Modified conservation-tillage trencher enhances sugarcane sustainability in Bangladesh

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Abstract: Small-scale farmers in Bangladesh face challenges in using existing tillage trenchers due to their larger size, which increases labor and fuel costs during sugarcane planting. In this study, a compact, cost-efficient, and accessible conservation tillage trencher (CTT) was modified in rotary shafts and toolbar-mounted to establish the easy sugarcane plantation in Bangladesh. The performance of the developed CTT was evaluated with small-scale farmer's practice (SFP) and large-farm practice (LFP) through a field experiment using three conservation tillage methods: i) bed cum trenching (BT), ii) zero-tillage trenching (ZT), and iii) strip-tillage (ST). The study reveals that the effective field capacities of CTT were 0.14 ha h^{-1}, 0.12 ha h^{-1} and 0.14 ha h^{-1} for BT, ZT, and ST, respectively. The modified CTT reduced operation time by 80% and 26%-37% over SFP and LFP, and required 96% and 26%-36% less labor than that of SFP and LFP, respectively. Conservation tillage methods also reduced fuel consumption, which lowered CO_2 emission by 60%-72% and 85%-89% and saved sugarcane land preparation costs by 85% to 90% compared to conventional tillage methods. This study suggests the use of CTTs could lead to saving of environment, labor and energy in the agricultural operation, making it an ideal solution for small-scale sugarcane farmers in Bangladesh.

Keywords: tillage, sugarcane plantation, energy consumption, conservation agriculture, greenhouse gas emission.

Citation: Tabriz, S. S., M. A. Kader, M. A. Awal, M. A. Islam, M. S. Hossen, M. R. Ali, M. A. Hanif. 2026. Modified conservation-tillage trencher enhances sugarcane sustainability in Bangladesh. *Agricultural Engineering International: CIGR Journal*, 28(2):121-134.

1 Introduction

Sugarcane (*Saccharum spp.*) is a key cash crop and the only source of white sugar in Bangladesh, yet it occupies only 0.87% arable land of the country (Tabriz et al., 2021). Natural resource-saving, profitable, and climate-smart farming innovations are essential at every step of sugarcane farming to increase and sustain yields in Bangladesh, thereby contributing to the reduction of the national sugar deficit. Tillage is an important agricultural management practice for crop production involving mechanical soil disturbance that makes planting easier and controls weeds, pests and diseases (Bell et al., 2019). In conventional sugarcane farming, the land is generally prepared using intensive tillage cultivation, which increases the cost of production. Conventional tillage practices for crop production in Bangladesh are highly resourced and

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Received date: 2025-05-28 **Accepted date:** 2025-08-14

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expensive in terms of cost, time, labor and fuel for tilling land (Islam et al., 2022). In contrast, two types of tillage operations carried out in Bangladesh during sugarcane land preparation are small-scale farmer's practice (SFP) and large farm practice (LFP) (Hossain et al., 2015). The SFP is based on the two-wheel tractor and manual human labor whereas LFP is based on four-wheel tractor-mounted tillage implements. Further, SFP is highly labor-intensive, time-consuming and costly whereas LFP requires large and costly machinery which is beyond the capacity of small-scale farmers (Tabriz et al., 2021). Still, small-scale sugarcane farmers are in trouble with land preparation due to the lack of suitable tillage implements. In contrast, excessive mechanical disturbance of soil through tillage is still in conflicts with soil conservation and accountable for soil degradation and yield declines (Derpsch et al., 2024).

Conservation tillage is the first and essential component among the three main components of Conservation Agriculture (CA) (Islam, 2017). It is an effective tool of agricultural management, which boosts sustainable and profitable sugarcane farming (Tenelli et al., 2019). Two-wheel tractors are very popular for land preparation in smallholder farming systems in South and East Asia, including Bangladesh (Hossain et al., 2015). Farmers of Bangladesh have accepted two-wheel tractor-operated CA machinery and local manufacturers' fabricated machinery (Rahman et al., 2021). Moreover, conservation tillage plays a vital role in enhancing soil fertility and reversing negative nutrient balances in intensive cropping systems (Islam et al., 2025). However, existing CA-machinery is suitable for cereal, pulse, and maize crops but not for sugarcane, because sugarcane setts or seedlings are not similar in size and shape to those seeds. Sugarcane setts or seedlings are planted in trenches or furrows by manual laborers. Therefore, to overcome the limitations, modifications of two-wheel tractor-mounted conservation tillage implements are necessary to make successful sugarcane trenches during crop planting with lower mechanical disturbance to soil.

