Design, development and performance evaluation of zone disc tiller drill for maize crop production in Pakistan

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Abstract: A light weight zone disc tiller drill was redesigned and developed employing Solid works and AutoCAD software's. For field performance evaluation of the machine, the experimental trials were conducted at Post Graduate Research Station, University of Agriculture, Faisalabad, Pakistan. An area of 2.5 ha (6.12 acres) was divided into two halves; one-half of the area was used for the conventional method of maize planting and the second half was used for maize planting by redeveloped zone disc tiller drill. It was observed that under the conventional method, extensive field preparation operations were performed, whereas no field preparation had been done for planting maize with a zone disc tiller drill. After harvesting the paddy crop, the zone disc tiller drill was passed through the standing stubble field and planted the maize seed in one pass. Crop planting results with zone disc tiller drill and conventional method under three levels of irrigation and three levels of fertilizer levels were compared for their impact on the crop parameters including emergence rate index, root length, root shoot ratio, shoot length, root fresh weight, root dry weight, shoot fresh weight, and shoot dry weight. All the data were statistically analyzed and found that the emergence rate index by using a zone disc tiller drill was 1.43 times greater than that under conventional maize planting. The emergence rate index at irrigation level I_3 (after 4 days) was 1.23 times greater than that at I_2 (after 6 days) and 1.40 times greater than that at I_1 (after 8 days). The value of the emergence rate index at fertilizer level F_3 (148.2 kg ha^{-1}) was 1.61 times greater than that at F_2 (123.3 kg ha^{-1}) and 3.32 times greater than that at F_1 (98.8 kg ha^{-1}). Plant shoot dry weight by using a zone disc tiller drill was 1.68 times greater than that observed under the conventional maize planting method. It was concluded from the cost analysis that the cost of sowing maize with a zone disc tiller drill on an area of one hectare was less as compared to the conventional method (tillage + sowing). The proposed study showed that the newly designed machine could sow maize seed in rice stubble field within an acceptable cost, saves time, improve soil physical parameters, and crop parameters for better production of maize.
Keywords: zone disc tiller drill, maize, design and development, crop parameters, conventional sowing

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1 Introduction

Pakistan is an agricultural country; the agricultural sector contributes 20.9% to the gross domestic products (GDP), provides 80% of total national export, and employs 44.6% of the labor force (Iqbal et al., 2012). At present, the country's population is enhancing by 2.68% annually (Mahmood et al., 2010). The population is increasing at a rapid rate in Pakistan and estimates indicate a near 243 million mouths to be

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fed by the year 2025 (Jehangir et al., 2003). Crop production should have to increase to fulfill the demand of the increasing population. This increment in the production of agricultural crops can be attained either by increasing the crop yield per unit area or by bringing more area under cultivation. The crop yield per unit area could be better by implementing conservation technologies i.e., zero-tillage, and minimum tillage (Giller et al., 2015; Omulo et al., 2022; and Thierfelder et al., 2013). However, continues use of conventional agriculture for a long time, which is done by means of mould board plough and rotavator, and the removal of crop residues from the farm field used as domestic fuel and fodder or burning of crop residue, resulted in severe degradation of land, decay of soil fertility and productivity (Hussain et al., 2016; Kuhwald et al., 2017; Montgomery, 2007; and Murphy et al., 2006), reduction in yield, and cost of production increased that seriously dangers food security (Chauhan et al., 2012; Jahun et al., 2020; and Jat et al., 2009). Therefore, an important need of the hour is to develop and promote technologies to meet the challenge of food production and increasing population (Ajmal et al., 2017; Faheem et al., 2021; Liu et al., 2019; Omulo et al., 2022; and Ur Rehman et al., 2016).

Among conservation tillage technologies, zero tillage provides the greatest input use efficiency, the lowest energy consumption, and the maximum net benefit to farmers (Erenstein and Laxmi, 2008; Gupta and Seth, 2007). In light of this, the department of on farm water management (OFWM) introduced zero tillage technology in Punjab province of Pakistan and more than 4454 hectares have been sown by this technique in Punjab during 1999-2000 Rabi seasons (Islam et al., 2019). Zero tillage is basically direct drilling of seed in the uncultivated soil with the help of a seed drill. Sowing of wheat with till-planting method minimizes intercrop gap and increases the yield by 15% higher as compared to conventional practice involving land preparation. It is considered an excellent practice for wind and water erosion control and thus storage of water in soil profile (Ibrahim et al., 2011). However, the handling of crop residue after harvesting is a serious constraint in the adoption of conservation tillage due to the mechanical interference of residue in sowing operations, especially in paddy fields of humid area (Carter, 1994). So, for precise sowing, efficient sowing machinery and effective residue handling is required (Carter, 2002).

For the placement of seed and crop straw management, a variety of furrow openers like chisel, hoe, inverted T, winged chisel, and disc type are utilized in conservation tillage systems. Some of these furrow openers are used in simple seed drill with single seed tube while others are used in seed cum fertilizer drills with separate tubes for seed and fertilizer application. There are advantages and disadvantages of these furrow openers with respect to soil disturbance and cutting force (Choudhari, 2001). The disc type furrow openers have lower soil disturbance than the hoe type furrow openers (Janelle et al., 1993; Parent et al., 1993). At the time of sowing, these types of furrow openers are used mostly as they are effective in straw cutting to clean the excess crop residues and soil failure. Among these furrow openers, the double disc furrow openers are considered the most efficient (Baker et al., 1996). In general, disc-type furrow openers used in zero and minimum tillage systems are classified as smooth-type, toothed-type, and notched-type, and either single or double-disked (Choudhari, 2001). A lot of studies has been done on furrow openers under low moisture content and their influence on seed emergence index, soil physical properties (Altikat et al., 2013; Doan et al., 2005a; Iqbal et al., 2012; Munir et al., 2012) , and seed distribution pattern (Chen et al., 2004; Doan et al., 2005b). The hoe-type furrow opener was better suited for hard and dry soil conditions at sowing time because of its better penetration (Bahri and Bansal, 1992). However, performance evaluation with double disc type furrow openers behind the wavy disc in no till paddy field is still need to be discussed. The wavy disc (used in this study) have greater contact surface, requiring a greater vertical force to penetrate the ground and cut the material than the previous ones, opening wider furrows and mobilizing a larger volume of soil (Becker et al., 2019).

