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Versatile Strip Seed Drill: A 2-Wheel Tractor-Based Option for Smallholders to Implement Conservation Agriculture in Asia and Africa

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Abstract: Smallholders in Asia and Africa require low-cost seed drills for minimal soil disturbance while establishing various crops. A seed drill that can be drawn by the widely-available two-wheel tractor (2WT) is an attractive option for mechanization of no-till in small-sized fields. The Versatile Strip Seed Drill (VSSD) was designed with the capacity to make up to 40 mm wide and 60 mm deep strips in untilled land along with seed and basal fertilizer application in a single-pass operation, while powered by the 8.95 to 11.93 kW 2WT. An important innovation of the VSSD was to fit the seed box with both fluted roller-type seed meters for delivery of sufficient small-size seeds to achieve adequate plant density per unit row length; and vertical disk-type seed meters for precision and spaced row planting of larger seeds. Both incessant seed dropping by fluted roller seed meters and spaced planting by vertical disk type seed meters provided optimum plant populations that were generally higher than in conventional, full-tillage plots with the same rate of hand broadcasted seed and fertilizers. Time required for crop establishment by VSSD ranged from 0.13 to 0.18 ha$\cdot$ h^{-1}. When the VSSD was attached to the 2WT for crop establishment, the diesel fuel consumption varied from 4.4 to 6.1 L$\cdot$ ha^{-1}, which was lower than for most 2WT-based planters previously used in Bangladesh. In on-farm multi-locations trials, wheat crops established with the VSSD had statistically similar grain yield compared to conventional tillage; however, significantly higher grain yield was obtained from mustard and lentil, by 14% and 19%, respectively. The VSSD is a unique, minimum-soil-disturbance multi-crop planter, and can be a platform on which to build conservation agriculture systems for small farms in Asia and Africa.

Keywords: crop establishment; crop residue retention; efficient diesel fuel use; minimal soil disturbance; planter; power tiller; strip tillage

1. Introduction

The use of 2-wheel tractors (2WT) for land preparation and crop establishment is spreading in Asia and Africa, replacing manual and animal-draught farm power [1]. Labor shortages, increasing labor costs, and crop intensification are trigger factors for increased adoption of mechanization by smallholder farms. Decreasing agricultural labor supply is particularly critical at the times of crop establishment and harvest. Fragmented small farm sizes (less than 1 ha) and low-buying capacity of the smallholders restricts the purchase and utility of 4-wheel tractors in many parts of Asia and

Africa. Hence, a wide range of 4-wheel tractor options for mechanized planting are not available to regions where field sizes are small and 2WT are the predominant source of power for mechanized tillage. However, to date, few mechanized, minimal soil-disturbance or no-till planters have been developed for 2WT [2]. A seed drill that can be driven by a 2WT and place seeds and fertilizer with minimal soils disturbance is an attractive option for mechanization in small fields.

Since 2001, in Bangladesh, the use of 2WT for land preparation and crop establishment has exceeded 75% of the cultivated land [3]. Mostly, 2WT have been used in full rotary soil tillage mode for dry land cultivation or to puddle wet soils for the transplanting of rice (*Oryza sativa* L.). Similar rapid adoption and spread in the use of 2WT for primary full soil tillage has occurred in the Eastern Indo-Gangetic Plains [4]. Hence, there are now large numbers of 2WT operating in South and South-East Asia (Table 1). There is also growing interest in their use in Africa [5,6]. However, repeated full rotary tillage of soil, sometimes practiced more than ten times per year, is not favorable to the enhancement or maintenance of soil organic matter (SOM) and soil structure, which are important soil health parameters for sustainable production intensification and for reducing crop production costs.

Table 1. Number of 2-wheel tractors (2WT) and power tillers in South and South-East Asian countries.

Country	Total 2WT and Power Tiller Number
Thailand	2,644,982
Philippines	1,526,557
Bangladesh	700,000
Vietnam	325,000
Myanmar	199,668
Indonesia	192,905
Cambodia	151,701
Sri Lanka	130,000
India	117,200
Afghanistan	20,000
Nepal	9123
Bhutan	5000
Timor-Leste	1000
Total:	6,023,136

Source: Table adapted from [7].

The building of SOM and soil structure can be promoted by minimizing or avoiding soil disturbance and increasing crop residue retention and cropping system diversity through the application of conservation agriculture (CA) principles [8,9]. Globally, CA is now practiced on over 157 million ha [10] of annual cropland, and, more recently, CA has been spreading in Asia and Africa. It has mostly been developed and adopted where 4-wheel tractor-based single pass no-till planters are applicable and available [11]. Most of the single pass systems have confirmed cost savings and increased grain yield [12]. However, the adoption of CA in smallholder farmers reliant on 2WT is very low, as the challenges remain to: design planters suitable for 2WT with minimum soil disturbance and to demonstrate their effectiveness, reliability, and durability at a price that fosters adoption in the target market.

