8	14.7	12.8	12.7	12.8
	LS		NS			NS	
	CV%		11.3			16.2	
2014	Alipur	14.5	15.7	15.1	13.5	12.8	13.2
	Digram	14.5	14.3	14.4	15.5	15.0	15.3
	Jogonnathpur	17.5	15.0	16.3	14.8	13.0	13.9
	Durbachor	15.2	14.2	14.7	13.2	13.2	13.2
	Mean	15.1	14.8		14.3	13.5	
	LS	L = NS, T = NS, LxT = NS			L = NS, T = NS, Lx T = NS		
	CV%		13.0			11.3	
2015	Alipur	18.7a	18.0	18.3A	16.2	16.2	16.2A
	Choighati	18.8	17.2	18.0AB	14.5	13.7	14.1B
	Digram	15.5	14.7	15.1CD	16.2	15.3	15.8A
	Jogonnathpur	15.3	14.3	14.8CD	14.7	13.8	14.3B
	Durbachor	15.3	13.5	14.4D	14.3	13.5	13.9B
	Sutiakhali	17.0	15.7	16.3BC	14.3	12.7	13.5C
	Mean	16.8a	15.6b		15.0a	14.2b	
	LS	L = **, T = *, L x T = NS			L = **, T = *, L x T = NS		
	CV%		13.9			11.4	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values having same capital letter in columns for location means and small letters in a row for means of the transplanting methods are not significantly different by DMRT.

had no effect on boro grain yield. The interaction effect between location and treatments (NT and PT) was observed in the boro season of 2015 where highest ($p < 0.05$) grain yield (6.10 t ha^{-1}) was recorded in NT, but among the locations it was only statistically higher at Alipur (Table 7).

During the aman and boro seasons of 2015, higher straw yield was recorded for NT treatment than PT (Tables 6 and 7).

3.3. Economics

3.3.1. Gross production cost

The average gross production cost of aman season rice in 2014 for NT treatment was US$ 998 ha^{-1} which was US$ 15 ha^{-1} higher ($p < 0.05$) than PT (Table 8). In the aman season of 2015, gross production cost was US$ 59 ha^{-1} lower ($p < 0.01$) for NT than PT (Table 8). Lower ($p < 0.01$) gross production cost for NT over PT was consistently found in boro seasons of 2013, 2014 and 2015 (Table 9).

3.3.2. Gross income

Higher ($p < 0.01$) gross income (earning from grain and straw sales) was reported for NT over PT during aman season of 2014 (Table 8). No difference on gross income was reported between two treatments (NT and PT) in the aman season of 2015 (Table 8). Higher ($p < 0.01$) gross income was attained from NT than PT during the boro season of 2015 (Table 9).

3.3.3. Net return or loss

The net returns of 2013 aman season rice for NT and PT were US$ 109 and US$108 ha^{-1}, respectively, which were statistically similar. The net loss for cultivation of aman season rice in PT treatment was US$ 139 ha^{-1} in

Table 5. Yield attributing characters of on-farm experiments of boro season rice.

		Number of effective tillers hill^{-1}			Number of ineffective tillers hill^{-1}			Panicle length (cm)		
Year	Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	23.2	21.8	22.50A	5.33	5.33	5.33A	19.7	19.3	19.50
	Digram	22.0	21.0	21.67A	4.50	4.16	4.30B	19.0	18.7	18.83
	Durbachor	17.3	17.8	21.50A	4.66	7.00	5.83A	19.5	18.0	18.75
	Kalitola	21.8	21.5	17.58B	4.83	6.83	5.83A	20.3	19.7	20.00
	Mean	21.1	20.5		4.82b	5.83a		19.6	18.9	
	LS	L = **, T = NS, L x T = NS			L = **,T = **, L x T = **			L = NS, T = NS, L x T = NS		
	CV%		9.6			19.10			10.1	
2014	Alipur	23.0	21.2	22.1A	5.16	5.66	5.41	20.5	20.5	20.50A
	Choighati	22.5	22.0	22.3A	5.50	5.33	5.41	22.0	19.5	20.75A
	Digram	19.5	18.2	18.8BC	5.16	6.16	5.66	19.2	19.8	19.50B
	Sutiakhali	20.8	18.3	19.6B	5.66	6.16	5.91	17.3	17.7	17.50C
	Durbachor	17.8	167	17.3C	5.00	5.50.	5.25	17.0	17.0	17.00C
	Kalitola	19.7	20.0	19.8B	5.00	6.00	5.50	18.2	17.3	17.75C
	Mean	20.6a	19.4b		5.25	5.80		19.1	18.6	
	LS	L = **, T = *, L x T = NS			L = NS, T = NS, L x T = NS			L = **, T = NS, L x T = NS		
	CV%		10.9			31.69			10.9	
2015	Alipur	23.2	22.5	22.8	6.16	5.50	5.83	16.5	15.5	16.00C
	Choighati	21.3	20.3	20.8	5.16	6.16	5.66	17.7	17.3	17.50BC
	Digram	22.5	21.0	21.8	6.00	6.16	6.08	18.5	18.2	18.33AB
	Jogonnathpur	22.7	20.7	21.7	4.66	5.50	5.08	20.3	19.2	19.75A
	Mean	22.4a	21.1b		5.50	5.83		18.3	17.5	
	LS	L = NS, T = *, L x T = NS			L = NS, T = NS, L x T = NS			L = **, T = NS, L x T = NS		
	CV%		9.4			21.3			10.3	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values having the same capital letter in columns for location means and small letters in a row for means of the transplanting methods are not significantly different by DMRT.

Table 6. Grain mass, grain and straw yield of on-farm experiments with aman season rice.