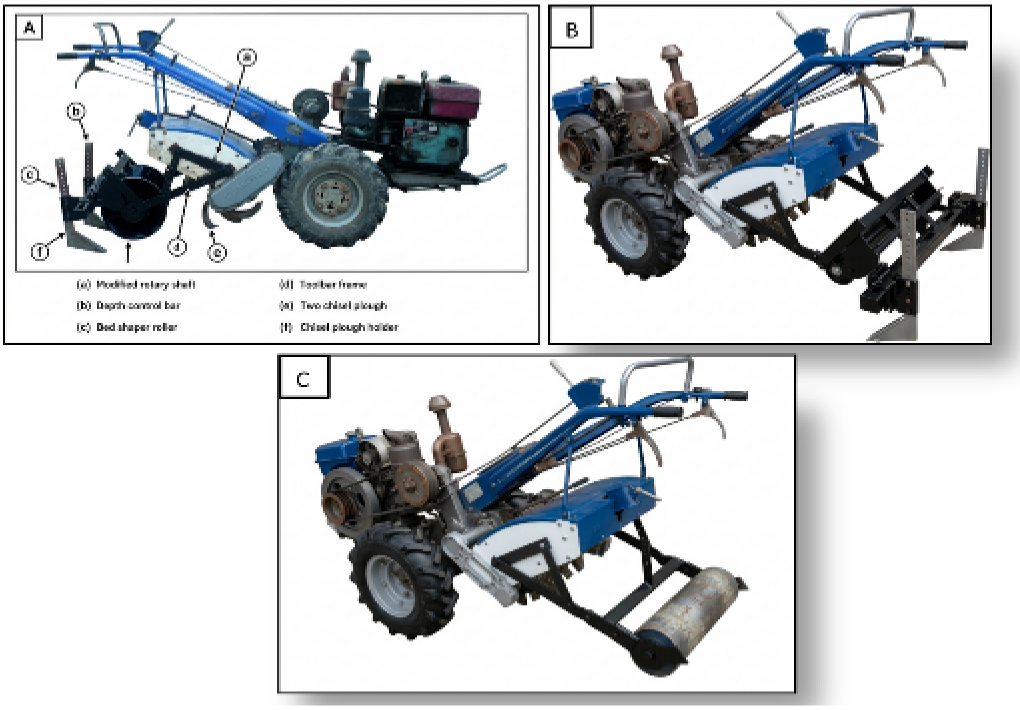
Advanced agricultural implementation and machinery are essential to uplift farm mechanization for increasing agricultural productivity (Hossen et al., 2020). Conservation Tillage Trencher (CTT) may provide less soil disturbance and optimum depth of trench instead of excessive tillage, thereby reducing machine energy consumption and labor involvement of trenching during sugarcane planting. Thus, the CTT can meet the present demand for tillage implementation and overcome the drawbacks of excessive tillage in sugarcane farming. Modification of the rotary shaft (blade arrangement) and attachment of components, such as chisel plough and bed shaper, can be incorporated in a two-wheel tractor-mounted conservation tillage trencher which may provide flexibility for preparing conservation tillage system including raised bed cum trench, zero-till trench, and strip tillage in sugarcane farming. Also, modification of the rotary shaft by reducing the number of blades as well as rearranging of blades could create favorable seedbed preparation with a single pass of tillage operation and avoid unnecessary tillage between two furrows of sugarcane planting. Moreover, an improved bed shaper can control the placement of soil troughed by improving the architecture of the bed cum trench, and a chisel plough can optimize the depth and width of the furrow. Therefore, improved design of farm implements can ensure timeliness and eco-friendliness of operation, cost-effectiveness, and reduce the drudgery of sugarcane farm operations.

The appropriate design and performance evaluation of the CTT is essential for advancing improved tillage practices in sugarcane cultivation in Bangladesh. The effectiveness of any tillage implement depends greatly on its design, which directly influences its field performance. In this study, a two-wheel tractor-mounted CTT was designed and fabricated in Bangladesh, followed by field performance testing in sugarcane farmland. Furthermore, the CTT's efficiency, measured in terms of fuel, time, labor savings, and environmental benefits, was compared with conventional tillage systems to assess its potential for enhancing sustainable sugarcane production.

2 Materials and methods

2.1 Description of the experiment

The modified CTT was tested through a single-factor field experiment arranged in a randomized complete block design (RCBD) with four replications, comprising three tillage methods: i) Bed cum trenching (BT), ii) Zero tillage trenching (ZT), and iii) Strip tillage (ST). A complete design of the different types of tillage trenchers is illustrated in Figure 1, and the fabricated design specifications are presented in Table 1.



(A) Bed cum trencher where a) modified rotary shaft, b) depth control bar, c) bed shaper roller, d) toolbar frame, e) two chisel Ploughs, and f) chisel ploughs holder; B) Zero tillage trencher; C) Strip-tillage

Figure 1Two-wheel tractor operated conservation tillage trencher for sugarcane,

Table 1 Detail specifications of the fabricated conservation tillage trencher for sugarcane.

Components	Descriptions
Name	Conservation tillage trencher
Dimension	600 mm ×1130 mm × 440 mm
Weight	50 kg
Speed of rotary shaft	250 rpm
Number of rotary blades	12 (L type for BT), 6 (L type for ST) and no blade for ZT
Power requirement	Two-wheel tractor (9 kW or 12 hp)
Price	US$295 (without 9 kW two-wheel tractor) & US$1705 (with 9 kW two-wheel tractor)

2.2 Fabrication of conservation tillage trencher for sugarcane

A two-wheel tractor-operated CTT for sugarcane was designed and fabricated at the workshop of Bangladesh Sugarcrop Research Institute (BSRI), Pabna, Bangladesh (24.12° N latitude and 89.13° E longitude). In the study, three conservation tillage options (BT, ZT and ST) for sugarcane farming were considered for evaluating developed CTT.

2.2.1 Design consideration of CTT

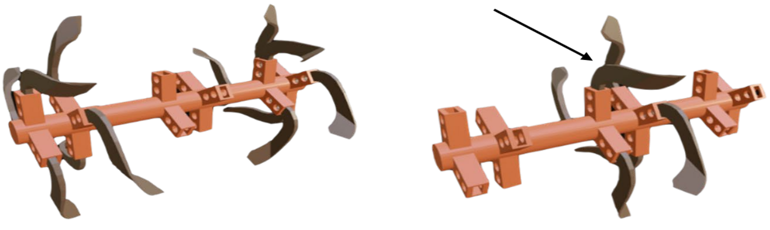
The following factors were considered in the design of the CTT: i) developed CTT can serve the purpose of sugarcane land preparation with less disturbance of soil, ii) local manufacturers of Bangladesh can easily fabricate, iii) low cost of fabrication so that small and medium farmers or service providers can purchase easily, iv) easy to operate by a single operator, v) easy to repair and maintain with low-cost involvement and vi) easy to transport from one place to another place.

2.2.2 Fabrication of CTT

The two-wheel tractor-mounted CTT was fabricated using mild steel (MS) materials considering low cost and availability in local markets of Bangladesh as MS angle, solid bar, MS sheet, ball bearing, and nut bolts. The main functional parts of CTT were a modified rotary shaft, toolbar frame, depth control bar, bed shaper roller, and two chisel ploughs (Figure2 to 7). The CTT was attached by a 2-wheel power tiller with power consumption between 9-12 kW.