In Bangladesh, the development of minimum soil disturbance 2WT-based planters started in 1995. There is now a range of such 2WT-based planters being developed [12]. Despite these promising developments, except for the Versatile Multi-crop Planter [13], none of the present planters for 2WT have the capability to be modified quickly for different seeding methods (e.g., continuous seeding or precision spaced planting), seed rate, fertilizer rate, row spacing, seed size, and planting depth. The challenge was to design a multi-function planter capable of sowing seed with minimal soil disturbance and to handle many crop types. In addition, none of the planters have the capacity to place seed and fertilizer in single pass operation, far enough apart to protect seeds/seedlings from the toxicity of the fertilizers.

In this paper we will report on the development of a 2WT-based Versatile Strip Seed Drill (VSSD) that could be useful for smallholder farmers in Asia and Africa. The aim of the study was to develop and evaluate the minimum soil disturbance planter in a range of crops grown on farmers' fields in Bangladesh.

2. Material and Methods

2.1. Construction of VSSD

The 2WT-based VSSD (Figure 1) was fabricated with locally available materials such as MS angle, solid bar, MS sheet, ball bearing *etc*. The main functional parts of the planter were: seed box (Figure 1a having six fluted-roller type seed meters mounted with a shaft plus the same number of vertical disk seed meters (Figure 1c and detail in Figure 2); the fertilizer box with fluted roller type metering mechanism (four flutes) (Figure 1b and detail in Figure 3);the toolbar frame (Figure 1d); depth controller-cum-press roller (Figure 1f); driving seat for transportation (Figure 1h); furrow opener (Figure 1j and detail in Figure 4), *etc*. The VSSD was powered by 8.95 to 11.9 kW Dongfeng (Figure 1), or Saifeng 2WT but could be used with any other 2WT with similar power rating and hitching arrangement. The Dongfeng or Saifeng 2WT have different but suitable hitching points to attach with the VSSD.

Figure 1. A Versatile Strip Seed Drill (VSSD) attached with Dongfeng-type 2-wheel tractor. Parts specification: (**a**) = seed box; (**b**) = fertilizer box; (**c**) = vertical disk seed meter; (**d**) = toolbar frame; (**e**) = seed delivery tube; (**f**) = pressing roller; (**g**) = cover of rotary shaft and tines; (**h**) = driving seat for transportation; (**i**) = depth control bar; (**j**) = furrow opener; (**k**) = seed and fertilizer off/on lever; (**l**) = seed rate adjustable lever for fluted roller type seed meters.

2.2. Versatile Strip Seed Drill Design

The VSSD is designed (Figure 1) with the capability of seeding using a fluted roller type seed meter for high density seeding and/or using a vertical disk for spaced planting and with fertilizer meters for the drilling of granular-type fertilizers in a row. The net weight of the VSSD is 161 kg (excluding driving seat arrangement) and the overall dimensions are 1270 mm (length), 762 mm (width), and 840 mm (height) (Figure 1).

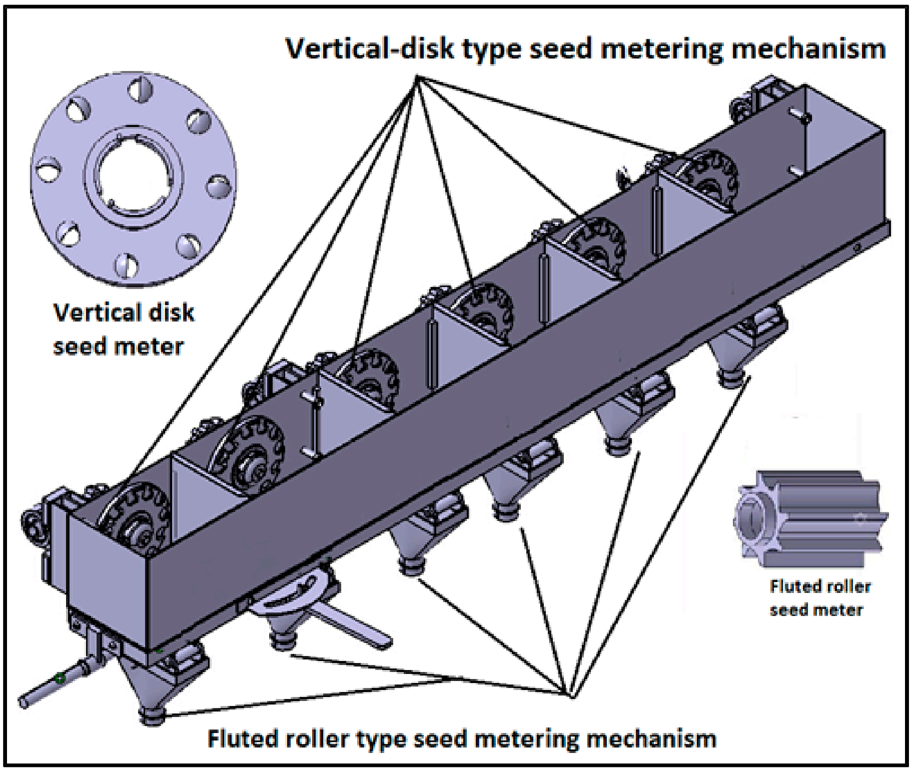

Figure 2. Seed box with vertical disk and fluted roller type seed metering mechanisms.