		Grain mass $^{-1000}$ (g)			Grain yield (t ha^{-1})			Straw yield (t ha^{-1})		
Year	Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	24.0	23.8	23.9	3.97	3.96	3.96	4.13	4.16	4.14
	LS		NS			NS			NS	
	CV%		9.1			9.5			12.3	
2014	Alipur	19.5c	18.5c	19.0A	4.50	4.33	4.41B	4.85	4.17	4.78C
	Digram	19.7c	21.3b	20.5B	4.45	4.48	4.46B	5.02	4.76	4.90B
	Jogonnathpur	23.2a	22.0ab	22.6A	5.36	5.18	5.27A	5.33	5.20	5.27A
	Durbachor	23.0a	23.0a	23.0A	4.71	4.41	4.56B	5.16	4.91	5.03AB
	Mean	21.3	21.2		4.75	4.60		5.09	4.89	
	LS		L = **, T = NS, L x T = *			L = *, T = NS, L x T = NS			L = *, T = NS, L x T = NS	
	CV%		8.8			9.6			17.5	
2015	Alipur	22.3	20.7	21.5A	4.60	4.56	4.58B	4.78	4.79	4.79B
	Choighati	21.3	20.8	21.1AB	4.69	4.45	4.57B	4.97	4.80	4.89B
	Digram	23.2	21.7	22.5A	5.07	4.96	5.02A	5.36	5.12	5.24A
	Jogonnathpur	18.0	16.3	17.2C	4.43	4.44	4.44BC	4.78	4.68	4.73B
	Durbachor	18.8	18.2	18.5C	4.12	4.11	4.11D	4.46	4.48	4.47C
	Sutiakhali	21.8	19.7	20.8B	4.30	4.18	4.24CD	5.13	4.73	4.93B
	Mean	20.9a	19.6b		4.54	4.45		4.92a	4.77b	
	LS		L = **, T = **, L x T = NS			L = **, T = NS, L x T = NS			L = **, T = *, L x T = NS	
	CV%		8.1			12.5			15.7	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). Values with the same capital letter in columns for location means and small letters in a row for means of the transplanting methods are not significantly different by DMRT.

2015, which was 59% greater ($p < 0.01$) than NT (Table 8) in the same year. The average net return for boro season rice cultivation with NT was US$ 411, US$ 82 and US$ 408 ha^{-1} during 2013, 2014 and 2015, respectively, which was higher ($p < 0.01$) than PT in all three years (Table 9). In aman season, 53 out of 66 farmers who practised NT reported higher net returns than in PT, while 49 out of 66 farmers reported higher yield with NT (Figure 6). In boro season of 2013, 2014 and 2015, the net return was higher in 90–92% of cases in NT than PT, while 75% had the same or higher grain yield (Figure 6).

3.4. Farmers' experiences and perception on NT

At the end of each aman and boro season, farmers' experiences and feedback on NT vs. PT were captured through farmers' meetings and FGD events. A total of 21 farmers' meetings and FGDs were conducted in different locations of the on-farm experiments where a total of 703 farmers (282 aman and 421 of boro seasons) attended and shared their experiences and perceptions as a group on the benefit and bottlenecks of NT. For consistency among the years, collected information from Alipur, Choighati and Digram locations were reported in Figure 7. Several farmers of Alipur locations were aware about the NT since 2008 (Haque et al., 2016), though the information on their perception and experience of NT was not previously collected. In this study, data were collected from Alipur location from the boro season of 2013 to aman season of 2015. After the first boro season, a total of 20 farmers attended the FGD at Alipur and reported various benefits of the NT over PT (Figure 7); however, the percentage of farmers reporting the benefits increased over time (Figure 7). During the boro season of 2013, about 55% of farmers reported that the adoption of NT could reduce land preparation cost, which was increased (R^2 = 0.85) up to 92% after the sixth season (aman season of 2015) (Figure 7). Similarly, 50% farmers in the boro season of 2013 reported higher grain yield which increased up to 70% of farmers at the end of aman season of 2015. Farmers of Alipur also similarly reported on the use of reduced labour numbers ha^{-1} for weeding and less weed infestation in the NT plots (Figure 7). Farmers' perception and experience on the negative aspects of NT declined over time at Alipur location (Figure 7).

At the beginning (from boro season of 2013), 50–60% of farmers of Alipur reported that: it was difficult to transplant rice seeding in NT; labourers were less willing (and sometimes charged more) to transplant rice seedlings in NT than PT; it was difficult to make strips in hard setting dry soil for NT; initial water requirement (number of irrigation events prior to transplanting of rice seeding in NT, but not total irrigation amount) was higher; farmers were discouraged by the neighbouring farmers to try NT for rice seedling transplanting; and land appeared untidy due to transplanting of rice seedling in retained residue under NT systems (Figure 7). However, after six cropping seasons, the negative perception had declined (Figure 7). Similar trends on the farmer's experience and perception for adoption of NT