Maize is used as an experimental material in this study. Maize is the third most important crop in the world after wheat and rice with respect to area and production (Government of Pakistan, 2009). In Pakistan, maize was grown on area of 1042 thousands hectares with a production of 3109.6 thousand tons with an average yield of 2984 kg ha^{-1} which is very low as compared with developed countries (Li et al., 2016). The cultivation of maize has been increased to an area of 1144000 hm^2 during the year 2018, which is 0.2% more than the previous year. The low yield is primarily due to substandard methods of cultivation and small plant population (Abbas et al., 2009). A next, logical step to increase their sustainability is to reduce tillage and manage plant residue of previous crop on the surface, and reshape the beds only as needed between crop cycles (Valdés, 2013). Although the soil and climatic condition of Pakistan are favorable for maize production its per hectare fodder yield is very low as compared to other maize growing countries of the world (Khandaker and Islam, 1988). The average yield of Pakistan is low due to lack of adaptation of improved planting methods and low plant density. It was found that grain yield of maize crop was greater with ridge sowing which was attributed to the greater amount of available nitrogen under this system (Amin et al., 2006). Currently, residue of paddy after harvesting is either burnt before preparation of field or mix into the soil. Mixing needs extra tillage operations, while burning of crop residue causes environmental pollution, and nutrients loss. Moreover, sowing of maize in standing stubble, and allowing the stubbles to decompose with time during growth span of maize crop. So, there is a need for development, modification of resource conservation technologies with minimum tillage in order to produce maize crop with highest yield in paddy growing areas of Pakistan.

For this purpose, a zone disc tiller drill (ZDTD) was re-designed (with frame, wavy disc in front of furrow openers, and maize metering device) and evaluated. ZDTD is a conservation tillage machine that cut and pulverizes the seed zones in front of furrow openers, and places the seeds at required depth without disturbing the remaining field. In one pass it prepares the seed bed, places seed and fertilizer together, ultimately saves energy, fuel, labor, and time. In this study, the ZDTD have been redesigned with the help of computer software's such as AutoCAD and Solid Works and fabricated accordingly. The maize crop was sown in standing paddy residue fields both with the help of redesigned ZDTD and conventional sowing methods. The different crop parameters by using newly developed ZDTD and conventional methods were also determined. Moreover, the cost analysis of maize sowing with newly developed ZDTD and conventional methods was also done. The redesigned machine performed satisfactorily in paddy stubble field with a 50 HP tractor and affordable for small scale farmers due to its low cost.

2 Materials and methods

The study was carried out to design, develop a ZDTD and compare its field performance with conventional method of maize planting (Iqbal et al., 2012) after paddy harvest. The new developed ZDTD adds additional option for fertilizer application, residue management, soil conservation, erosion control and other environmental friendly management options. The use of newly developed ZDTD plays an important role in conservation agriculture. A ZDTD consists of soil tilling unit and seed furrow opening and seed placement unit. The soil tilling unit had seven way discs (457 mm diameter with 50 mm wave). The tilling unit rotates at 242 rpm at rated speed of tractor PTO shaft (540 rpm). Two gear reduction devices have been employed to reduce 540 rpm of PTO to 240 rpm at disc shaft. Each disc prepares a narrow slit (50mm wide × 100mm deep) in front of each furrow opener. The seed/fertilizer metering device, meter seed/fertilizer to place fertilizer deeper than seed in bulk. Each furrow opener is followed by a furrow covering device (drag bar type) to cover seed by soil.

2.1 Machine development

Efficient performance of a machine is the outcome of a sound design and fabrication. Hence, efforts were made to select proper materials for design components of machine and fabricate with skilled technology. Designing was done by using the AutoCAD and Solid Works software applications. The 3-D view of designed ZDTD machine is shown in Figure 1. The machine was developed using locally available material and facilities in agricultural machinery manufacturing industry. All the dimensions are in millimeters.

The developed machine and its different unit are shown in Figure 2. The ZDTD machine consisted of two units that are zone till unit and seed drilling unit. The explanation of these units is given in below.

2.1.1 Components of zone tilling unit

Zone till unit consisted of wavy disc assembly, frame, disc type furrow openers, universal shaft, power transmission shaft, and side gear drive. The front view of redesigned zone till unit is shown in Figure 3a and three dimensional isometric and two dimensional front view of zone till unit is shown in Figures 3b and 3c. All the units in the diagrams are in millimeters.