2.2.3 Modified rotary shaft

Several pockets for blades setting in the rotor has rearranged and "L" shaped blades were used for bed cum trenching and strip tillage. However, the total number of blades used during different conservation tillage operations has reduced for minimum disturbance of the soil. Six numbers of blades were set along two perimeters at each end of the rotary shaft having an inward facing for bed cum trenching (Figure 2a). That will cut as well as through the soil back having an inward direction. In addition, six blades were set along two perimeters as well as at the middle of the rotor having inward facing during strip tillage (Figure 2b) and no blades were used during zero-tillage trenching.


(a) Six "L" shaped blades at each end of the rotary shaft.

(b) Six "L" shaped blades at middle of the rotary shaft.

Figure 2 Blade arrangement on the rotating shaft for (a) bed cum trenching tillage and (b) strip tillage.

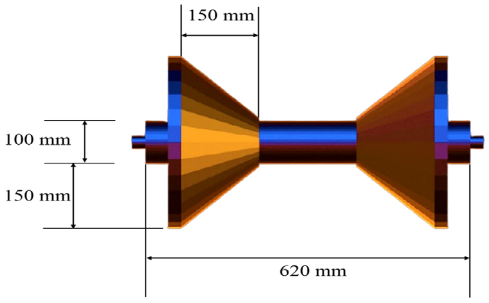


Figure 3 Fabricated design of bed shaper roller for bed cum trenching.

2.2.4 Bed shaper roller

A special type of roller was fabricated at BSRI workshop using a 1mm thick MS sheet and two conical structures with large outward facing at both end edges (Figure3). The inner distance between the two conical-shaped structures of the roller confirms the width of the bed since that conical-shaped structure increases the inward movement of the back throw soil by the rotor and the inner part of the roller press the soil that makes the bed.

2.2.5Two chisel ploughs

The basic functions of chisel ploughs involve increasing depth of trench to make it suitable for sugarcane plantation. Two small size chisel ploughs were fabricated using 5 mm thick MS plate/MS Flat bar and placed behind the roller with a frame using the holder. Distance between two chisel ploughs and vertical movement of those ploughs can adjust through positioning of trenchers using chisel ploughs holders.

2.2.6Chisel plough

Soil failure pattern by a narrow cutting blade can be describe as the failure wedge ahead of the blade, consisting of the center wedge, two side crescents, and a straight rupture plane at the bottom, as shown in

Figure3(McKyes and Ali, 1977; Swick and Perumpral, 1988). According to this soil failure pattern, the force acting on a narrow cutting blade depends on the rake angle of the cutting blade (α), the angle of the soil failure plane (β) and rupture distance (r) where the rake angle (α) is the geometric parameter of the tillage tool (Figure4).

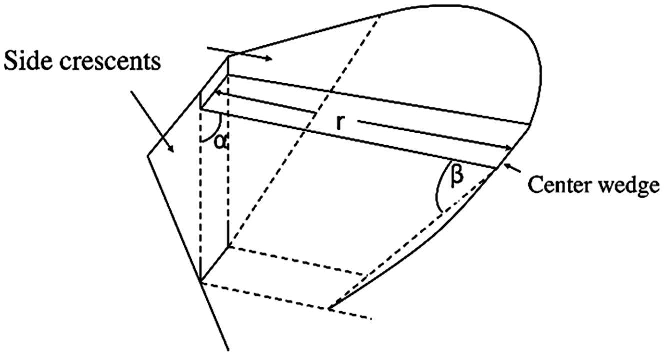
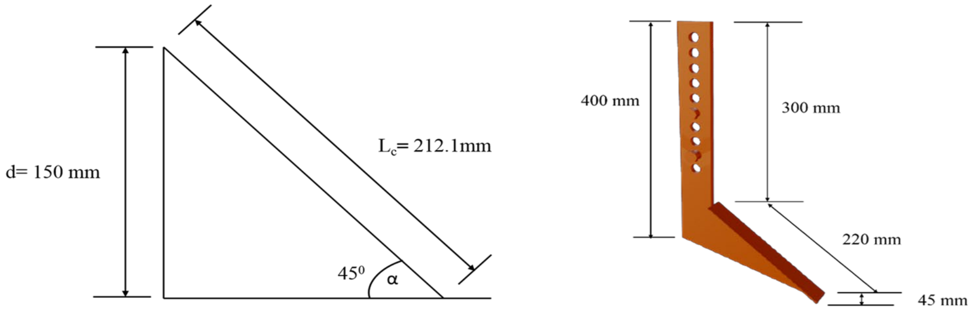


Figure 4 Double-wedge failure zone of the McKyes-Ali model (α-rake angle; β-angle of soil failure plane; r-rupture distance) (Swick and Perumpral, 1988)

Hence, the efficiency of a chisel plough directly depends on the rake angle of the chisel plough. The draft force decreased with the rake angle and reached its minimum value at 45° rake angle (Tong and Moayad, 2006). Hence, 45° rake angle has been chosen for our developed chisel plough. Besides that, the length of the trencher (L_C) will depend on the depth of plantation. Sugarcane plantation at a depth of 100-150 mm is enough for crop establishment and production (Hossain et al., 2005). Since the desired depth is150 mm, length of trencher (chisel plough or narrow blade) will be L_C = 212 mm or more as 220 mm (Figure 5 a, b) and Equation 1.

$$L_c = \frac{depth}{\sin\theta} = \frac{150\,mm}{\sin 45°} = 212 \text{ mm} \tag{1}$$



(a)

(b)

(a) Length determination of chisel plough (d = desired maximum depth of trench; L_C = length of chisel plough; α = rake angle) (b) design of chisel plough.

Figure 5 Determination of chisel plough dimensions and structural design:

Usually, the maximum diameter of sugarcane is less than 50 mm, so the width of the trencher was taken as 50 mm. Due to the side crescents, the width of the trench will be more than 50 mm, which is enough for insertion of sugarcane set or seedlings.