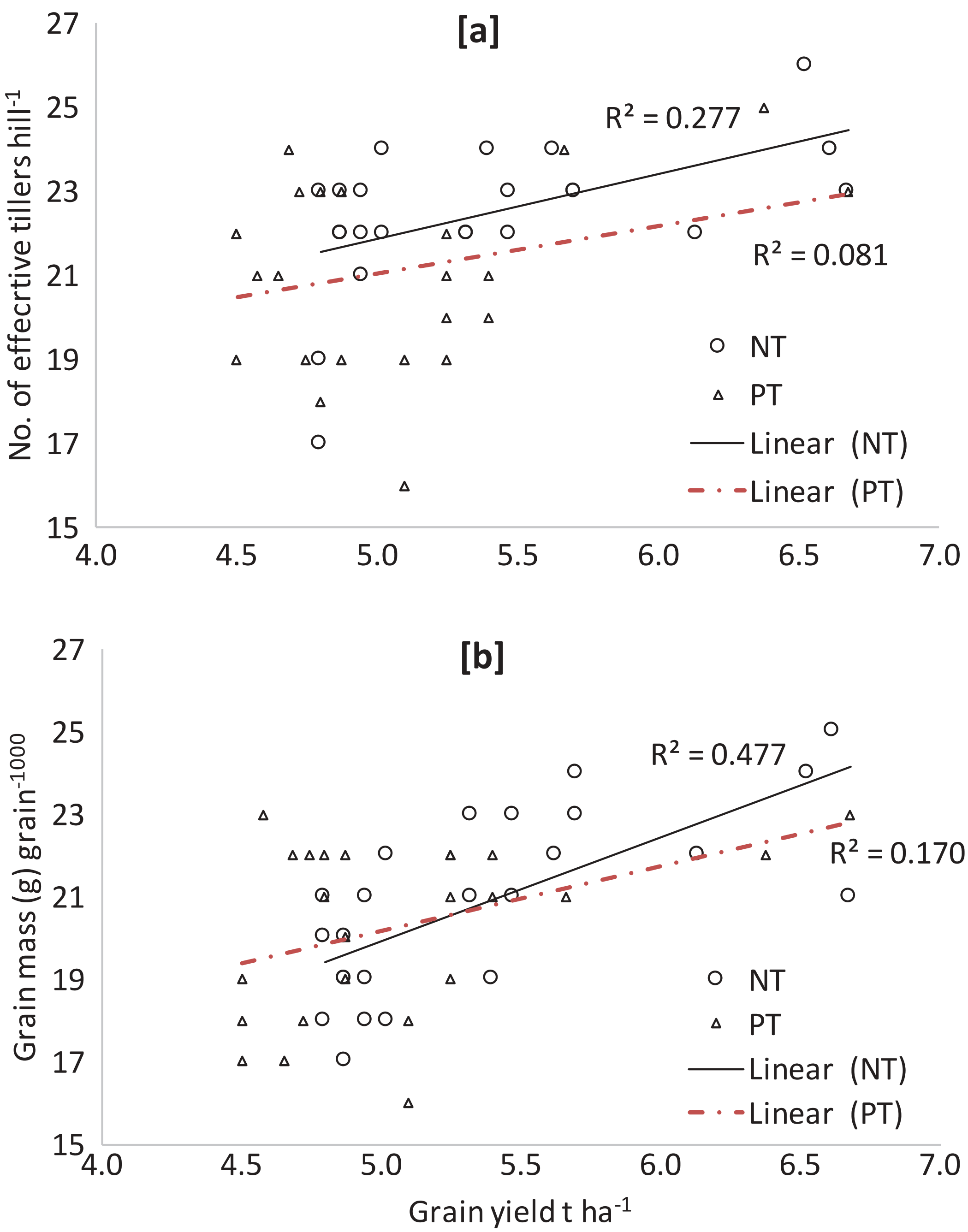

Figure 5. Relationship between grain yield for non-puddled transplanting (NT) and puddled transplanting (PT) of rice with [A] number of effective tillers and [B] thousand grain mass for 2015 boro rice.

were reported from Choighati and Digram locations (Figure 7).

4. Discussions

From the 150 farmer-managed experiments during aman and boro seasons of three consecutive years, it was confirmed that rice cultivation commencing with NT of rice seedlings provided similar or greater grain yield of rice to that under full tillage and puddling of soil followed by transplanting (PT). Indeed 83%, 61% and 75% farmers obtained higher or similar boro rice grain yield in NT over PT during 2013, 2014 and 2015, respectively (Figure 6). A similar trend was also found in the case of aman season where 67%, 75% and 75% farmers received higher or similar rice grain yield in 2013, 2014 and 2015, respectively (Figure 6). This result indicated that although there were no substantial rice grain yield increases in the case of NT, the majority farmers obtained higher rice yield in NT (Figure 6).

Table 7. Grain and straw yield of on-farm experiments with boro season rice.

		Grain mass $^{-1000}$ (g)			Grain yield (t ha^{-1})			Straw yield (t ha^{-1})		
Year	Location	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	23.3	22.2	22.8A	5.85	5.71	5.78B	6.33	6.17	6.25A
	Digram	21.2	20.7	20.5B	5.23	4.92	5.08C	5.55	5.43	5.49B
	Durbachor	19.5	18.0	18.8C	4.77	4.55	4.66D	5.07	4.92	5.00C
	Kalitola	21.7	20.7	21.2D	6.46	6.19	6.32A	6.45	6.24	6.34A
	Mean	21.4a	20.2b		5.58	5.34		5.85	5.69	
	LS		L = **, T = *, L x T = NS			L = **, T = NS, L x T = NS			L = **, T = NS, L x T = NS	
	CV%		8.6			7.71			15.2	
2014	Alipur	19.8	21.7	20.8A	6.02	6.05	6.04A	6.22	5.65	5.93A
	Choighati	19.8	17.7	18.8BC	4.58	4.45	4.51CD	5.06	4.97	5.01B
	4.72Digram	21.7	21.3	21.5A	4.76	4.61	4.69C	5.13	5.15	5.23B
	Sutiakhali	18.7	18.8	18.8BC	4.53	4.27	4.40D	4.75	4.68	4.72C
	Durbachor	18.8	17.7	18.3C	4.73	4.72	4.73C	5.05	5.26	5.14B
	Kalitola	20.5	19.3	19.9AB	5.19	4.96	5.08B	5.18	5.11	5.15C
	Mean	19.9	19.4		4.97	4.85		5.26	5.13	
	LS		L = **, T = NS, L x T = NS			L = **, T = NS, L x T = NS			L = **, T = NS, L x T = NS	
	CV%		10.1			11.1			16.0	
2015	Alipur	22.5	22.0	22.3A	6.10a	5.56b	5.83A	6.03	5.70	5.86A
	Choighati	18.7	18.3	18.5B	4.95cd	4.71d	4.83C	5.43	4.93	5.18C
	Digram	20.0	19.5	19.8B	4.92cd	4.85cd	4.88C	5.58	5.52	5.55B
	Jogonnathpur	22.2	21.3	21.8A	5.48b	5.17bc	5.33B	5.57	5.41	5.49B
	Mean	20.8	20.3		5.36a	5.07b		5.65a	5.39b	
	LS		L = **, T = NS, L x T = NS			L = **, T = **, L x T = *			L = **, T = **, L x T = NS	
	CV%		7.3			7.5			16.3	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1% and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values with the same capital letter in columns for location means and a small letter in a row for means of the transplanting methods are not significantly different by DMRT.