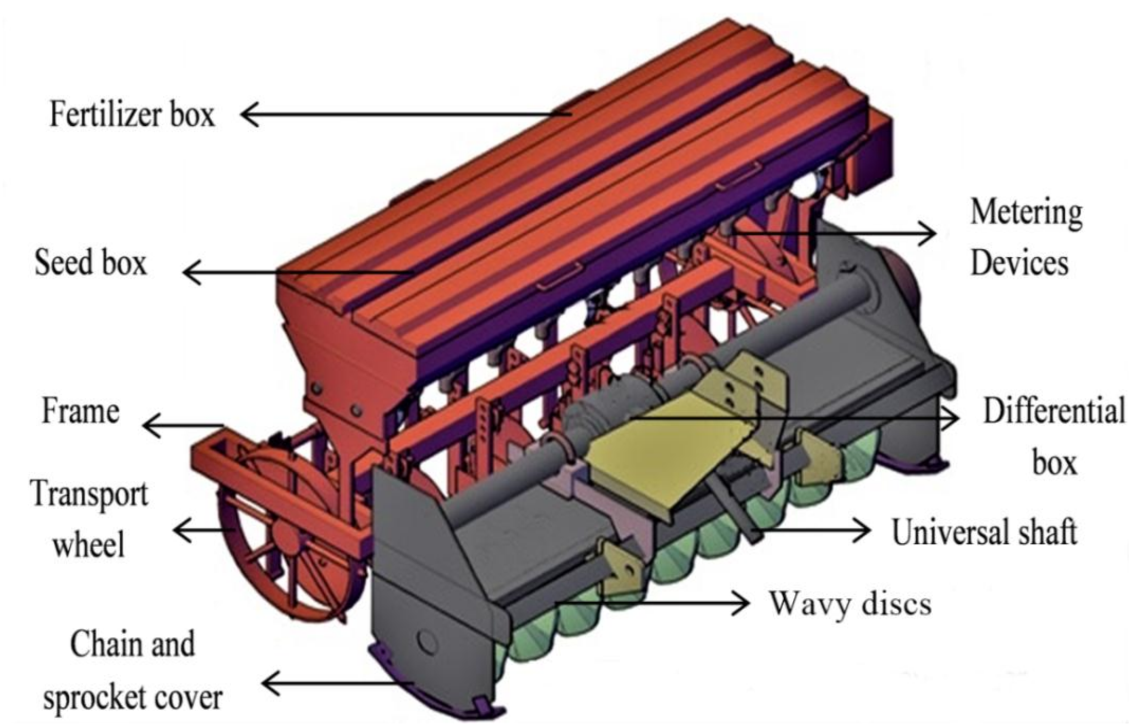
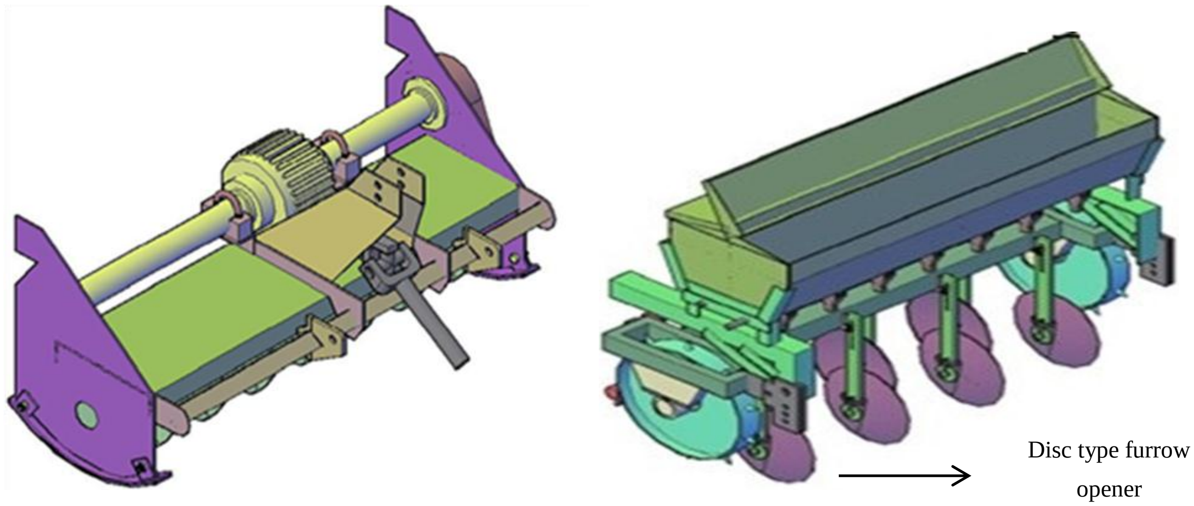
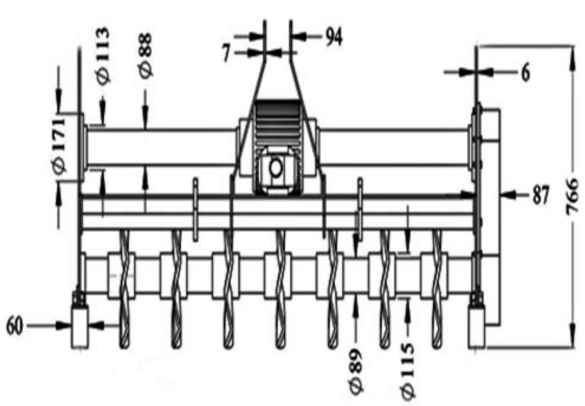


Figure 1 Three-dimensional isometric view of modified zone disc tiller drill

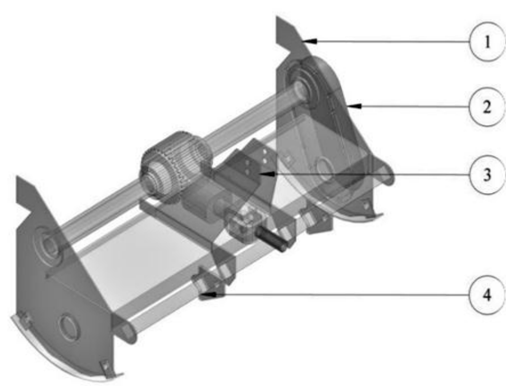


(a) Zone tilling unit (Front part of machine); (b) Drilling unit (Back part of machine)

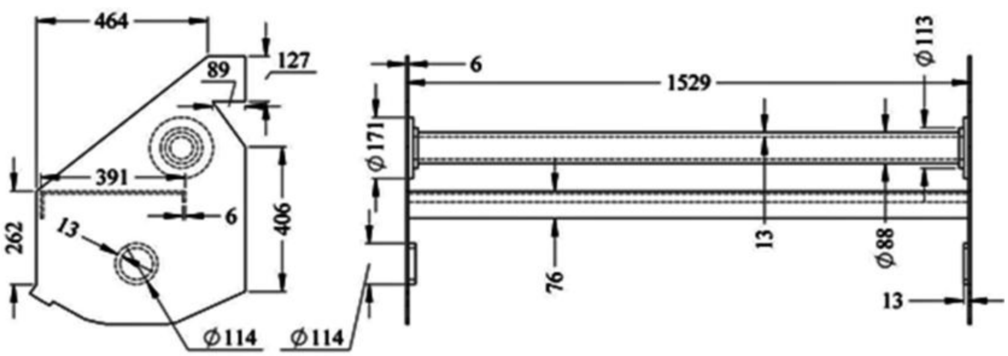
Figure 2 Isometric view of zone tilling unit and drilling unit