2.2.6 Toolbar frame

The toolbar frame was fabricated using available mild steel materials in Bangladesh to mount chisel ploughs and bed shaper roller. Some solid mass was removed from 113 cm long trencher mounting structure of the toolbar frame to reduce the weight of the implement (Figure6) so that operator can easily turn out during operation. The toolbar frame and bed shaper roller are attached behind the rotor using a flat bar and two depth control bars.

2.2.7 Depth control bar

Two MS flat bar, each 5 mm thick, 50 mm wide, and 300 mm long, having 14 holes, were attached to toolbar frame (Figure6) to lift and down the bed shaper roller and toolbar frame, thereby controlling depth of tillage.

2.2.8 Chisel ploughs holder

Two clamps were used to attach the chisel ploughs with chisel ploughs mounting structure of toolbar frame as chisel ploughs holder (Figure 7).

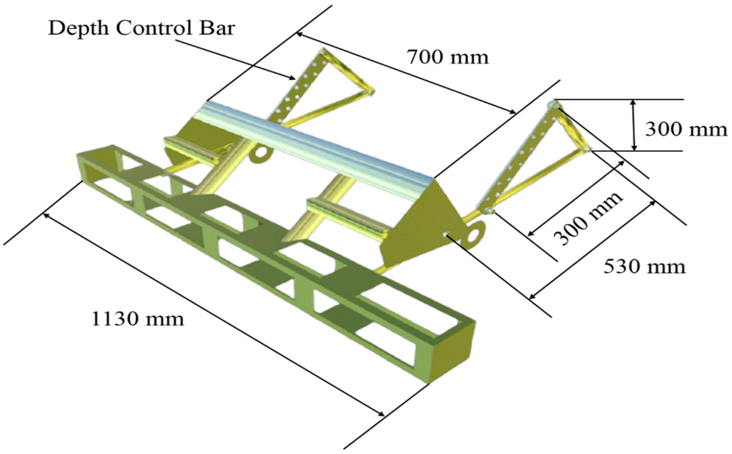


Figure 6 Details of tool bar frame including with depth control bar.

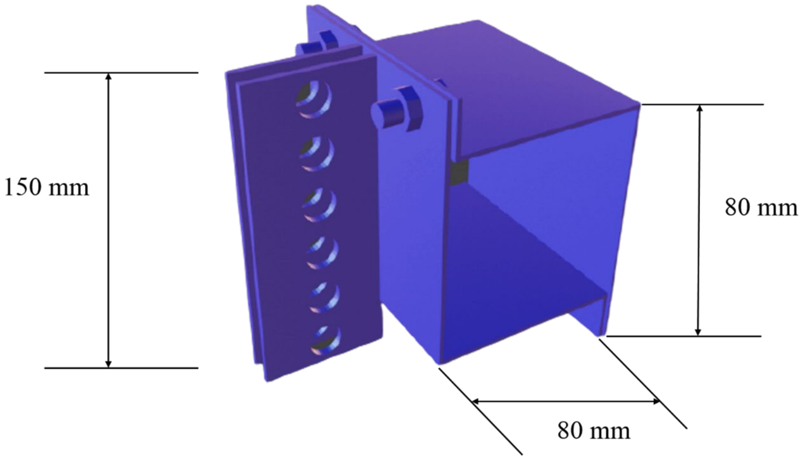


Figure 7 Details of chisel ploughs holder.

2.3 Evaluation of field test

The field performance of developed CTT machine was tested in the BSRI farm in Pabna, Bangladesh (24.12° N latitude and 89.13° E longitude) for determining implements forward speed, effective soil cutting width, turning time, and field capacity. Before field test, selected field was fallow for one year. The soil of experimental field was a silt loam, which contains 21% sand, 57% silt, and 22% clay. During field test, soil properties were measured in the field at 0-150 mm depth: soil moisture content (17%, oven dry method), penetration resistance (1.25 kg cm^{-2}, pocket penetrometer), and bulk density (1.45 g cm^{-3}, core sampling method). The developed CTT implement was also compared with two conventional land preparation methods in terms of fuel consumption, CO_2 emission for fuel consumption, time and labor requirement for sugarcane land preparations. Conventional methods of land preparation for sugarcane are four-wheel tractor base land preparation (single pass of disc plough + 2 passes of disc harrow + single pass of tractor trencher) and two-wheel tractor base land preparation (4 passes of two-wheel tractor + manual trenching using spade).

Each type of method was tested repeatedly for three times on three different plots with size of 40 m × 27 m. Prepared lands were also evaluated in terms of depth and width of trench. Necessary data were recorded from each test and equations as described below were used to calculate different performance indicators as stated above. Arithmetic mean of results from three repetitions were considered as average value of each performance indicators. Finally, land preparation cost of each method was calculated by financial analysis. Forward speed of the machine can be calculated following Equation 2 (Hunt and Wilson, 2015).

$$S = \frac{3.6\,d}{t} \tag{2}$$

where,

S = forward speed (km h^{-1});

d = distance traveled (m);

t = travel time (s). Effective field capacity (EFC) is the actual area covered by the machine within unit time (Kepner et al., 1978).

$$\text{Effective field capacity (EFC)} = \frac{A}{T} \tag{3}$$

Where, EFC is in ha h^{-1}, A = area covered by the machine (ha) and T = total time required to cover the area (h). Fuel consumption of the machine was measured using top fill method where fuel tank was filled before operation and re-filled after each operation. Here, fuel consumption was equivalent to re-filled quantity of fuel.

$$\text{Fuel consumption, litter ha}^{-1} = \frac{\text{Re-filled quantity of fuel in Litre}}{\text{Area covered in ha}} \tag{4}$$

2.4 Estimation of CO_2 emission

Diesel content carbon, and during burning, the carbon combines with oxygen to form CO_2. Thus, tillage operation emits a large amount of CO_2 in atmosphere. Tillage machinery discharge 2.64 kg CO_2 from utilization of one liter diesel during tillage operation and that is a vital source of Green House Gases (GHG). So, CO_2 emission per ha was calculated using the following (Grace, 2003).