Haque et al. (2016) reported that the rice grain yield in Bangladesh was similar in non-puddled rice establishment systems irrespective of four tillage methods; however, straw yield was significantly higher in NT which depressed the harvest index. In this on-farm study, no significant difference in rice grain and straw yield between NT than PT during aman seasons of 2013–2015 and boro seasons of 2013 and 2014 were followed by significantly higher straw yield in the aman season of 2015 and both grain and straw yields in the boro season of 2015 under NT than PT. It is possible that the yield increases in the later years represent the benefits of farmer learning of the technology of NT. While rice cultivation under full soil tillage and puddling is a decades-old practice and farmers are well trained to practice PT, rice cultivation under NT is new technology

Table 8. Economics for on farm experiments of aman season rice.

		Gross production cost (US$ ha^{-1})			Gross income (US$ ha^{-1})			Net return (US$ ha^{-1})		
Year	Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	947	838	944	1124	1124	1124	109	108	109
	LS		NS			NS			NS	
	CV%		11.9			13.5			35.7	
2014	Alipur	964	966	965C	1132	1091	1111b	73	39	56B
	Digram	1014	993	1004AB	1124	1126	1125b	11	50	31C
	Jogonnathpur	1021	997	1009A	1340	1297	1319a	226	2090	217A
	Durbachor	994	978	986B	1188	1114	1151b	123	54	88B
	Mean	998a	983b		1196a	1157b		108	88	
	LS		L = **, T = *, L x T = NS			L = **, T = *, L x T = NS			L = **, T = NS, L x T = NS	
	CV%		12.4			16.4			81.7	
2015	Alipur	899i	973ef	936D	977	968	972B	4	−83	−39B
	Choighati	986de	1060a	1023A	997	946	971B	−69	−195	−132CD
	Digram	955gh	991d	973C	1077	1051	1064A	53	−9	22A
	Jogonnathpur	945h	1007c	975C	943	943	943BC	−79	−202	−110C
	Durbachor	968fg	1010bc	989B	877	875	876D	−161	−202	−181E
	Sutiakhali	957gh	1021b	987B	920	893	907CD	−109	202	−156DE
	Mean	951b	1010a		965	946		−60a	−139b	
	LS		L = **, T = **, L x T = **			L = **, T = NS, L x T = NS			L = **, T = **, L x T = NS	
	CV%		11.2			15.4			−54.5	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** and * mean significant at 1 and 5%, respectively]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values with that same capital letter in columns for location means and small letters in a row for means of the transplanting methods are not significantly different by DMRT.

Table 9. Economics for on farm experiments of boro season rice.

		Gross production cost (US$ ha^{-1})			Gross income (US$ ha^{-1})			Net return (US$ ha^{-1})		
Year	Location (L)	NT	PT	Mean	NT	PT	Mean	NT	PT	Mean
2013	Alipur	1013	1041	1027B	1548	151	1530B	483	417	450B
	Digram	1026	1056	1041A	1382	1304	1343C	3036	197	250C
	Durbachor	1001	1037	1020BC	1261	1204	1232D	200	106	153D
	Kalitola	987	1028	1008C	1698	1628	1663A	656	548	602A
	Mean	1007b	1041a		1473	1412		411a	317b	
	LS		L = **, T = **, L x T = NS			L = **, T = NS, L x T = NS			L = **, T = **, L x T = NS	
	CV%		11.6			17.3			29.6	
2014	Alipur	1072	1148	1110	1470	1471	1471a	338	268	303A
	Choighati	1080	1090	1085	918	1092	1005d	−11	−115	−63CD
	Digram	1093	1153	1123	1167	1132	1149BC	−22	−75	−26D
	Sutiakhali	1099	1172	1176	1106	1047	1077CD	−40	173	−106D
	Durbachor	1093	1177	1135	1158	1138	1138BC	27	−59	−16C
	Kalitola	1087	1157	1119	1266	1212	1239B	154	22	88B
	Mean	1087b	1148a		1181	1185		82a	−22b	
	LS		L = NS, T = **, L x T = NS			L = **, T = NS, L x T = NS			L = **, T = **, L x T = NS	
	CV%		13.9			22.5			242	
2015	Alipur	1007	1043	1025B	1680	1537	1608a	603	424	514A
	Choighati	969	1015	992D	1374	1303	1338c	329	213	271C
	Digram	995	1030	1012C	1370	1350	1360c	302	241	271C
	Jogonnathpur	1048	1115	1082A	1514	1431	1473b	397	1457	321B
	Mean	1005b	1051a		1485a	1406b		408a	281b	
	LS		L = **, T = **, L x T = **			L = **, T = **, L x T = NS			L = **, T = **, L x T = NS	
	CV%		11.3			17.1			29.5	

NT = Non-puddled transplanting of rice seedling; PT = Conventionally puddled transplanting of rice seedling; LS = Level of significance [** mean significant at 1%]; NS = Not significant; CV = Coefficient of variation; L = Locations; T = Transplanting methods (NT or PT). US$1 = Tk. 78. Values with the same capital letter in columns for location means and small letters in a row for means of the transplanting methods are not significantly different by DMRT.

whose potential benefit may take time to realize. There was also a substantial increase in positive perceptions and decline in negative perceptions about NT among farmers over the three years of gaining experience with the technology and gathering evidence of its benefits. This adds to previous results on NT (e.g. Ladha et al., 2009; Saharawat et al., 2009) which found that NT into zero tilled soil increased average rice yields on farmer's fields by 0.3 t ha^{-1}, whereas Ladha et al. (2009) reported a range of rice yield responses to zero tillage NT from −0.8 to +1.5 t ha^{-1}.