(a)) Front view of zone till unit of zone disc tiller drill



(b) Three dimensional isometric view of zone till main frame

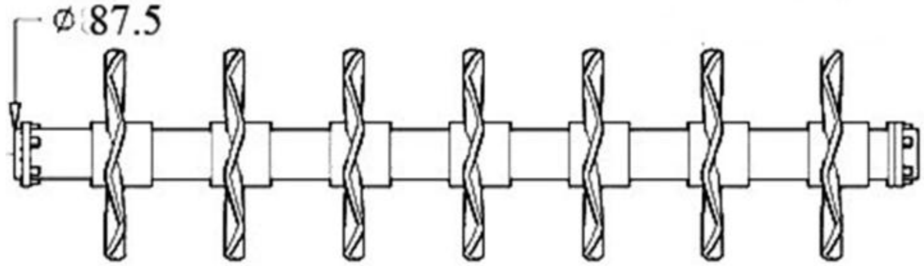


(c) Two dimensional front view of main frame and side supporting plate of zone till unit

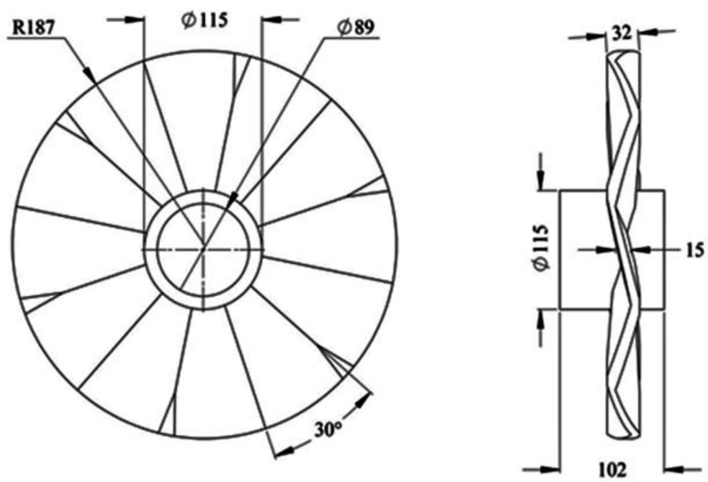
1- Side plate, 2-Chain and sprocket cover, 3-Top linkage point, 4-Lower linkage point

Figure 3 Zone disc tilling unit

A coulter shaft having seven wavy discs was mounted on mild steel hollow shaft as shown in Figure 4a. Each wavy disc was rigidly held in position by two flanges. The space between two adjacent discs was kept same as row spacing for maize crop to be planted. Power to the wavy disc shaft was provided from the tractor power take of shaft (PTO), the speed reduction gearbox and a train of gears. Two gear reduction devices have been employed to reduce 540 rpm of PTO to 240 rpm at disc shaft. The shaft was replaceable type that could be easily attached and detached. Two dimensional side and front view of wavy disk is shown in Figure 4b.



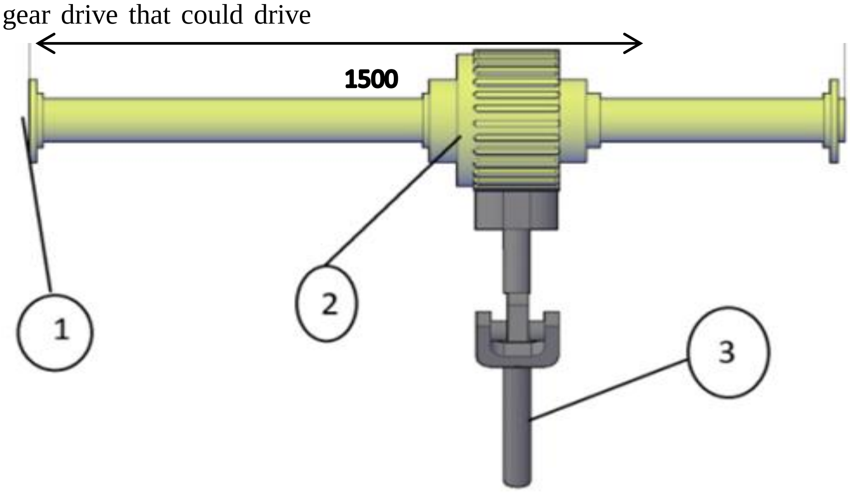
(a) Hidden wireframe of zone till coulter assembly



(b) Wavy disk

Figure 4 Three dimensional side and front view

A suitable power transmission shaft was employed to transmit power of tractor PTO from machine single speed gearbox to the side gear drive that could drive the wavy disc shaft through heavy duty chain as shown in Figure 5.