$$\text{CO}_2 \text{ emission (kg ha}^{-1}) = 2.64 \times \text{Fuel consumption (l ha}^{-1}) \tag{5}$$

2.5 Economic evaluation of conservation tillage trencher

Total costs of machine operation at farm level are divided into fixed cost and variable cost. Components of fixed cost included depreciation, bank interest rate (%), shelter, taxes, and insurance. Fixed cost per year (FC_{yr}) was calculated using Equation 6 (Hunt, 2001) and fixed cost per hectare (FC_{ha}) was calculated using Equations 7 and 8.

$$FC_{yr} = D + I + STI \tag{6}$$

where, FC_{yr} = total fixed cost per year in US\$ yr^{-1}; D = depreciation, US\$ yr^{-1}; I = interest on investment (bank interest rate on agricultural loans), US\$ yr^{-1}; STI = shelter, tax and insurance US\$ yr^{-1};

Fixed cost per hectare,

$$\text{FC}_{\text{ha}} = \frac{FC\text{yr}}{A_{yr}} \tag{7}$$

where,

$$Ayr = \text{Area covered per year} = \frac{\text{Annual operating time}}{\text{Time required to prepare 1 ha}} \tag{8}$$

One four-wheel tractor was considered for disc ploughing, harrowing and tractor trenching. Therefore, during operation of one implement, another two were in rest and time required for tractor to prepare 1 ha land was the cumulative time required for disc ploughing, harrowing and trenching. Time required by a tractor to prepare 1 ha land was used to calculate area covered per year by a four-wheel tractor that was the area covered per year by disc plough, disc harrow and trencher. Annual operating time of machine operation was assumed as 960 h considering 8 h for 120 days because the planting of sugarcane in Bangladesh starts from middle October and ends in middle February. Depreciation was calculated following sinking-fund depreciation method and using Equation 9 (Hunt, 2001).

$$\text{D} = [(\text{P} - \text{S})\{\frac{(1+i)^L - (1+i)^n}{(1+i)^L - 1}\} + S] - [(\text{P} - \text{S})\{\frac{(1+i)^L - (1+i)^{n+1}}{(1+i)^L - 1}\} + S \tag{9}$$

where,

D = depreciation, US\$ yr^{-1};

P = purchase price (Table 3), US\$;

S = salvage value (10% of P), US\$;

L = Effective machine life, yr (Table 3);

n = age of machine at beginning, yr; i = annual interest rate, decimal. For a new machine n = 0 and uniform depreciation per year Equation 9 becomes as Equation 10.

$$\text{D} = (\text{P} - \text{S})\left\{\frac{i}{(1+i)^L - 1}\right\} \tag{10}$$

Interest on investment (I) is the charge due to interest of the money that is used as capital investment for the machine either the money was borrowed or not. The interest rate was assumed as 9% and Equation 11 was used for the calculation of interest on invest (Hunt, 2001).

$$I = \frac{P+S}{2} \times i \qquad (11)$$

Taxes, Shelter and Insurance (STI) were considered as 2.5% of purchase price of machine and expressed as Equation 12.

$$STI = 2.5\%\ of\ P \qquad (12)$$

Table 2 Market purchase price and expected machine life of farm machinery and equipment used in different tillage system

Tillage system	Required machinery	Purchase price(US$) *	Expected machine life
SFP	Two-wheel tractor	1410	15
Conservation tillage (ST, BT and ZT)	CTT + PT	1705	15
LFP	Four-wheel tractor	34117	20
	Disc plough	2000	20
	Disc harrow	1000	20
	Tractor trencher	600	20

Note: *Local market prices were considered. SFP: Small-scale farmer's practice, ST: Stripe tillage, BT: Bed cum trenching, ZT: Zero-tillage trenching, LFP: Large farm practice, CTT: Conservation tillage trencher

Variable costs are expenses that occur due to the operation of the machine. It depends on different input costs for operation and the time required (hr) for each field operation. Operator/labor charge was considered as the labor rate in US$ per day. The fuel and oil costs were determined by multiplying their respective prices by their respective consumption rate. Equation 13 was used to calculate variable costs [18].

Variable Cost (US$ ha^{-1}), $\mathrm{VC} = \mathrm{Lb} + \mathrm{F} + \mathrm{O}\,\&\,L + R\&M + Mc$ (13)

Where, L_b= Operator & labor cost, US$ ha^{-1}, F = Fuel cost, US$ ha^{-1}=Fuel consumption (l ha^{-1}) Fuel price (US$l^{-1}), O & L = Oil & lubrication cost = 15% of fuel cost, R & M = Repair and maintenance cost per year (3.5% of P)/A_{ha}, M_c = Miscellaneous cost (US$ ha^{-1}) was not considered in this cost calculation. Total operating costs are the expenses required to operate and maintain a machine during its useful life (White et al., 1989). Total costs of land preparation in US$ per ha were calculated using Equation 14 as the summation of fixed costs (US$ ha^{-1}) and variable costs (US$ ha^{-1}).

Total operating costs (US$ ha^{-1}), TC= FC+VC (14)

3 Results and discussion

3.1 Performance conservation tillage trencher

Developed CTT was attached with two-wheel tractor (Figure1) for preparing sugarcane farmland at different conservation tillage methods. The CTT was 600 mm long, 1130 mm wide and 440 mm high (Table 2). The width of the CTT was 1130 mm since toolbar frame was extended for maintaining 1 m maximum distance between the two trenches. The speed of the rotary shaft was 250 rpm, which was similar to the rotational speed of the conventional tiller. Blade numbers as well as location were different and adjustable on modified rotary shaft for different operations (Figure 1). Moreover, total 12 numbers of L type blades containing 6 blades at each end of rotor for BT and 6 numbers of L type blades at middle of rotor for ST were attached with modified rotary shaft (Table 1). No blade was used for ZT (Table 1) where only two chisel ploughs were used to make a trench for sugarcane planting. Total numbers of blades used for each tillage method were reduced significantly as well as rearranged that ensure favorable soil condition for seedbed preparation. Conservation tillage can be done successfully through modification of the rotary shaft by rearranging and reducing rotary blades (Haque et al., 2016). During BT, the bed shaper was used for making bed cum trench and two chisel ploughs of developed CTT were for increasing depth of trench. CTT needs to rearrange different functional components for using different options. Local manufacturers could easily fabricate the two-wheel tractor operated CTT using available MS materials in Bangladesh. The weight of developed CTT was 50 kg (Table 1). Our developed CTT implement has a low weight, which is preferable to operate by single user. Fabrication cost of CTT was US$295 without two-wheel tractor and US$1705 including 9 kW two-wheel tractor (Table 4). It is affordable for small-scale farmers of Bangladesh.

