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Water and fuel saving technologies: Unpuddled bed and strip tillage for wet season rice cultivation in Bangladesh

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Abstract
Shortages of water and the rapid spread of two-wheel tractors (2WT) have created the opportunity to develop locally-adapted conservation agriculture (CA) techniques for crop establishment by rice-based smallholders in South Asia. During 2009, the wet season rice (*Oryza sativa* L.) was transplanted into minimum tillage puddled; unpuddled-bed and strip tillage conditions in the drought-prone area of Bangladesh, to assess establishment methods that could reduce crop production cost and water use. Land preparations were done by the 2-WT operated, Versatile Multi-crop Planter (VMP) recently developed by CIMMYT, Bangladesh. Tillage treatments did not influence the shoot dry matter production. There was 65 % less diesel fuel required in the strip tillage treatment than with beds formed by VMP. Labour requirement for land preparation in beds formed by a shaper were 4.5 times higher than single pass puddling and beds formed by VMP. Time required to transplant seedlings was almost doubled in unpuddled plots relative to puddled plots. Weeding cost was higher in beds formed by VMP and strip tillage plots compared to other tillage treatments. Regardless of tillage treatment, 41-43 % less irrigation water was used by crops established by VMP planting operations as compared to a traditional tillage system.

Key Words
Versatile Multi-crop Planter, drought, bed formation, transplanted rice

Introduction
The northwest region of Bangladesh has drought prone areas, even though mean annual rainfall is 1645 mm (BMDA 1995). This area is covered with thick clay layers, which have low permeability. At the same time, the average depths of the deep tubewells already sunk into the soil are greater in comparison with other areas of Bangladesh (Khan *et al.* 1997). Due to uneven distribution of rainfall and limited availability of surface water, groundwater becomes the main source of irrigation water. Climate change, particularly higher temperatures, and higher rates of groundwater withdrawal may exacerbate drought during cool and dry seasons. Lower rainfall reduces recharge to the aquifers. The water table is declining and many of the tubewells are inoperable in the dry season (Bhuiyan 1982). Moreover, at the end of the transplanted rice season, puddled paddy fields dry and form cracks. The cracks accelerate water evaporation. The hard, dry surface of such soils hindered crop establishment until the introduction of 2-WT for cultivation. Presently, more than 0.35 million Chinese-made 2-WTs are being used in Bangladesh for agricultural purposes (Haque *et al.* 2004). Conservation agriculture helps farmers to reduce production costs while maintaining or increasing crop yields, and improving soil health, crop diversity and timeliness of cultivation. The CA technologies like reduced tillage, strip tillage, bed planting, and direct seeding might be applicable to conditions in northwest Bangladesh. Successful development of 2-WT based implements, zero tillage, strip tillage, minimum tillage and bed planters in Bangladesh have created several avenues for the pursuit of CA. However, farmers could only afford to engage in CA if they could purchase a single implement able to perform many operations. Thus, the 2-WT tractor operated VMP was developed with the provision to use adjustable row spacing of crops for zero tillage, strip tillage, minimum tillage, bed planting, and even conventional tillage operation; seeding and fertilizer application occur simultaneously in a single pass operation (UNAPCAEM 2009). A single tillage system is not feasible for all soils and climatic conditions. Therefore, the choice of the best suited tillage system must be appropriate for the particular agroecological environment. In this study, different tillage systems were compared in wet season rice during 2009 for establishing rice in a drought-prone zone of Bangladesh.

Methodology
The experiment was conducted at the Bangladesh Rice Research Institute (BRRI), Regional station, Rajshahi. The study area lies at 24°69′N and 88°30′E. Agroclimatic (rainfall, evapotranspiration and thermal

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condition) data were collected from the BRRI weather station. Initial bulk density in 0-7.5 cm depth was 1.21 (g/cm^3) at 39.7 % gravimetric water content and bulk density in 7.5-15 cm depth was 1.51 (g/cm^3) at 26.3 % gravimetric water content. The soil pH and organic carbon in the experimental field were 7.96 and 7.9 g/kg, respectively.