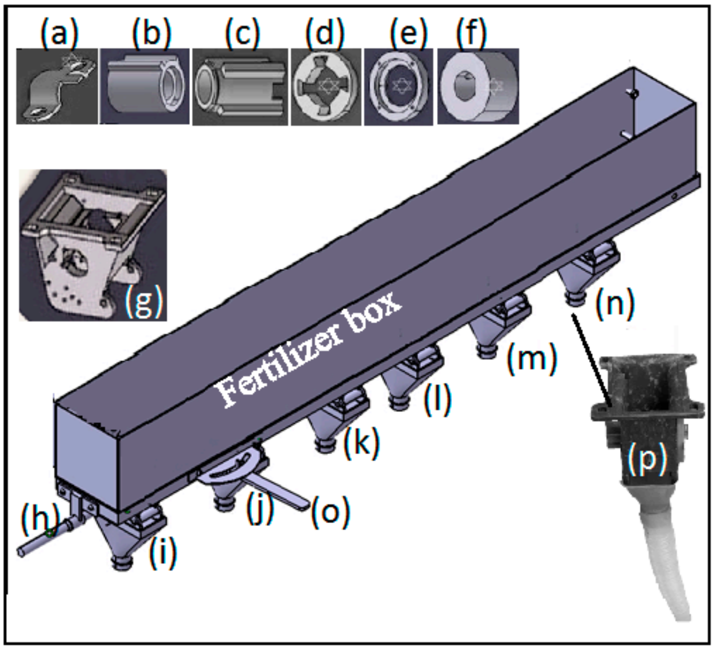

Figure 3. Fertilizer box with metering mechanism; (**a**) nose clump; (**b**) bush; (**c**) fluted roller type fertilizer meter; (**d**) roller regulating bush; (**e**) bush cover; (**f**) bush clump; (**g**) fertilizer meter housing; (**h**) fertilizer meter regulating shaft; (**i**–**n**) fertilizer dropping funnel (six rows); (**o**) fertilizer rate control/adjustment lever; (**p**) a complete seed metering mechanism for one row having (**a**–**g**) parts.

The furrow openers were designed (Figure 4) with the capacity to separate seed and fertilizers while planting, and were bolted to the base of the rotary shaft cover of the VSSD. A pressing roller 1200 mm long with a diameter of 127 mm (Figure 1f), made from a 2 mm iron sheet, is attached behind the furrow openers using a pair of arms. The VSSD is mounted on a toolbar, attached through side arms, and connecting the rods to the main handle of the 2WT. Seed and fertilizer boxes are mounted on top of the toolbar frame. The seed and fertilizer boxes have provisions for seeding and fertilizing up to six rows (200 mm row distance), and down to three rows (600 mm row distance) (Figure 2).

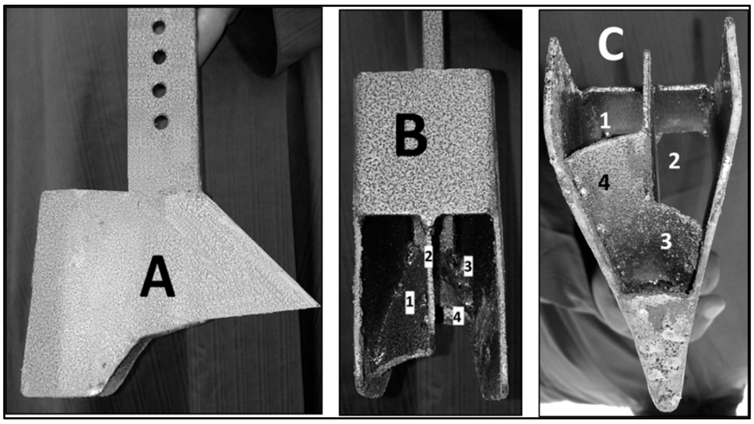

Figure 4. Side (**A**), back (**B**); and bottom (**C**) view of a newly developed furrow opener with the capacity to separate seed and fertilizer; B1/C1 = seed delivery channel, B2 = seed and fertilizer separator, B3/C2 = fertilizer delivery channel, B4/C3 = soil scraper to ensure about 20 mm soil layer between seed and fertilizers.