(A) Bed cum trenching, (B) Zero-tillage trenching, (C) Strip tillage showing row spacing

Figure 8 Pictorial view of different conservation tillage showing row arrangement and spacing

3.2 Operating performance of CTT

Modified 2-wheel tractor operated CTT used to prepare land for sugarcane plantation through a single pass and was capable to choose some conservation tillage options as i) bed cum trenching with minimum-tillage (Figure 8A), ii) zero-tillage trenching (ZT) (Figure 8B) and iii) strip tillage (Figure 8C) by operating at different tillage mode whereas conventional tillage required multiple activities. Single pass of this machine made a pair of trenches at a distance of 0.6 m during BT (Table 3).

Table 3 Field performance evaluation of the fabricated conservation tillage trencher

Parameters	ST	ZT	BT
Number of trenches per pass	1	2	2
Spacing between two trenches (m)	Adjustable *	1**	0.6***
Effective width (m)	0.9	1.8	1.8
Forward speed (km hr^{-1})	1.9	0.9	1.1
Machine-turning time (sturn^{-1})	8-9	8-9	8-9
Effective field capacity (ha hr^{-1})	0.14	0.12	0.14
Depth of trench (mm)	80-100	120-150	120-150
Width of trench (mm)	60-80	80-100	80-100

Note: *ST can create a single row in one pass and operator may able to maintain any desire distance between two rows.

**ZT can create two trenches in one pass with maintaining a maximum distance of 1.0 m.

***BT can create two trenches in one pass with maintaining a maximum distance of 0.6 m.

But optimum row-to-row distance of sugarcane plantation in Bangladesh is about 0.9 to 1.0 m (Alam et al., 2015). However, operators can control distance between two pairs of trenches easily according to requirement during BT. Hence average row distance is maintained as optimum by increasing distance between two pairs of rows that ensures optimum plant population. Thus, effective width becomes 1.8 m through maintaining 1.2 m distance between two pairs of rows. Moreover, this type of row adjustment has a positive impact for intercropping in sugarcane farming without any yield penalty of sugarcane (Alam et al., 2016; Hossain et al., 2015). The CTT also made a pair of trenches through a single pass during zero-tillage trenching but distance between two trenches can be up to 1 m (Table 3). Considering trench to trench distance as 0.9 m effective width becomes 1.8 m during ZT. During strip tillage, a single pass could make only one row and row-to-row distance could maintain according to requirement. So, effective width could be considered as 0.9 m during strip tillage. Sugarcane farmers of Bangladesh maintain this distance to take their satisfactory yield as also reported by Alam et al. (2015,2016).

Forward speed of developed CTT was different for different type of tillage as 1.1 kmhr^{-1} for BT, 0.9 kmhr^{-1} for ZT and 1.9 kmhr^{-1} for ST (Table 3). Speed of CTT was highest during ST because chisel plough was not used for ST. On the other hand, lowest speed was found during ZT because two chisel ploughs were used and no rotary blade was used. Resistance of soil on chisel plough works against forward speed and force acting on rotary blades helps to increase forward speed of CTT. Besides that, effective field capacity of the CTT for different types of tillage were found 0.14 ha h^{-1}, 0.12 ha h^{-1} and 0.14 ha h^{-1}for bed cum trencher, zero tillage trencher and strip tillage, respectively (Table 3). Effective field capacity varies on soil conditions, field size and shape as well as system limitations. Effective field capacity of BARI developed CA machine named BARI seeder was found 0.098 ha h^{-1} for strip tillage and 0.099 ha h^{-1} for shallow tillage (Mottalib et al., 2019). Lower weight of developed CTT may be responsible for improving machine maneuverability, especially that can save machine-turning time at the end of field. Machine-turning time at the end of field for CTT was only 8-9 seconds (Table 3). Effective field capacity of a machine directly depends on turning time (Hunt, 2015).

Depth and top width of developed trench during bed cum trenching and zero tillage trenching were nearly same, and the values are 120-150 mm and 80-100 mm, respectively (Table 3). Depth and width of tillage portion during strip tillage were about 100 mm and 60-80 mm, respectively (Table 3). All these tillage operations were suitable for sugarcane plantation considering depth of tillage since sugarcane plantation at a depth of 100-150 mm is enough for optimum yield and cane quality (Hossain et al., 2005). This type of conservation tillage provides benefits of tillage for seed bed preparation as well as gain benefits of non-tillage by avoiding tillage between two rows (Licht and Al-Kaisi, 2005).

3.3 Sustainable resource consumption by tillage trencher

SFP was the most time-consuming tillage method that required 41hours per hectares when 10 labors worked at a time for manual trenching (Table 4).

Table 4Comparison of different conservation tillage using CTT with conventional land preparation methods in sugarcane field in terms of resource consumption

Tillage system	Operations	Time (hrha^{-1})	Fuel (lha^{-1})	Labor (hrha^{-1})
SFP	4 Passes of PT	25	25	25
	Manual trenching	16 hr for 10 labors	-	160
	Total	41	25	185
LFP	1 Pass of Disc plough	5	25	5
	2 Pass of Disc harrow	3.8	20	3.8
	1 Pass of trencher	2.5	20	2.5
	Total	11.3	65	11.3
BT	Single pass (Total)	7.14	8	7.14
ZT	Single pass (Total)	8.33	10	8.33
ST	Single pass (Total)	7.14	7	7.14

Note: SFP: Small-scale farmer's practice, ST: Strip tillage, BT: Bed cum trenching, ZT: Zero-tillage trenching, LFP: Large farm practice.