Many previous studies on minimum soil disturbance crop establishment have also reported equivalent crop yields to traditional full tillage systems. However, most of the previous researchers had examined minimum soil disturbance vs. full tillage with rainfed crops (e.g. Sharma, Abrol & Sharma, 2011) rather than transplanted rice. For rainfed crops, Baker and Saxton (2007) report that it is common to experience some yield reduction in the first few no-tillage years, largely because it takes time for the soil to re-establish favourable soil structure after minimum tillage is implemented. If a transition period of yield reduction occurs, it can often be overcome or even averted with increased fertility, fertilizer banding with drill openers and careful crop selection (Baker & Saxton, 2007). Sharma et al. (1995) examined transplanted rice after one full tillage pass in wet soil to puddle the soil and reported similar rice yield to transplanting after full soil puddling involving several tillage operations; however, single-pass full tillage in wet land while reducing the number of tillage passes failed to take advantage of minimum soil disturbance and the benefits it affords. The present study now shows that transplanting rice seedlings into the narrow strips of disturbed soils (that covered about 20–25% of the soil) without puddling (i.e. NT) produces greater or at least similar yield to the conventional crop establishment by transplanting on fully puddled (i.e. PT) soils. The increases in grain yield of boro rice in 2015 with NT were associated with higher number of effective tillers hill^{-1} and higher grain^{-1000} weight (Figure 5). This suggests that less post anthesis crop stress, along with farmers' improved skills of NT management, enhanced effective tiller numbers and grain mass which might explain the increased rice grain yield in the case of NT. In two experiments where soils have been continuously managed by CA practices (SP + NT plus increased crop residue retention) for 5 years, rice crop N uptake was increased in the post-tillering phase of growth (Md. K. Alam, personal communication). If the same improvement in post-tillering N uptake occurred in the NT crops in 2015, that might explain the increased grain weight, effective tiller number and grain yield. The beneficial effects of strip placement on rice crop N fertilizer availability are discussed below. However, further research is still needed to pinpoint the main physiological or nutritional factors that increase grain yield of NT rice crops.

Several studies, including Haque et al. (2016), reported that poor weed control was a threat to rice grain yield under NT. However, in the present study,

Table 10. Cost of actual different inputs and outputs (US$ ha^{-1}).

	2013		2014		2015	
Inputs and outputs (unit)	Aman	Boro	Aman	Boro	Aman	Boro
Land preparation cost for puddled transplanting (US$ ha^{-1})	83.65	83.29 (64.42–105.77)	91.35 (67.31–105.77)	95.10 (81.73–105.76)	93.44 (67.31–105.77)	103.37 (81.73–144.23)
Land preparation cost (single pass with VMP) (ha^{-1}) in the case of NT	28.85	28.85	33.65 (28.85–38.46)	28.85 (25.99–38.46)	35.99 (28.85–38.46)	36.26 (33.65–38.46)
Seedlings cost (ha^{-1})	115.38	81.73	81.73	72.12	67.30	76.92
Urea[a] fertilizer cost (kg^{-1})	0.21	0.21	0.21	0.21	0.21	0.21
Di-ammonium phosphate (DAP)[b] fertilizer cost (kg^{-1})	0.35	0.35	0.35	0.35	0.35	0.36
Murate of potash (MoP) [c] fertilizer cost (kg^{-1})	0.19	0.19	0.19	0.19	0.19	0.19
Gypsum[d] fertilizer cost (kg^{-1})	0.09	0.09	0.09	0.09	0.09	0.09
Zinc sulphate[e] fertilizer cost (kg^{-1})	1.53 (1.15–1.92)	1.54 (1.28–1.92)	1.28	1.41 (1.15–1.92)	1.28	1.71 (1.28–1.92)
Boron[f] fertilizer cost (kg^{-1})	2.5 (2.31–2.56)	2.5 (2.31–2.56)	2.50 (2.31–2.56)	2.76 (2.31–3.85)	2.31	3.08 (2.31–3.85)
Irrigation water cost (ha^{-1}) NT	32.59 (0–67.31)	211.53	20.83 (0–57.69)	201.92	38.46	177.88 (163.46–192.31)
Irrigation water cost (ha^{-1}) PT	30.45 (0–61.30)	215.53	31.25 (0–67.92)	201.92	57.69	177.88 (163.46–192.31)
Pre-planting herbicide, round-up (glyphosate) herbicide cost (l^{-1})	4.49	4.49	4.49	4.49	4.49	4.49
Labour cost (person day^{-1})	3.85	3.85	3.69 (3.21–3.85)	3.53 (2.56–3.85)	3.46 (2.82–3.85)	3.69 (3.21–3.85)
Contractual harvesting and threshing cost (ha^{-1})	168.27	192.31	192.31	182.69	173.08	193.72 (163.46–217.18)
Post-planting herbicide (Pretilachlor) cost (kg^{-1})	8.65	8.65	8.65	8.65	8.65	8.65
Post-planting herbicide (Pyrazosulfuron ethyl 20 WP) cost (kg^{-1})	4.80	4.80	4.80	4.80	4.80	4.80
Virtako 40 WG (Thiamethoxam + Chlorantraniliprole) cost (kg^{-1})	282.05	282.05	282.05	282.05	282.05	282.05
Imidacloprid cost (l^{-1})	24.36	24.36	24.36	24.36	24.36	24.36
Rent of the land (ha^{-1})	384.62	230.76	346.15	288.46	288.46	211.56 (182.69–240–39)
Sale price of rice (t^{-1})	256.41	243.59	230.76	230.77	205.13	256.41
Sale price of straw (t^{-1})	25.64	19.23	19.23	12.82	12.82	19.22

Note: Numbers in the cells denote the average price and numbers in parenthesis represent the range (minimum and maximum) of the inputs and outputs price. [a] See Table 1 for fertilizer composition.