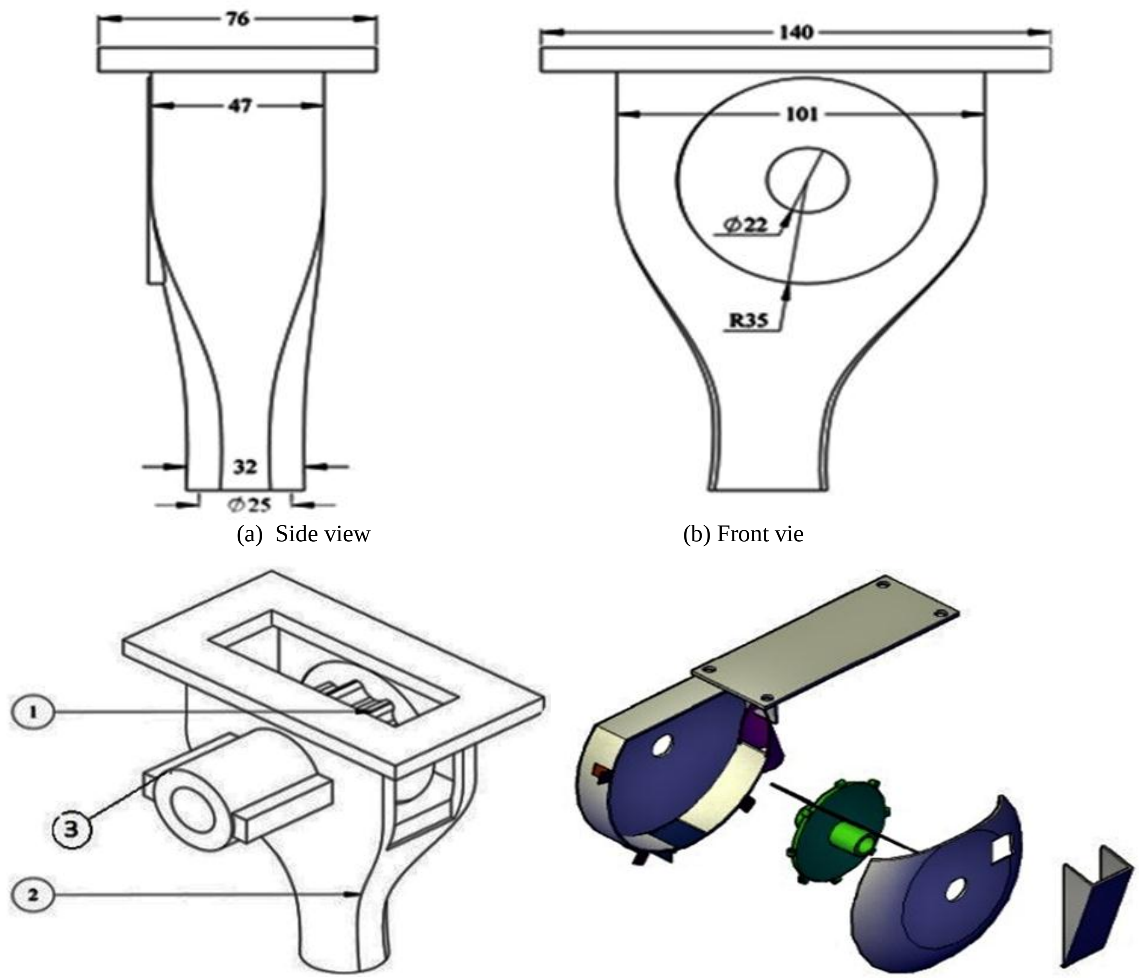


1-Power transmission shaft, 2-Differential box, 3-Universal shaft

Figure 5 Three dimensional top view of power transmission shaft and universal shaft

2.1.2 Components of drilling unit

In order to open furrows in tilled strips and place seeds in these furrows and cover them, a drilling unit was fabricated behind the zone till unit. The main components of the drilling units included seed and fertilizer boxes, seed metering device, and drive mechanism, fertilizer metering mechanism and seed and fertilizer placement mechanism etc (Qin et al., 2018). Seed drills have been provided with metering devices that determine a given volume of seed for random distribution along the row. Fluted roller type seed metering devices were mostly used for wheat (Matin et al., 2021; Munir et al., 2012). Keeping in view the wide use of fluted roller type mechanism and its capability of handling various crops like wheat, chickpea, mungbean, pigeon pea, soybean and sorghum etc, the fluted roller type seed metering device with straight flutes were used for maize seed as shown in Figure 6.



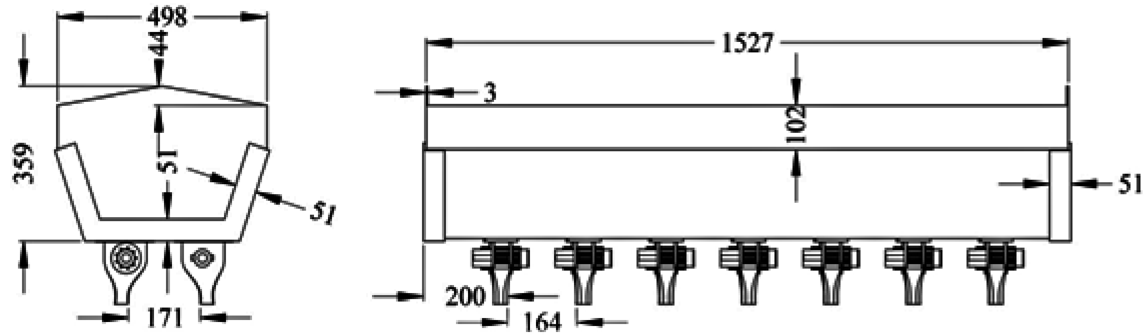
(a) Side view (b) Front vie

(c) Three dimensional view

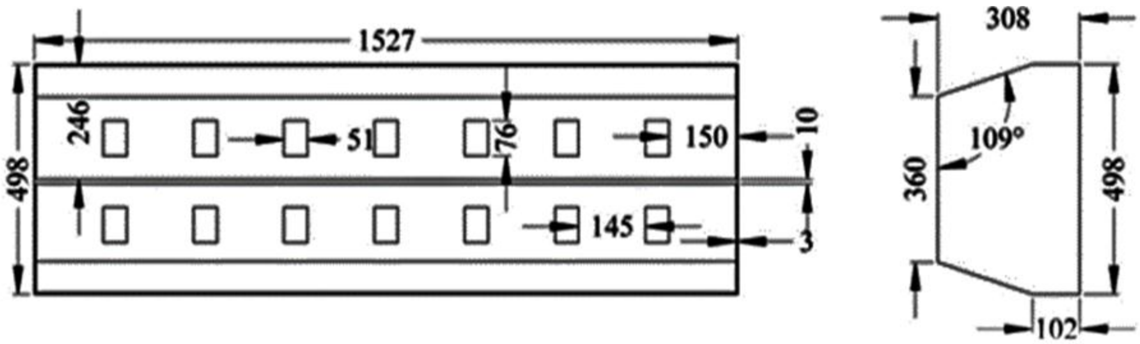
1-Fluted roller, 2-Seed dropper pipe, 3- topper roller

Figure 6 Seed metering device

A box with two partitions one for seed and other for fertilizer was fabricated as seed cum fertilizer drill. There are seven metering devices that are attached behind the both partitions for metering seed and fertilizer into the soil. The length of seed box is 1527 mm and width of seed box is around 498 mm. The two dimensional front, side and top view of seed and fertilizer box along with dimensions are shown in Figures 7a and 7b.