The maximum 46 numbers of tines (Figure 5) could be attached with the rotary shaft. The 1200-mm long cylindrical rotary shaft (Figure 6) is operated by the 2WT at 475 or 550 rpm through a chain and gear mechanism. The power transmission chain box is located on the right side of the planter (Figure 1), with 28 teeth on the upper sprocket attached to the drive shaft, and 14 teeth on the lower sprocket attached to the rotary shaft. The rotary shaft and tines are covered by a metal sheet (Figure 1). The rotary shaft is designed with 23 pairs of tine holders to fix 46 tines (Figure 5). The settings of the tine holders and the tines on the rotary shaft, for various row-spacing crops, are shown in Figure 6. Each pair of tine holders should have one right and the other left, twisted, 160-mm long, and 37-mm width tine, with a 52° bend at the end so that the cutting edge tills up to about a 50-mm width in the row (Figure 5).

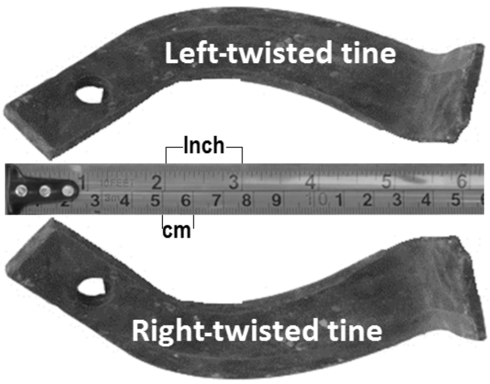

Figure 5. Photograph of right- and left-twisted tines.

A total of six, fluted roller-type seed meters were fitted to the base of the seed box, and the same number of vertical seed meters were fitted to the front wall of the seed box (Figure 2). Depending on the level of precision in seed placement, either fluted roller type or vertical plate type seed meters can be chosen for seeding. Seed rate can be adjusted by sprocket size in the case of vertical plate meters.

Sprocket sizes range from 10 to 40 teeth, providing five settings for seed rate and seed size. For the fluted roller seed meter, seed rate is varied by adjusting the length of the fluted rollers using a handle. By fitting seed meters with 4, 8, or 16 flutes, delivery of different-sized seed can be regulated. The fertilizer box (Figure 3) is made from the same iron sheet and has the same external dimensions as the seed box. The fertilizer box is fitted with six fluted roller-type meters, with eight or four deeper flutes (Figure 3).

Seed and fertilizer meters are attached to separate shafts. The power for the fertilizer meters comes from the 2WT differential shaft, through a chain, driven by a 19-tooth sprocket, and is relayed to the fertilizer meter shaft through a chain and sprocket. Seed and fertilizer delivery tubes made as 27-mm in diameter, clear polypropylene pipes, are attached behind the furrow opener. A pressing roller, 1200 mm long with a 127-mm diameter (Figure 1f) is attached behind the furrow openers by a pair of arms, 560 mm long.