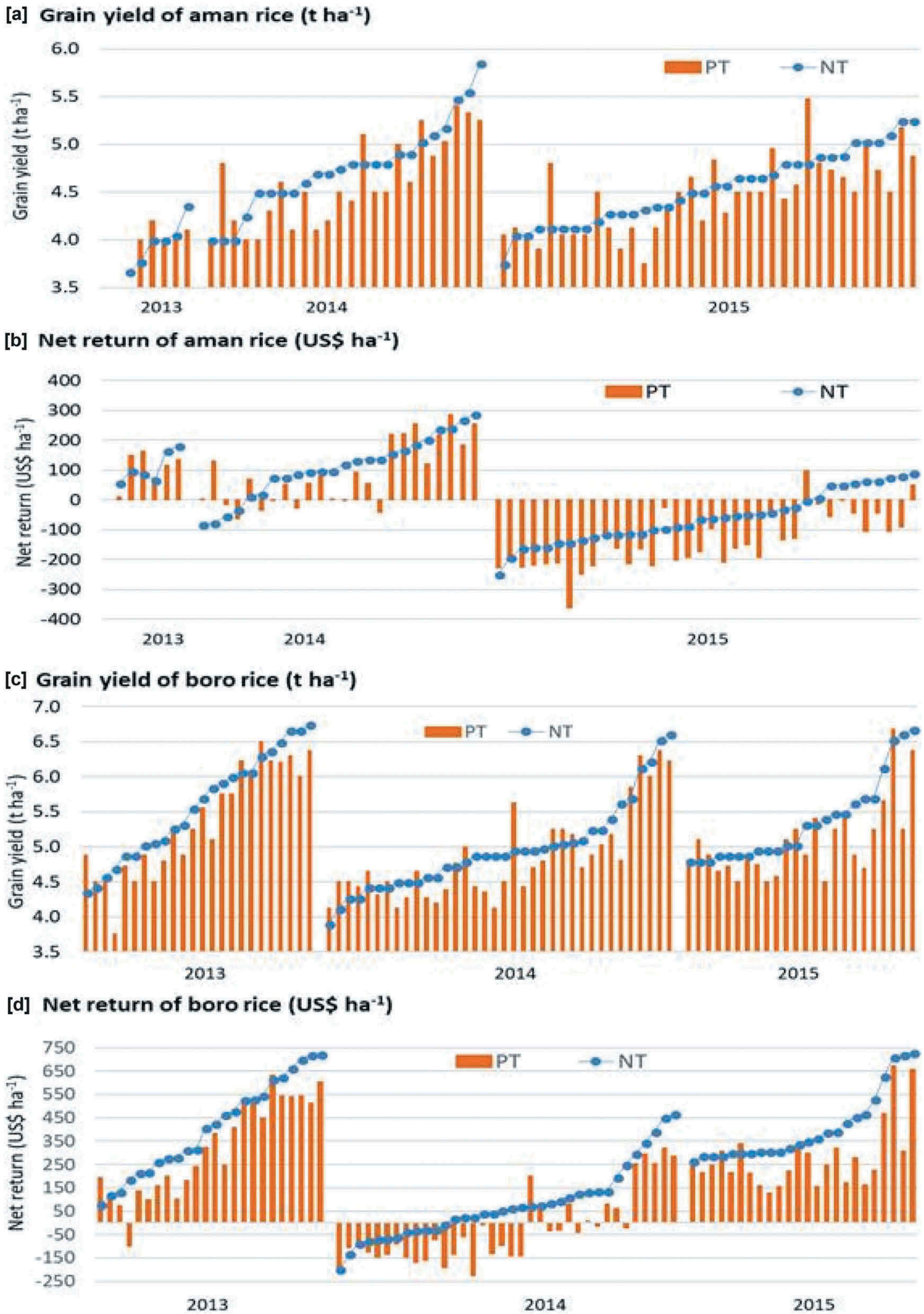

Figure 6. Ranking of individual farmers' rice grain yield (t ha^{-1}) (aman rice [A] and boro rice [C]) and net return (aman rice [B] and boro rice [D]). Sites are ordered by net returns from low (left) to high (right) for NT [blue line with closed circles] for 2013, 2014 and 2015. Paired PT crops are shown underneath for each site by orange-coloured bars.

the application of the non-selective herbicide, glyphosate, prior to land preparation for NT was practised sufficiently well by farmers to control pre-germinated weeds in NT establishment of rice. Indeed, the labour requirement for weeding was lower in PT fields than NT rice despite the fact that the full tillage help to kill