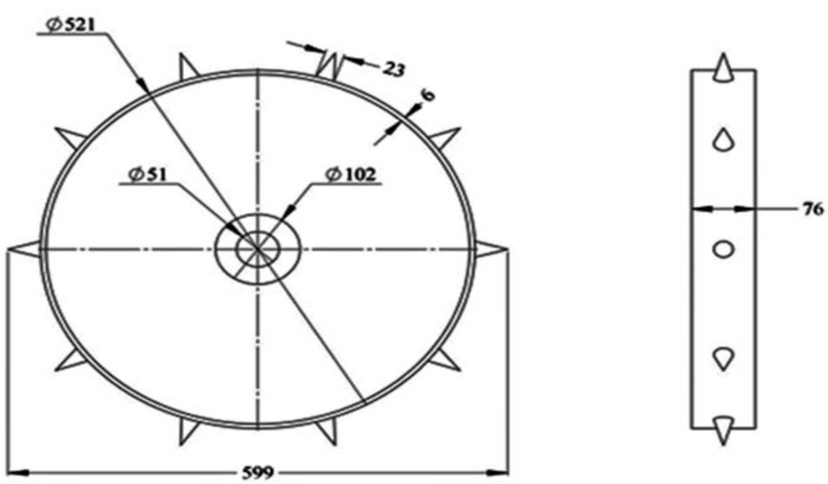
(a) Seed and fertilizer box



(b) Seed and fertilizer box with inner dimensions

Figure 7 Two dimensional front, top and side view

Two ground wheels were provided on either end of the unit. One wheel gave drive to seed metering shaft while the other to the fertilizer metering shaft through chain and sprocket drives. The lugs were welded on the wheel to reduce the slippage. A positive drive chain and sprocket system was used to transmit power from ground wheel to the shafts that derived seed metering mechanism and fertilizer metering mechanisms. The wheel which was used to drive the metering devices shaft and chain and sprocket with dimensions are shown in Figure 8.

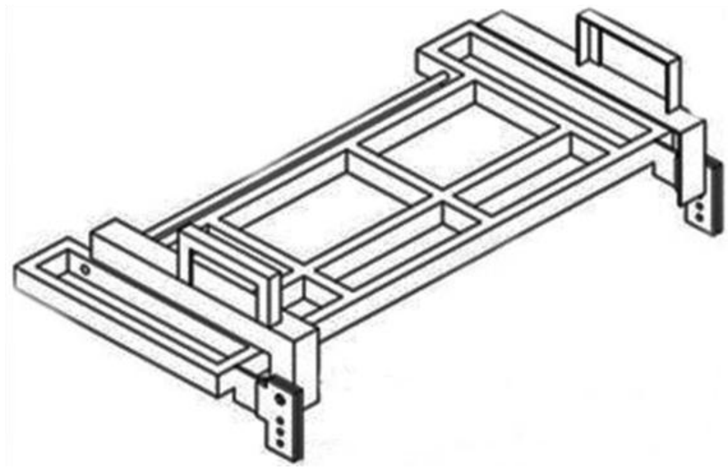


(a) (b)

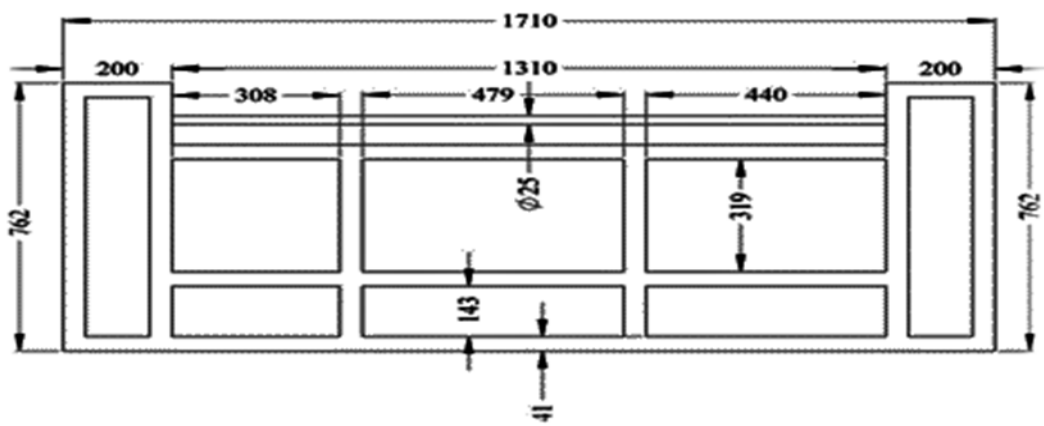
Front view; (b) Side view

Figure 8 Front and side view of ground wheel

Disc type 55 mm curved furrow openers were used to open furrows in tilled strip. Locally available transparent plastic tubes were used to drop seed and fertilizer from their respective boxes. A partition in each furrow opener was provided to avoid mixing of seed and fertilizer while drilling. Old frame of the machine is given in Figures 9a and 9b, the modified form of this frame was used in light weight ZDTD. New frame is short in length which leads to reduction in weight (800 kg of existing machine to 750 kg of newly developed machine) and easiness in handling machine with 50 HP tractor. The two dimensional top view of new modified frame is shown in Figure 10.