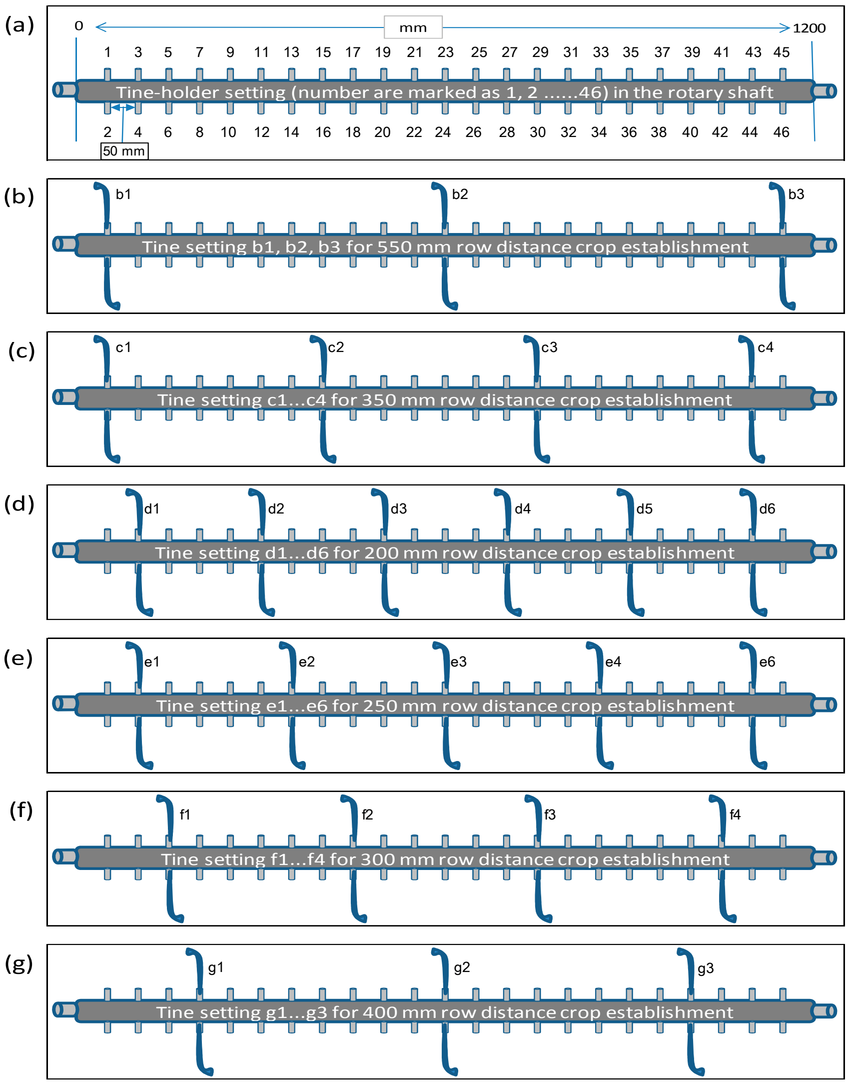

Figure 6. (**a**) Diagram of rotary shaft of Versatile Strip Seed Drill with tine holder positions; (**b**) diagram of tine settings with rotary shaft for 550 mm row-spaced crop establishment; (**c**) diagram of tine settings with rotary shaft for 350 mm row-spaced crop establishment; (**d**) diagram of tine settings with rotary shaft for 200 mm row-spaced crop establishment; (**e**) diagram of tine settings with rotary shaft for 250 mm row-spaced crop establishment; (**f**) diagram of tine settings with rotary shaft for 300 mm row-spaced crop establishment; and (**g**) diagram of tine settings with rotary shaft for 400 mm row-spaced crop establishment.

2.3. Initial Testing of VSSD

The VSSD was initially tested for up to six rows of strip planting with six pairs of small "L" shaped blades attached in rows. Eight- and four-flute types of seed and fertilizer meters, respectively, were used to successfully regulate seeds and fertilizers in the case of continuous seed delivery of wheat, lentil, chickpea, mustard, *etc.*, and basal fertilizer banding in the same strip. Seed and fertilizer in the soil were mostly consolidated by the press roller in a single pass operation. The seeding and fertilizing depth was maintained in a range, from 20 to 60 mm. The vertical-type seed meters with three different apertures were successfully used for the precision planting of maize, rice, and okra seeds.

2.4. Seed Calibration

Seed rate was calibrated over a 20-m travel distance with a 120-mm sowing width. This procedure was used to calibrate the VSSD for a range of crop species (Table 2) before performing the test planting in fields. Data on labor requirement, operational time, time loss, and field capacity were recorded during the field test. The time losses due to turning, clogging and operators' personal needs were also recorded. The rate of area coverage (field capacity) during planting was also determined [14] for the VSSD while establishing various crops (Table 2).

Table 2. Initial field trials to evaluate the performance of Versatile Strip Seed Drill (VSSD) for establishment of wheat, rice, chickpea, lentil, and maize at Savar, Dhaka district, Bangladesh, 2013.

Crop	Seed Rate ($kg \cdot ha^{-1}$)	Seeding Depth (mm)	Type of Seed Meter Used	Number of Rows Planted in Each Pass	Effective Field Capacity ($ha \cdot h^{-1}$)	Fuel Consumption ($L \cdot ha^{-1}$)	Plant Population m^{-2} (15 Days after Establishment)
Wheat (n = 3)	120	20–40	8 flutes	6	0.18 (2nd gear)	4.97 (±0.46)	137 (±19)
Rice (n = 3)	27	30–60	Vertical disk	6	0.13 (1st gear)	6.08 (±0.52)	78 ± 11 (24 hills)
Chickpea (n = 5)	30	30–50	8 flutes	5	0.18 (2nd gear)	4.42 (±0.39)	58 ± 6
Lentil (n = 4)	34	20–40	8 flutes	5	0.17 (2nd gear)	4.79 (±0.42)	169 ± 23
Maize (n = 6)	18	30–50	Vertical disk	3	0.13 (1st gear)	4.47 (±0.35)	9 ± 2

2.5. Soil Types and Agro-Ecology of Initial Field Trials of VSSD

Initial field trials were conducted at Savar upazila, Dhaka District and Baliakandi upazila, Rajbari District in Bangladesh; and Chaibasa District of Jharkhand State in India from June to December, 2013. The Savar site is under Agro Ecological Zone (AEZ)-8 (young Brammaputra and Jamuna floodplain) [15] with silty clay loam soil. The Baliakandi site is under AEZ-11 [15] (low Ganges river floodplain) and the soil type is sandy loam to loamy [15,16]; and the soil type of Chaibasa is loamy to clay [17].