Time will increase when labor number decreases for manual trenching and time decreases if labor number increases. LFP required only 11.3 hours, which was the time required for disc ploughing, harrowing as well as trenching (Table 4). Land preparation using developed conservation tillage implement required only 7.14 h ha^{-1}, 8.33 h ha^{-1}, and 7.14 h ha^{-1} for BT, ZT and ST, respectively (Table 4). The result of the study reveal that different conservation tillage methods (BT, ZT and ST) are time saving method that saves about 80% time than SFP and 26%-37% than LFP. Conservation tillage increases yield through ensuring early planting by reducing the time required for land preparation (Tabriz et al., 2021; Haque et al., 2016). SFP is the most labor expensive method (185 labor-hha^{-1}), followed by LFP (11.3 labor-h ha^{-1}), ZT (8.33 labor-h ha^{-1}) where BT and ST are the most labor-saving tillage method that requires only 7.14 labor-hha^{-1}) for each (Table 4). As a result, conservation tillage methods (BT, ST and ZT) saved labor about 96% than SFP and 26%-36% than LFP. In contrast, introduction of farm machinery and conservation tillage can save farm labor requirements (Haque et al., 2016), and the saved labor shifted from agriculture to more specialized rural and urban jobs, as well as to the new jobs and opportunities created.

The LFP required highest amount of fuel to prepare land for sugarcane planting and the amount was about 65 lha^{-1} followed by SFP (25 lha^{-1}), ZT (10 lha^{-1}), BT (8 lha^{-1}) and ST (7 lha^{-1}) (Table 4). Thus, conservation tillage saved about 85%-89% fuel than LFP and 60%-72% than SFP. Earlier, it was also recorded that conservation tillage reduces diesel fuel consumption significantly and that could reduce fuel consumption more than 80% compared with conventional tillage practices (Haque et al., 2016). It was estimated that 127% of diesel fuel could save through conservation tillage in India (Erenstein et al., 2007). Therefore, use of conservation tillage implement is appreciable for sustainable cultivation of sugarcane in limited-resource areas. Therefore, conservation tillage as BT, ST and ZT saves natural resources (fuel, labor and time) significantly than conventional tillage (SFP and LFP).

3.4 CO_2 emission

Highest amount of CO_2 emission was found from LFP (172 kg ha^{-1}) and lowest was only 18 kg ha^{-1} from ST as shown in Figure 9. CO_2 emission from SFP, BT and ZT were 66 kg ha^{-1}, 21 kg ha^{-1} and 26 kg ha^{-1}, respectively (Figure 9). Highest amount of mechanical works for vigorous tillage in LFP increased demand of fuel consumption and thus increases CO_2 emission. Use of CTT in conservation tillage reduced mechanical works and fuel consumption, and reduced CO_2 emission. Generally, diesel fuel is the source of energy for mechanical tillage. After burning, it produces $CO_2$and emits it to atmosphere as exhaust gas of engine, making it an important source of greenhouse gases (GHG) (Grace, 2003).

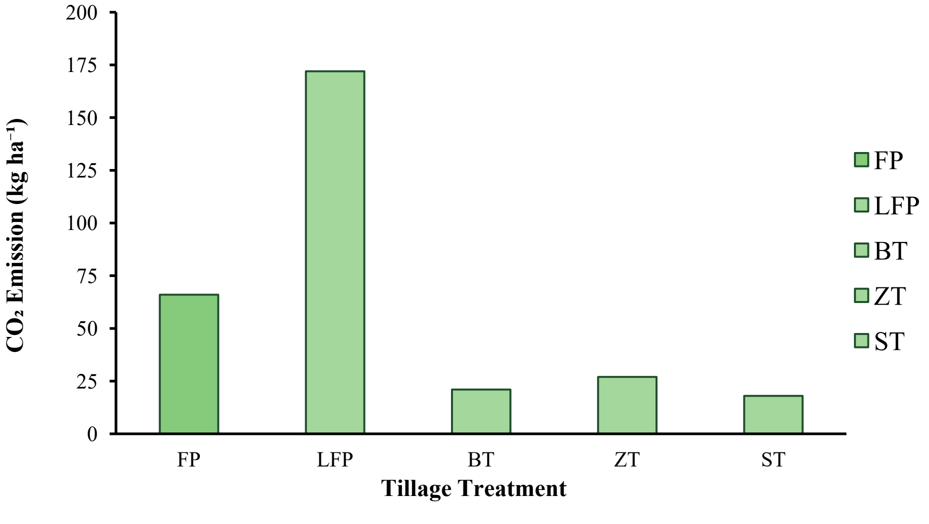


Figure 9 CO_2 emission of different tillage methods

However, it may vary slightly depending on the engine condition. Therefore, higher amount of fuel required for conventional tillage is responsible for higher amount of CO_2 emission. Releases of greenhouse gasses due to the burning of fossil fuels have significant impact on global climate changes patterns (Matthes, 2007). Conservation tillage in sugarcane farming reduced CO_2 emission to atmosphere in comparison with SFP and LFP by 60%-72% and 85%-89%, respectively. Conservation tillage saves fuel and reduces CO_2 emission (Alam et al., 2015). Therefore, adoption of CTT can lead to sustainable farming of sugarcane since that reduces GHS especially CO_2 emission to atmosphere and thus contributes to slow down the climate change process and facilitates climate smart land preparation method.

3.5 Sugarcane germination under different conservation tillage mode

Different tillage treatments have significant effect on germination where ST showed lowest germination percentage followed by ZT as described in Figure 10. LFP (51%) have the largest germination percentage followed by BT (50%) that was statistically similar to LFP. Significantly, lower germination under ST followed by ZT, indicating unfavorable seedbed quality along planting row of sugarcane.