(a) Isometric view



(b) Two dimensional top view

Figure 9 The isometric view and two dimensional top view of old machine frame

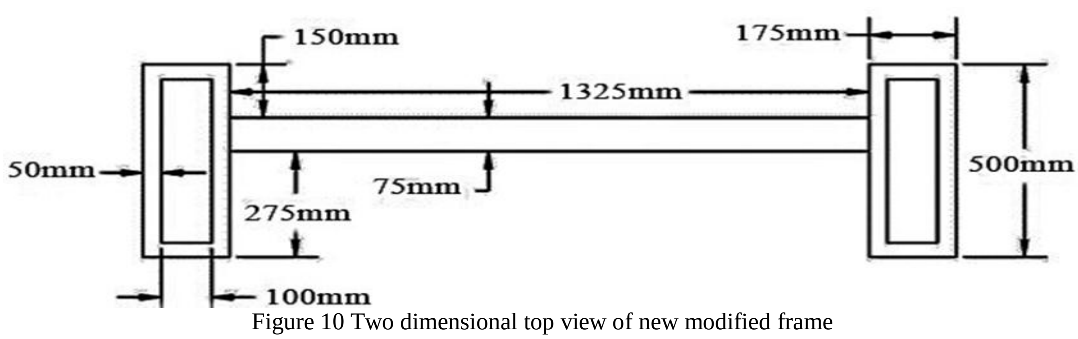


Figure 10 Two dimensional top view of new modified frame

Wavy disc were made of temper steel and their diameter was selected according to penetration depth and cut the paddy stubbles. Disc type furrow openers were used behind the wavy disc with diameter of 356 mm and 55 mm width of furrows. Disc type furrow openers operate more easily and their performance was excellent in residue management. Disc type furrow openers were used behind the zone tilling unit for the placement of seed. The front and side view of disc type furrow opener is shown in Figure 11.

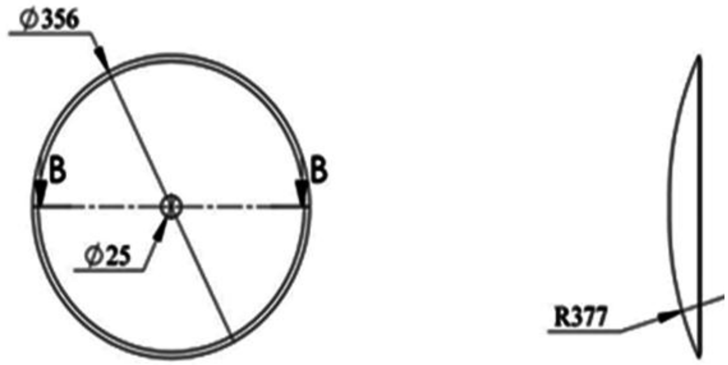


Figure 11 Two dimensional front and side view of disc type furrow opener

2.2 Field performance evaluation of machine

Maize variety (MMRI-Yellow) was sown at the rate of 30 kg ha^{-1} with target seeding depth of 4.5 cm, inter and intra row spacing of (65 cm, 25 cm respectively). Moisture content and bulk density of the soil during seeding were 14.56% and 1.42 g cm^{-3}. Experimental trials were conducted at Post Agricultural Research Station (PARS) of the University of Agriculture, Faisalabad (UAF). Total area was about 2.5 ha (6.12 acres). Out of the total 2.5 ha, one half of the area had been allocated for conventional sowing method (about 3 acres), while the second half of the area (about 3 acres) allocated for maize planting by ZDTD. Each block has a dimension of 41.67 m × 33.33 m (about 1 acre). The field layout of planted maize by ZDTD and by chokka (conventional) method is given below Table 1. In conventional method of maize planting, seedbed preparation was done after a lot of farm practices, like two passes of cultivator, two passes of disc harrow and three operations of a planker/sohaga, and finally conventional maize planter was used for planting of maize.

Table 1 The field layout of planted maize by ZDTD and by chokka method

M_1				M_2			
B_1	I_1 F_1 F_2 F_3	I_2 F_1 F_2 F_3	I_3 F_1 F_2 F_3	B_1	I_1 F_1 F_2 F_3	I_2 F_1 F_2 F_3	I_3 F_1 F_2 F_3
B_2	I_3 F_2 F_3 F_1	I_1 $F_2F_3F_1$	I_2 F_3 F_2 F_1	B_2	I_3 F_2 F_3 F_1	I_1 $F_2F_3F_1$	I_2 F_3 F_2 F_1
B_3	I_2 F_3 F_1 F_2	I_3 F_1 F_3 F_2	I_1 F_2 F_1 F_3	B_3	I_2 F_3 F_1 F_2	I_3 F_1 F_3 F_2	I_1 F_2 F_1 F_3

Note: M_1, M_2 are the methods of sowing by ZDTD and dibbler (chokka) method respectively; B_1, B_2 and B_3 are the different blocks respectively; I_1, I_2 and I_3 are the different irrigation levels respectively; F_1, F_2 and F_3 are different amount of fertilizers respectively.

While, no field preparation had been done for planting maize with the ZDTD. After harvesting the paddy crop and paddy stubble height is around 13-15 cm (5-6 inches), newly developed machine ZDTD planted maize seed in one pass in the standing paddy crop residue as shown in Figure 12.

2.3 Treatments and their description for two planting methods

The field experiment consisted of a factorial design of three irrigation levels and three fertilizer levels embedded in randomized complete block (RCBD) statistical design as shown in Table 2.

Treatments were replicated three times using RCBD design. First irrigation was applied after 8 days, 2nd after 6 days and 3rd after 4 days. First, second and third levels of fertilizer were 98.8, 123.3 and 148.2 kg ha^{-1} respectively. Three speeds of tractor were selected i.e., 3.75, 4.5, and 6.3 km h^{-1}.

Figure 12 Field condition after passing zone disc tiller drill

Table 2 Treatment level and their description

Sr. No.	Treatments/parameters	Levels
1	Irrigation level (I)	Three irrigation level I_1 I_2 I_3
2	Fertilizer (F)	Three fertilizer rate F_1 F_2 F_3
3	Blocks (B)	Three blocks B_1 B_2 B_3

Note: I_1, I_2 and I_3 are the different irrigation levels. I1= irrigation applied after 8 days, I_2 = irrigation applied after 6 days, I_3 = irrigation applied after 4 days. F_1, F_2 and F_3 are different fertilizer levels. F_1=98.8 kg ha^{-1}, F_2=123.3 kg ha^{-1}, F_3=148.2 kg ha^{-1}. B_1, B_2 and B_3 are different blocks.