2.6. Field Evaluation of VSSD

2.6.1. Initial Field Trials of VSSD

The average field size of the initial trials was 900 m^2 in Savar, 1200 m^2 in Baliakandi, and 2250 m^2 in Chaibasa. The initial field trials of the VSSD were done by attaching it to a 11.9 kW Dongfeng 2WT manufactured in China. The VSSD was used to seed rice, wheat (*Triticum aestivum* L.), maize (*Zea mays*), lentil (*Lens culinaris*), chickpea (*Cicer arietinum*), mustard (*Brassica napus* L.), okra (*Abelmoschus esculentus* L. Moench), and jute (*Corchorus olitorius*); and basal fertilizers (granular form) of diammonium phosphate and triple superphosphate were banded at the time of crop establishment.

2.6.2. Multi-Locational on-Farm Evaluation Trials

In 2013–2014, a total of six multi-locational on-farm evaluation trials (Table 3) were conducted for the planting of wheat seed. In 2014–2015, similar trials were repeated to establish wheat, mustard, and lentil crops (Table 4) in the same area. All multi-locational on-farm evaluation trials plots were located at Baliakandi upazila in the Rajbari District. The average plot sizes of the multi-locational on-farm trials were 1220 to 1340 m^2 and the tillage treatments were:

1. SP = Locally hired VSSD was used in dry land to open 20- to 50-mm deep and 40- to 50-mm wide planting strips; seed and fertilizers were placed in rows, either by a vertical-type seed meters for spaced planting (1 seed of maize and 3–4 seeds of rice per hill) or a fluted roller-type seed meter for high density seeding (for wheat, mustard, jute, and lentil) in a single pass operation.
2. CT = Land preparation for crop establishment was done by locally hired 2WT using 2 to 4 full rotary tillage passes in dry land followed by 1 to 2 leveling operations. The tillage depth of CT was 45–55 mm. The seed and fertilizers were hand broadcast prior to final soil tillage and leveling.

Table 3. Grain yields of multi-locational on-farm evaluation trials by VSSD to establish wheat, mustard, and lentil in the Rajbari District, Bangladesh.

Treatments	Grain Yield ($Mg \cdot ha^{-1}$) (n = 6)			
	Wheat (2013-14)	Wheat (2014-15)	Mustard (2014-15)	Lentil (2014-15)
SP	3.13	3.50	1.44a	0.88a
CT	2.95	3.34	1.27b	0.74b
Level of significant	NS	NS	**	**
CV	8.9	5.2	6.3	6.4

Note: SP = Locally hired VSSD was used in dry land to open 20 to 50 mm deep and 40 to 50 mm wide planting strips; seed and fertilizers placed in rows either by vertical-type seed meters for spaced planting (1 seed of maize and 3–4 seeds of rice per hill) or fluted roller-type seed meter for high density seeding (for wheat, mustard, jute, and lentil) in single pass operation; CT = Land preparation for crop establishment was done by locally hired 2WT using 2 to 4 full rotary tillage passes in dry land followed by 1 to 2 leveling operations. The tillage depth of CT was 45–55 mm. The seed and fertilizers were hand broadcast prior to final soil tillage and levelling; ** = Significant at $p < 0.01$; NS = Non-significant.

2.6.3. VSSD Contract Planted Fields

A local service provider (LSP) offered contract planting using VSSD to establish wheat, lentil, jute, mustard crops on more than 70 farmers' fields including several farmers who used the VSSD to make strips in untilled fields before establishing unpuddled transplanted rice [18] during 2013–2014 and 2014–2015. The contracted land sizes were 850 to 4500 m^2. Most of the farmers had retained rice residue at the height of 150–200 mm (equivalent to 1.5 $t \cdot ha^{-1}$), but no problem was encountered with use of the VSSD up to that level of retained residue. The VSSD was used to establish crops in half of the plots while CT was used to establish the same crops on the other half.

2.6.4. VSSD for Establishing Unpuddled Rice Seedling Transplanting

The VSSD was used to make 20–40 mm wide and 40–50 mm deep tilled strips (that preserved about 80% undisturbed soil) in undisturbed flat land: Following this, strip making ponded irrigation water to soak the soil for 24 h. Rice seedlings were transplanted manually in strips [18] at 250 mm between rows and 200 mm between hills.

2.7. Data Collection

2.7.1. Data on Initial Field Trials of VSSD

Initial field trial data were collected from three quadrats (1 m^2 each) and the averages of the three quadrats are presented in Table 2; for emergence of wheat, rice, chickpea, and maize. The field capacity of the VSSD for sowing and fuel consumption of initial field trials was collected from the whole plot at Savar, Dhaka, Bangladesh and converted to ha^{-1} (presented in Table 2).

2.7.2. Multi-Locational on-Farm Evaluation Trials

Individual whole plot grain yield data on multi-locational on-farm evaluation trials of SP and CT were collected from all trials and converted to ha^{-1} (Table 3).