Four tillage treatments in the experiment were: (i) Single pass puddling by 2 WT (T_1); (ii) Single pass puddling by 2 WT followed by bed formed by operating a shaper tool manually 8 days after transplanting (T_2); (iii) Bed formed by VMP in single pass (T_3) and; (iv) Strip tillage by VMP in single pass (T_4). The plot size was 221 m^2. Before transplanting, land was leveled in the puddled plots. Two persons were engaged in the leveling operation. One labourer was needed to pull the shaper in the puddled field. The shaper was operated in the field three times to form a good bed shape. Wet season rice (July – November) grown was BR11, a popular high yielding variety. Thirty-five day old seedlings were transplanted in all tillage treatments. Seedlings were transplanted into puddled conditions (T_1 and T_2) or unpuddled conditions (T_3 and T_4). The treatments were arranged in a randomized complete block (RCB) design. The seedling spacing for T_1 and T_2 was 25 x 15 cm, and 20 x 15 cm for T_3 and T_4. In the T_2 and T_4 treatments, the width of beds and furrows were 35 cm and 20 cm, respectively. Data on task time, fuel consumption and agronomic performance were collected from all treatment plots. Derived-carbon dioxide emissions from field operations were calculated from the diesel used in tillage operation using the conversion factor of 2.6 kg of CO_2 per kg of diesel consumed (Greece 2003). Duncan's Multiple Range Test (DMRT) was used to determine the significant differences among the treatments.

Results and discussion

Fuel consumption

Fuel consumption was significantly higher (26.8 l/ha) in T_3 treatment than other treatments (Table 1). Fuel consumption in T_4 treatment was lowest (9.5 l/ha) among the tillage treatments i.e. 65 % less fuel was required compared to T_4. Conventional puddling required 16.5 l/ha whereas, tilling and seeding operation done by 2 WT operated seeder (PTOS) in single pass operation saved 40 % of diesel fuel per hectare per year (Miah *et al.* 2008). Carbon dioxide emission was higher (69.7 kg/ha) in T_3 treatment whereas CO_2 emission was lower in T_4 treatment (24.7 kg/ha) (Figure 1). Conventional puddling was done by 2 WT and required 4-5 passes to make a favourable condition for establishing transplanted rice. Strip tillage method reduced by 65 and 48 % CO_2 emission as compared to the bed by VMP and single pass puddling operations, respectively.

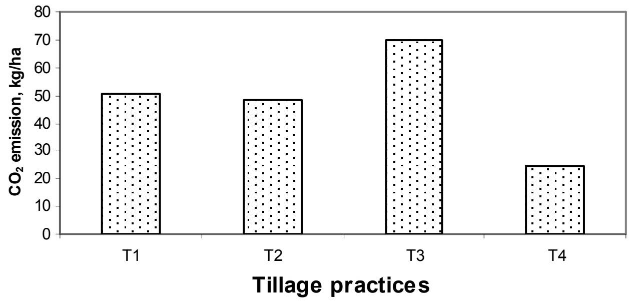

Figure 1. Effect of tillage practices on carbon dioxide emission.

Field capacity

Tillage treatments had a significant effect on the field capacity (Table 1). Field capacity of VMP during bed formation in a single pass was lowest i.e. (0.065 ha/hr). Conventionally, a farmer would use 6-8 tillage passes, 2-3 leveling passes and 50-60 man days labour (0.002 hr/ha) to make a bed. Whereas, the field capacity of 2 WT using the rotavator to puddle the plot in a single pass operation was 0.166 ha/hr.

Labour requirement in land preparation and transplanting

Land preparation included tillage operation by VMP and puddling, leveling and shaper operation manually. Labour requirement for land preparation in T_2 treatment was 4.5 times higher than in T_1 and T_4 (Table 1). There was no significant difference in labour requirements for land preparation between T_1 and T_4. The greatest time was required for transplanting seedlings in T_4 (296.1 man-hr/ha) i.e. almost double the time needed in T_1 and T_2 (Table 1). Poor visibility of strips under muddy flood water caused difficulties for people when transplanting seedlings in the hard surface of untilled soils. Similar problems were encountered when transplanting seedlings in T_3. The whole plot was inundated one day before transplanting so the soil was not soft enough to push the seedling roots into the soil easily.

Table 1. Tillage effect on fuel consumption, field capacity, labour requirement in land preparation and transplanting.

Treatment	Fuel consumption (l/ha)	Field capacity (ha/hr)	Labour requirement (man-hr/ha)	
			Land preparation	Transplanting
T_1	19.5 ab	0.166 a	19.2 c	151.1 c
T_2	18.6 b	0.160 ab	85.5 a	168.2 bc
T_3	26.8 a	0.065 c	32.3 b	200.6 b
T_4	9.5 c	0.109 bc	19.0 c	296.1 a

In a column, means followed by a common letter are not significantly different at 5 % level by DMRT.