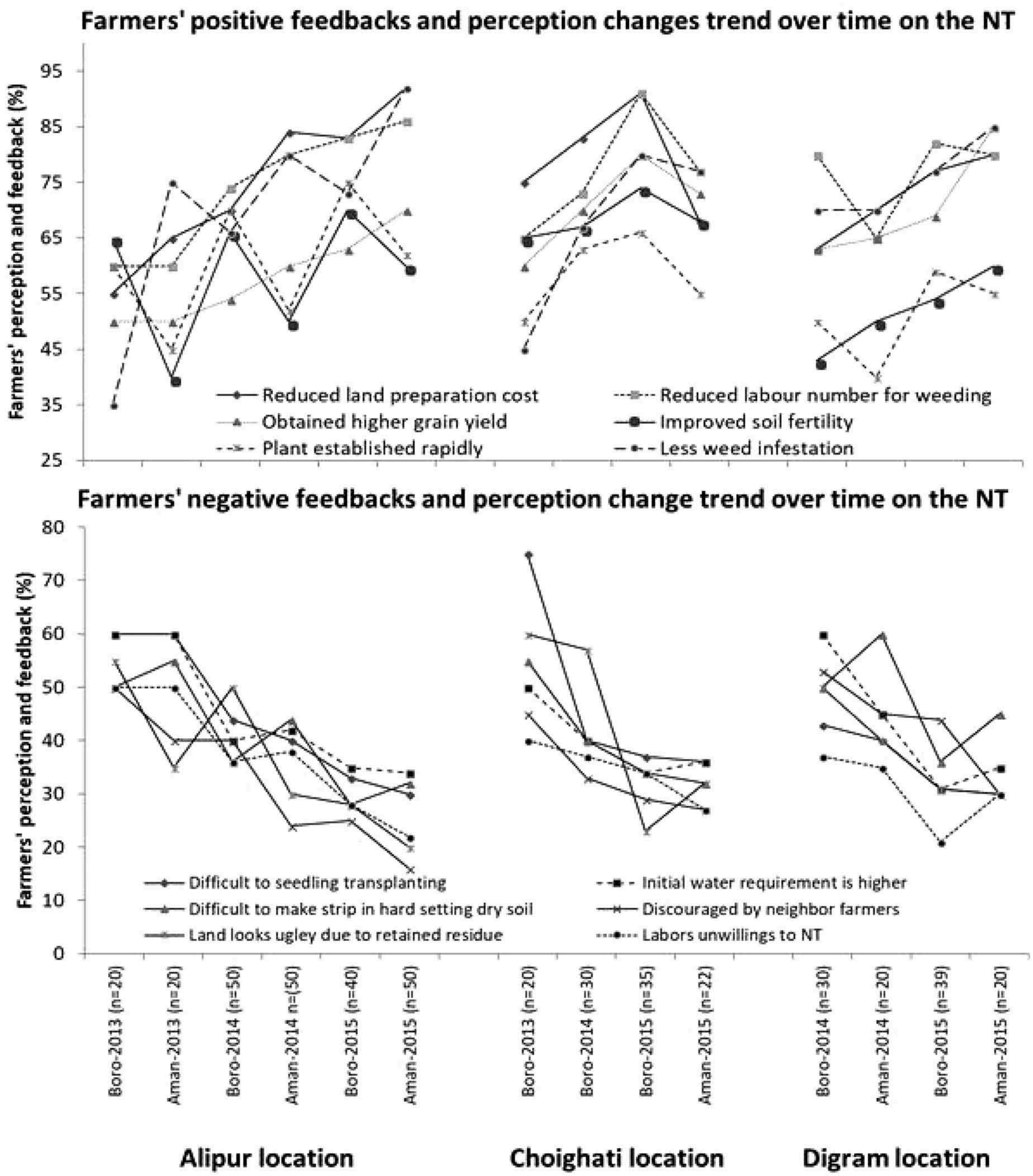

Figure 7. Percentage of farmers' with positive or negative perceptions about aspects of non-puddled transplanting (NT) from focus group discussions in three locations after each of six seasons. The percentage values are for the whole group in each location and season.

weeds before transplanting. In NT plots, on average US$ 4.5 ha^{-1} was required for killing pre-emerged weed (Table 10), whereas substantial amount of money (US$ 83 to US$ 103 ha^{-1}) was required for land preparation (Table 10) including killing pre-emerged weeds of PT plots. Application of knock-down herbicide and minimum soil disturbance for NT might help to reduced post-transplanting weeding labours for aman and boro rice (Tables 2 and 3). Weed infestation is also a persistent constraint in direct seeding of rice in both wet and dry seeding that results in lower grain yield (Singh et al., 2011) and hinders widespread adoption by farmers (Farooq et al., 2011). Hand weeding in these farming systems is hampered by the increasing scarcity of labour and its high cost. Other than hand weeding, there are many pre- and post-transplanting herbicides available (Haque et al., 2018; Zahan et al., 2014). Selection of effective herbicides will play a key role in maintaining weed control for PT and NT rice (Zahan, Hashem, Rahman, Bell & Begum, 2018). It remains unclear whether residue retention and the lower suspended sediment load in standing water of non-puddled soils alters the efficacy of the pre-emergence and early post-emergence herbicides commonly used in wetland rice. The use of herbicide in conventionally puddled rice fields (e.g. PT) to control weed is rapidly increasing in Bangladesh particularly for rice crops due to limited availability of labour (Haque et al., 2018). The farmers in the study areas used knock-down herbicide for NT, and selective herbicides for both NT and PT to control weeds, which ensured satisfactory weed control. Hossain et al. (2017) also confirmed that the higher level of straw mulching or appropriate selection of herbicide could successfully suppress weeds in NT rice fields.

Specific crops and varieties might be better adapted to particular levels of soil disturbance and agronomic practices. Sayre (1998) reported that the crucial step in promoting bed-planting of wheat was to test a wide spectrum of varieties with differing heights, tillering abilities, phenology and canopy architectures in order to identify the plant phenotype for optimum performance on beds. The same is probably true for NT rice. The present rice cultivars have been selected under PT, but it remains unclear whether these cultivars are most suitable for NT. Hossain et al. (2017) reported that the rice cv. BR11 and BRRIdhan-46 produced higher grain yield and benefit cost ratio (BCR) in the NT than other cultivars but more rigorous assessment of cultivar suitability for NT is still needed. For minimum tillage methods, early vigour of transplanted seedlings would be beneficial for suppressing weeds (Dingkuhn, Johnson, Sow & Audebert, 1999). Hence, there is potential to achieve greater productivity of the NT rice through research to identify varieties better adapted to this planting approach.