2.7.3. VSSD Contract Planted Fields

Individual whole plot grain yield data supplied by LSP for VSSD and CT were collected from 43 farmers' fields. The grain yield data reported ha^{-1} (Table 4) were for sun-dried grain yield at approximately 13%–15% moisture in the grain.

Table 4. Grain yield comparisons of contracted VSSD planting (SP) with farmers' conventionally planted (CT) plots to grow wheat, mustard, lentil, and unpuddled rice.

Treatments	**Grain Yield (Mg·ha^{-1})**				
	Wheat (2013-14) (*n* = 8)	**Wheat (2014-15) (*n* = 10)**	**Mustard (2014-15) (*n* = 10)**	**Lentil (2014-15) (*n* = 10)**	**Unpuddled Rice (2015) (*n* = 5)**
SP	3.31a	3.73a	1.30	0.89a	5.02a
CT	2.96b	3.40b	1.18	0.75b	4.74b
Level of significant	**	**	NS	**	*
CV	6.5	5.3	13.7	12.7	3.8

Note: Note: SP = Locally hired VSSD was used in dry land to open 20 to 50 mm deep and 40 to 50 mm wide planting strips; seed and fertilizers placed in rows either by vertical-type seed meters for spaced planting (1 seed of maize and 3–4 seeds of rice per hill) or fluted roller-type seed meter for incessant seeding (for wheat, mustard, jute, and lentil) in single pass operation; CT = Land preparation for crop establishment was done by locally hired 2WT using 2 to 4 full rotary tillage passes in dry land followed by 1 to 2 levelling operations. The tillage depth of CT was 45–55 mm. The seed and fertilizers were hand broadcast prior to final soil tillage and levelling; Note the rice was manually transplanted as seedlings in strips prepared by VSSD. ** = Significant at $p < 0.01$; * = Significant at $p < 0.05$; NS = Non-significant.

2.8. Data Analysis

2.8.1. Initial Field Trials of VSSD

For the initial field trials of VSSD, effective field capacity, fuel consumption, and plant population were computed by Microsoft Excel 2010 to present mean and standard error (SE) (Table 2).

2.8.2. Multi-Locational on-Farm Evaluation Trials and Contracted VSSD Planting

Data were analyzed statistically using one-way analysis of variance (ANOVA) with Statistics 10 statistical software. Means were compared with least significant difference (LSD) test at $p < 0.01$ and $p < 0.05$ (Tables 3 and 4).

3. Results and Discussion

3.1. Effective Field Capacity of VSSD for Seed Sowing

The effective field capacity of VSSD for seed sowing ranged from 0.13 to 0.18 ha·h^{-1} (Table 2). Effective field capacity was highest for sowing wheat seed in six rows and chickpea seed in five rows with fluted roller-type seed meters in the 2nd gear position of the 2WT; and the lowest capacity was for sowing maize and rice seeds in the 1st gear position of 2WT with vertical disk-type seed meters (Table 2). The latter is, nevertheless, faster than most other 2WT-based tillage planters [13]. The effective field capacity of 2WT was reported to be 0.11 ha·h^{-1} [12] and 0.14 ha·h^{-1} [19]. However, the field capacity of CT in those studies ([12,19]) was calculated based on a-single pass tillage by a 2WT; thus, the actual and comparable field capacity of CT needs to be multiplied by the number of applied tillage passes (e.g., 2 to 4 tillage passes).

3.2. Fuel Consumption of VSSD

Lowest diesel fuel consumption (4.42 L· ha^{-1}) was recorded in the case of chickpea planting and highest in rice (6.08 L· ha^{-1}) establishment (Table 2) by VSSD in SP treatment, which was lower compared to most 2WT-based tillage planters [13] used in Bangladesh. Previously, the fuel consumption of 2WT for CT was reported to be 33 L· ha^{-1} [12] and 39 L· ha^{-1} [19], meaning that using the VSSD could reduce diesel fuel use by more than 80%, which is attractive for the cultivation of crops in limited-resource areas [20].

3.3. Performance of VSSD for Crop Establishment

The initial field trial of VSSD in Savar, Dhaka, with the fluted roller type seed meter established an optimum plant population of wheat, chickpea, and lentil; as did the use of the vertical disk type seed meter for rice and maize. Using recommended seed rates, the average plant populations recorded per m^2 at 15 days after sowing was 137, 78, 58, 169, and 9 for wheat, rice, chickpea, lentil, and maize, respectively (Table 2). Placement of seed and fertilizer in the optimum moisture zone by the VSSD ensured the optimal plant population.

3.4. On-Farm Multi-Locational Evaluation Trials of VSSD for Crop Cultivation

3.4.1. Wheat

Wheat grain yields averaged 3.13 and 3.50 Mg· ha^{-1} from VSSD on-farm evaluation trials in the case of SP treatment during 2013–2014 and 2014–2015, respectively, and which were statistically similar to yields from CT plots, which averaged 2.95 and 3.34 Mg· ha^{-1}, respectively (Table 3).