Irrigation water savings

CA tillage treatment types did not have any significant effect on irrigation water requirement during wet season rice cultivation, but about 41-43% less water was required compared to reports from a conventional tillage system by Rashid (2005) (Table 2). Lowest water usage was required in T_3 (614 mm). Rahman and Islam (2008) observed that 37 % water usage can be saved if rice is transplanted in a bed as compared to the conventional tillage system without sacrificing grain yield during the dry season (January to May).

Table 2. Water requirement in different tillage system.

Treatment	No. of irrigation	Irrigation water, mm	Effective rainfall[1], mm	Total water, mm	Water savings (%)
Conventional tillage*	Not available	207	775	1082*	-
T_1	10	260	376	636	41
T_2	10	254	376	630	42
T_3	10	240	376	614	43
T_4	10	247	376	623	42

*Rashid (2005), [1]http://www.alanasmith.com/theory-Calculating-Effective-Rainfall.htm

Effect of tillage on plant height, number of tillesr per hill, and crop growth rate

Numbers of hills/m^2 were significantly different in the tillage plots due to varied line spacing (Table 3). Number of hills/m^2 was higher (30.8) in strip tillage plots than others. Tillage treatments had a significant effect on plant height up to 55 days after transplanting (DAT)(Table 3). The number of tillers/hill increased with time, up to 40 DAT, during which time there was also a significant effect of tillage treatment on tiller number/hill. After 40 DAT, the numbers of tiller per hill declined and tillage treatment had no significant effect on tiller number per hill in 55 DAT. This suggests an overriding effect of plant competition among the tillers by 55 DAT. Regardless of tillage treatment, shoot dry matter of plants per ha were similar, up to 55 DAT.

Table 3. Effect of tillage on plant height, number of tillers per hill and shoot dry matter.

Parameter	DAT	Tillage treatment			
		T_1	T_2	T_3	T_4
No. of hill/m^2	0	23.4 b	23.2 b	22.2 b	30.8 a
Plant height, cm	20	36.7 a	35.7 a	36.4 a	34.2 b
	40	60.9 b	61.6 a	59.1 c	56.8 d
	55	81.0 a	81.4 a	79.4 ab	77.5 b
	65	83.7 a	83.8 a	82.4 ab	80.1 b
No. of tiller/hill	20	10.2 a	9.8 a	10.2a	7.8 b
	40	20.7 ab	20.7 ab	22.4a	18.1 b
	55	19.3	19.8	21.1	17.3^{NS}
	65	18.2 b	19.3 ab	20.4 a	16.3 c
Shoot dry matter, kg/ha	20	434	331	370	375
	40	2927	2570	2452.	3080
	55	5370	5912	5475	6109

In a row, means followed by a common letter are not significantly different at 5 % level by DMRT. NS- Not significant

Cost of land preparation and transplanting, weeding and irrigation under different tillage system
Highest land preparation cost was incurred by the T_2 treatment (49 US$/ha) and lowest cost (14 US$/ha) by T_4 because of low fuel and labour requirement. Tillage treatment had a significant effect on transplanting cost (Table 4). Transplanting cost was highest in T_4 because more time was needed to transplant seedling in unpuddled conditions. Weeding cost was highest in T_3 and T_4. Tillage treatment had no significant effect on irrigation cost.

Table 4. Cost of land preparation and transplanting, weeding and irrigation (US$) under different tillage systems.

Parameter	Tillage treatment			
	T_1	T_2	T_3	T_4
Land preparation	21 c	49 a	31 b	14 c
Transplanting	43 c	48 bc	57 b	84 a
Weeding	65 b	58 b	194 a	166 a
Irrigation	17	16	15	15

In a row, means followed by a common letter(s) are not significantly different at 5 % level by DMRT.

Conclusion
Regardless of the form of CA tillage treatment, about 41-43 % less water was required compared to a conventional tillage system. Lowest water usage was required in the beds formed by the shaper treatment (614 mm). Fuel consumption had significant variation among the treatments, with 65 % less fuel required in strip tillage treatments by VMP. However, labour use was higher for transplanting and weeding in unpuddled strip tillage. Irrespective of tillage treatment, shoot dry matter production was similar up to 55 DAT. Initial results indicate that the VMP could be used in multiple modes for crop establishment of rice, i.e., strip tillage, minimum tillage, bed formation and conventional tillage.

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