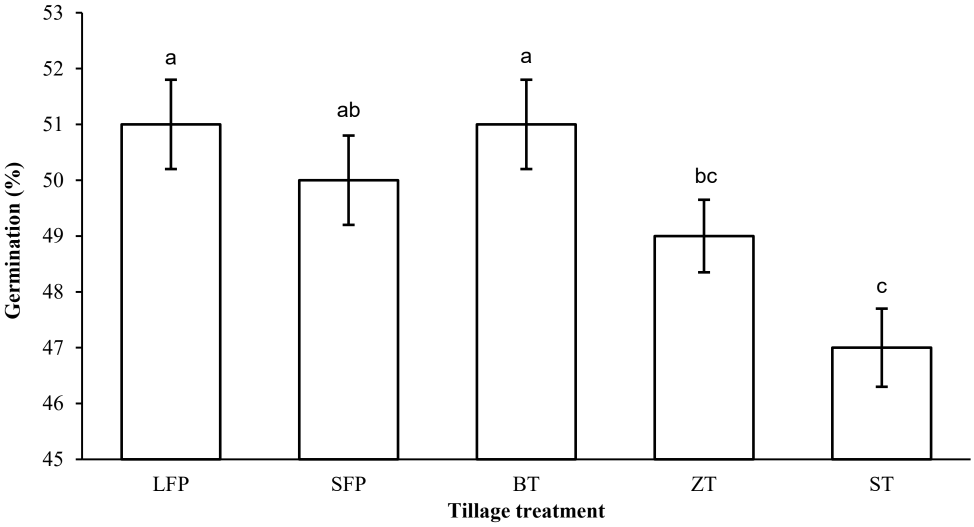


Figure 10 Effect of different tillage treatments on sugarcane germination

Hoque et al. (2021) revealed that inadequate soil coverage above seed causes less establishment and reduce early vigor of crops. Nevertheless, BT is a conservation tillage treatment that produced similar germination percentage compared to conventional tillage treatment of vigorous tillage. In BT, soil is prepared through loosening and trenching along planting furrow that ensure quality seedbed for planting sugarcane. On the other hand, inter-row remains undisturbed that harvest the benefits of conservation tillage.

3.6 Economic performance of CTT

The economic analysis of developed CTT was done by considering fixed cost, variable cost and total cost of land preparation for sugarcane plantation under different tillage methods (Table 5). Fixed cost to prepare sugarcane land for plantation was highest for LFP (40.9 US \$ ha^{-1}) followed by SFP (3.9 US \$ ha^{-1}) as well as conservation tillage using CTT as ZT (1.6 US \$ ha^{-1}), and lowest for BT and ST (1.4 US \$ ha^{-1}). It was due to high investment for LFP. But SFP requires highest variable cost (171.3 US \$ ha^{-1}) followed by LFP (81.7 US \$ ha^{-1}), ZT (16.0 US \$ ha^{-1}), BT (13.2 US \$ ha^{-1}) and ST (12.3 US \$ ha^{-1}).

Table 5 Estimated cost involvement to prepare farmland for sugarcane plantation by different tillage methods

Tillage system	FC	VC	TC
		(US \$ ha^{-1})	
SFP	3.9	171.3	175.2
LFP	40.9	81.7	122.6
BT	1.4	13.2	14.6
ZT	1.6	16.0	17.6
ST	1.4	12.3	13.7

Note:1 US\$ = 85 BDT; FC: Fixed cost, VC: Variable cost, TC: Total cost, SFP: Small-scale farmer's practice, LFP: Large farm practice, ST: Strip tillage, BT: Bed cum trenching, ZT: Zero-tillage trenching.

Manual trenching was responsible for highest variable cost than SFP, and high fuel consumption was responsible for second highest variable cost of LFP. Total cost of land preparation was highest for SFP (175.2 US \$ ha^{-1}) followed by LFP (122.6 US \$ ha^{-1}), ZT (17.6 US \$ ha^{-1}), BT (14.6 US \$ ha^{-1}) and ST (13.7 US \$ ha^{-1}). Thus, cost savings by any conservation tillage for sugarcane farming using CTT was 90%

comparing with SFP and above 85% comparing with LFP. Conservation tillage saves large amount of costs than conventional tillage (Grange et al., 2005) and found as economical land preparation method for sugarcane cultivation (Moraes et al., 2017). Conservation tillage for sugarcane plantation is cost saving land preparation system since it requires less labor and fuel (Tabriz et al., 2021). Conservation tillage also increases net economic return as it reduces cost of cultivation (Jat et al., 2020). Therefore, it can be concluded that developed CTT is economically suitable for small-scale sugarcane farmers to adopt conservation tillage considering initial investment and low cost of production.

4 Conclusions

In this study, a conservation tillage trencher was modified which offers a resource saving and climate smart land preparation method in sugarcane cultivation in Bangladesh. Developed conservation tillage implement is capable of making bed-cum trench, zero tillage trench and strip tillage options for sugarcane plantation which ensures minimum tillage and saves land preparation time. Using the CTT implement in sugarcane farming saved fuel cost by 60%-89%, field labor by 26%-96%, and time by 26%-80% over the conventional tillage trencher. The CTT implement also reduced CO_2 emission by 60%-72% and 85%-89% compared to conventional tillage of SFP and LFP, respectively. Use of developed conservation tillage implement for sugarcane land preparation saved85%-90% operating cost compared to SFP and LFP. Therefore, considering the lower energy consumption and higher economic benefits, developed conservation tillage implement has a great potential in small-scale sugarcane farming system in Bangladesh.

Acknowledgements

The first author is grateful and thankful to acknowledge to the National Agricultural Technology Project (NATP); Phase-II, Bangladesh Agricultural Research Council (BARC) and Bangladesh Sugarcrop Research Institute (BSRI) for financial support to conduct the research. The authors also gratefully acknowledge the contribution of Quazi Srasthatya Prottasha, Artist-Cum-Illustrator, BSRI for his cordial cooperation.

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