Changes in nutrient availability and soil strength under NT may also favour cultivars with greater early rooting vigour or nutrient uptake efficiency (Borrell, Garside, Fukaj, & Reid, 1998). Initial shorter term studies on the N fertilizer requirements for rice under NT had shown no change in fertilizer N requirement vs. PT (Jahiruddin, Islam, Haque, Haque & Bell, 2014). These findings need to be verified in longer term studies in farmer-managed NT. However, the addition of DAP in the strip means that NT seedlings have greater access to N and P fertilizer after transplanting which may increase the early vigour of NT seedlings. Observations of NT seedlings in farmers' field suggest that the seedlings recover faster after transplanting and have darker green leaves and more early vigour (M.E. Haque, personal communication). This may be related to the close proximity of NT seedling roots to strip-placed DAP, as compared to the broadcast and incorporated DAP for PT seedlings. On the other hand, K, S, Zn and B fertilizers are incorporated into soil during the final tillage operation, while in the NT crop those fertilizers are broadcast on the soil surface but not incorporated. Hence, plant availability of K, S, B and Zn fertilizers applied may be greater under PT than NT.

In the study areas, cultivation of boro rice fully depends on irrigation water. The charge for irrigation water in the study areas was based on lump-sum fixed cost per ha. Hence, there is presently no decrease in cost of irrigation water when farmers use reduced volume of irrigation water as was the case for NT in the present study. Cultivation of aman rice in the study areas mostly depended on rain water. In several cases, supplementary irrigation water was required to cultivate aman rice in the study areas, so farmers hired irrigation pump on an hourly basis and recorded irrigation costs for NT and PT separately (Table 10). This record confirmed that the aman rice cultivation with supplementary irrigation water using NT saved about 33% irrigation water and cost over PT (Table 10).

Greater net returns (or minimized losses) were calculated for NT in aman season by 50%, 63% and 92% farmers in successive years. Due to low price of aman rice grain, a declining price trend (256, 231 and 205 US$ t^{-1}), and increasing trend of gross production cost during 2013, 2014 and 2015, respectively, net losses occurred for rice cultivation in several cases in 2014, and most cases in 2015 (Figure 6). However, overall farmers increased profit or minimized the net losses with NT relative to PT (Figure 6). During harvesting period, the boro rice grain price was 244, 231 and 256 US$ t^{-1} in 2013, 2014 and 2015, respectively. Overall 92%, 94% and 92% farmers increased their net return (or minimized net losses) where NT were practised in boro season of 2013, 2014 and 2015, respectively (Figure 6). Above results confirmed that while there were sometimes economic losses in both PT and NT in the farmers' fields due to low grain prices, the majority of farmers increased economic returns from NT, especially in boro season.

The transplanting of rice seedlings in puddled fields by hand is the common practice (about 100% of rice fields) in Bangladesh. However, labourers were initially reluctant to transplant rice seedling in NT fields perceiving that the soils in NT will be harder to transplant. However, the reluctance diminished steadily over time (Figure 7). On a sandy loam soil in south-west Bangladesh, Rashid et al. (2018) found a positive effect on rice yield of zero tillage NT with a mechanized transplanter, but not with manual transplanting. Wider application of mechanical rice transplanters may enhance the adoption of NT rice by removing concerns of labour about the slower process of transplanting in non-puddled soils which took about 2 person-days ha^{-1} longer and negated some of the decrease in labour required for weeding. Hossen, Hossain, Haque and Bell (2018) successfully developed a conventional rice transplanter of PT which could be used for both NT and PT; and on-station trial results confirmed that there were no significant yield differences using the transplanter for both NT and PT; however, greater cost and time saving, and higher BCR were reported in NT than PT.

Other than PT of rice seedlings, rice seed can be broadcasted directly in moist soils or sown by zero tillage. Due to labour shortages for rice seedling transplanting, wet direct seeding has become popular in Vietnam, Thailand, Lao PDR, Haryana and Punjab of India. However, wet direct seeding still needs puddled soil. Risks of severe weed infestation (Singh et al., 2011), bird damage, low productivity, uncertain and erratic rainfall (Singh et al., 2011), insecure irrigation water supply and high irrigation water requirement during early seedling stage are the major constraints to adoption of zero tillage direct seeded rice (Haque et al., 2016) hindering the replacement of puddled rice transplanting by direct seeding rice in most rice growing areas (Farooq et al., 2011).

5. Conclusions

Due to farmers' preference for puddled transplanting to establish wetland rice seedlings, adoption of CA in rice-based systems has been slow. From 150 farmer-managed evaluations in both aman and boro seasons during 2013, 2014 and 2015, we conclude that transplanting of rice seedlings in non-puddled soils following strip tillage is feasible as an option. Moreover, the strip tillage non-puddled rice transplanting reduced the cost of rice cultivation and increased gross margin for the rice farmers. Over the 3 years, 69% of boro season crops and 67% of aman season crops had higher gross margin with NT. Within three consecutive years comprising six rice seasons, there was generally no significant yield difference between NT and PT; however, in the boro season of 2015, NT produced significantly higher grain and straw yield of rice than the conventional puddling and transplanting. This suggests that the benefits from non-puddled transplanting in terms of cost and greater grain and straw yields can be sustained over time. In farmers' fields, strip tillage, flooding soils for 18–24 h and then transplanting rice into non-puddled soil could be an option for rice establishment in rice-based systems which could enhance the adoption of CA.

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