3.4.2. Mustard

Significantly higher seed yield of mustard (1.44 Mg· ha^{-1}) was recorded from SP treatment by VSSD relative to CT (1.27 Mg· ha^{-1}) (Table 3). The size of mustard seed is very small (<2 g 10^3 seeds) and placement of seed at shallower depth is essential to achieve optimum plant population. Hand broadcasting of mustard seed in CT could not ensure seed placement at an optimal depth, however, the VSSD had the capability to place seed and fertilizers uniformly in an optimal moisture zone, which ensured homogeneous plant growth, from emergence to maturity of the mustard crop, which may have contributed to yield increases.

3.4.3. Lentil

The SP using VSSD planting produced significantly higher (19%) grain yield of lentil (0.88 Mg· ha^{-1}) compared to CT (0.74 Mg· ha^{-1}) (Table 4). Higher plant population and uniform plant growth were observed (data not shown here) in the case of VSSD-planted lentil, which may account for increased yields.

3.5. Performance of VSSD in Contracted Farmers' Fields

3.5.1. Wheat

In 2013–2014, eight farmers reported an average wheat grain yield of 3.3 Mg· ha^{-1} from SP by VSSD contract-planting which was significantly higher (12%) than their paired CT-planted crops (Table 4). Similarly, in 2014–2015, from ten farmers' fields, a 10% grain yield of wheat (Table 4) was obtained in SP with VSSD-contracted planting.

3.5.2. Mustard

In 2014–2015, ten farmers reported that they had harvested an average of 1.30 and 1.18 Mg· ha^{-1} of mustard seed yield from SP by VSSD and CT planted plots, respectively (Table 4).

3.5.3. Lentil

Significantly higher seed yield of lentil was recorded from SP by VSSD contract-planted plots (0.89 Mg· ha^{-1}), which was about 19% higher than from the CT lentil planted on the same fields (Table 4).

3.5.4. Unpuddled (No-Till) Rice Seedling Transplanting

Five farmers reported that they had harvested 0.28 Mg· ha^{-1} more rice grain yield where they used contracted VSSD to prepare the land for unpuddled rice transplanting [18] compared to CT puddled transplanting of rice in the same fields (Table 4).

4. Conclusions

Small holders in South and South-east Asian countries are using large numbers of 2WT as a power source and for primary tillage (Table 1, [21,22]). In the Eastern Indo-Gangetic Plains, farmers are buying tens of thousands of 2WT [4]. The use of 2WT for agriculture in Thailand increased by a factor of 6–7 in the 15-year period between 1978 and 1993. Similar trends have occurred in Vietnam, Malaysia, and Indonesia (Table 1). Successful mechanization can be seen in the Philippines, Thailand, Indonesia, and Bangladesh, where the simple 2WT has proved a viable tool for many small-land holder farmers [18]. Parts of Africa have begun importing Chinese 2WT, and Nigeria may have close to 1000. Hence, the potential for application of minimum soil disturbance planters with these 2WT is potentially very extensive. Adoption of farm mechanization and minimum soil disturbing planting systems have saved farm labor requirements in Punjab and Haryana [18], and the saved labor shifted from agriculture to more specialized rural and urban jobs, as well as to the new jobs and opportunities created.

Conventional land preparation with up to 12 tillage passes per year for crop establishment (average four tillage passes for each of the three crops in a year) is time consuming, laborious, and costly. By contrast, the VSSD does not require any preceding tillage, which can reduce crop production cost and time. The VSSD has the capability of establishing diversified crops in untilled soils with anchored residue fields; thus, VSSD is a feasible option for smallholders implementing CA in Asia and Africa. In large areas of South and South-East Asia where 2WT are already widely spread, this type of planter could play a role in the mechanization of planting and fertilizer application, as well as being a vehicle for crop establishment with minimum soil disturbance and residue retention. In Bangladesh, it is not farmers themselves who are purchasing the VSSD, but, rather, small agricultural contractors (*i.e.*, local service provider—LSP) who then rent it out for crop establishment on a fee-for-service basis. The average rate of return on investment by renting out the Chinese 2BG-6A planters for single pass shallow tillage planting with a 2WT tractor was 2.6 yr^{-1} implying that a planting service is highly profitable for the LSP [23]. Similar, or more, profit can be expected from the VSSD. In attempting to commercialize this technology in Bangladesh, we have learned the importance of maintaining quality control during the manufacture and use of high quality materials. Operators also need on-going training for at least two years for the effective use of the VSSD to achieve reliable crop establishment outcomes across a range of field types. Planters, such as the VSSD, could be used to develop CA practices across a wide range of cropping systems used by smallholder farmers in Asia and Africa.

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