2.4 Machine evaluation under crop parameters

In order to evaluate its performance, the parameters studied were emergence rate index (ERI), root length, shoot length, root shoot ratio, root fresh weight, root dry weight, shoot fresh weight and shoot dry weight .Crop variety "nelam" was selected for the comparison of both sowing methods. Fertilizer had been applied to the field in three dozes. An area of one square meter each was selected in every experimental plot for the determination of seedling emergence and ERI as explained by (Colvin and Erbach, 1982).

$$\mathrm{ERI}=\sum_{i=1\mathrm{First}}^{n}\frac{\%i-\%(i-1)}{i} \quad (1)$$

where, *ERI* is the emergence rate index, *i* is the number of days since planting, *%i* is the plants emerged on day '*i*' as a percent of total seed emergence, *%(i-1)* is the plants emerged on day '*i-1*' as a percent of seeds planted, *1* is the first counting day after emergence started, *n*is the last counting day when emergence completed. The root and shoot of plants was analyzed as suggested by (Allen et al., 1974).

Root shoot ratio is calculated by using Equation 2.

$$Root\ shoot\ ratio = \frac{root\ length}{shoot\ length} \qquad (2)$$

The roots of most of the plants remain within the surface 60 cm, therefore, roots cores should be focused up to this depth. It simply calculated by taking the root of plant and then weights it by using electrical balance. Root dry weight was calculated by taking the roots into oven for drying at 65°C for 24 hours and then weighed (Follett and Kimble, 2000). The shoot fresh weight simply calculated by taking the shoot of plant and then weighs it by using electrical balance (Sharp and LeNoble, 2002). Shoot dry weight calculated by taking the shoot into oven for drying at 65°C for 24 hours, and then weighs it (Sharp et al., 2000).

2.5 Cost analysis of machine

The cost analysis for the ZDTD and conventional seed drill was done to evaluate the field capacity, man h/ha and total operational cost per hour. A comparison of the costs, both for the ZDTD (no field preparation required), and the conventional seed drill (including soil preparation required prior to drilling), was made in order to evaluate the differences. The cost comparison included the cost of machinery, the land preparation cost, operational cost, and labor cost.

3 Results and discussion

This study was divided in two phases' viz. design and development of machine and its testing evaluation. The experiments were conducted to assess machine's performance. The crop was planted both by ZDTD machine and conventional method. The crop parameters studied were ERI, root length, shoot length, root shoot ratio, root fresh weight, root dry weight, shoot fresh weight and shoot dry weight. All the data was statistically analyzed by using software statistics 8.1. The statistically analyzed data which show the effect of planting methods, irrigation levels, and different fertilizer level on maize crop has been present in Table 3.

3.1 Effect of planting method, irrigation level and fertilizer level on crop parameters

Table 3 showed that method M_1 produced significantly greater ERI than that with method M_2. Too low ERI at method M_2 could be due to improper placement of seed, less availability of minerals and less availability of water to the roots of plants. It can be seen from Table 3 that the ERI under method M_1 was 1.43 times greater than that observed under method M_2. It clearly showed the effectiveness of planting method on ERI.

Table 3 Effect of planting method, irrigation levels and fertilizer levels on different crop parameters

Crop parameters	Planting method		Irrigation level			Fertilizer level		
	M_1	M_2	I_1	I_2	I_3	F_1	F_2	F_3
ERI (% seed emerged per day)	6.479^{a*}	4.544^{b}	4.944^{b*}	5.668^{ab}	6.944^{a}	2.593^{c*}	5.341^{b}	8.600^{a}
Root length (cm)	6.916^{b*}	7.277^{a}	9.244^{a*}	5.455^{b}	3.700^{c}	8.861^{a*}	6.944^{b}	5.594^{c}
Shoot length (cm)	26.759^{a*}	18.300^{b}	18.939^{c*}	21.289^{b}	24.361^{a}	18.833^{c*}	21.433^{b}	25.322^{a}
Root shoot ratio	0.2556b*	0.4630^{a}	0.461^{a*}	0.344^{b}	0.294^{b}	0.450^{a*}	0.344^{b}	0.223^{c}
Root fresh weight (g)	3.444^{b*}	4.609^{a}	4.466^{a*}	4.168^{ab}	3.444^{b}	7.144^{a*}	4.841^{b}	3.099^{c}
Root dry weight (g)	$2.684b^{*}$	4.631^{a}	3.672^{a*}	3.063^{ab}	2.733^{b}	6.044^{a*}	3.608^{b}	2.822^{c}
Shoot fresh weight (g)	22.759^{a*}	13.507^{b}	5.466^{a}	4.168^{ab}	3.4444^{b}	1.827^{c*}	2.608^{b}	3.678^{a}
Shoot dry weight (g)	22.759^{a*}	13.507^{b}	13.700^{b*}	17.456^{c}	20.244^{a}	19.861^{a*}	17.944^{c}	16.594^{b}

Note: *Means in each row followed by the same letter are not significantly different at 5% probability level. Where, M_1=planting maize by ZDTD and M_2= planting maize by chokka method, I_1=irrigation applied after 8 days, I_2= irrigation applied after 6 days and I_3= irrigation applied after 4 days, F_1=98.8 kg ha^{-1}, F_2=123.3 kg ha^{-1} and F_3=148.2 kg ha^{-1}

The effects of irrigation levels on ERI presented in Table 3 shows that significantly greater ERI was observed at I_3 than those observed at I_2 and I_1 respectively. Too low ERI at I_1 might not be suitable due less availability of water to the roots of plants. Table 3 showed that ERI at I_3 was 1.23 times greater than that at I_2 and 1.40 times greater than that at I_1. It clearly showed the effectiveness of irrigation level on ERI. The effect of fertilizer levels on ERI is shown in Table 3. The results show that significantly greater ERI was achieved at F_3 followed by those at F_2 and F_1. Too low value of ERI at F_1 might not be suitable due to less availability of minerals to the roots of plants. It is clear from Table 3 that ERI value at F_3 was 1.61 times greater than that at F_2 and 3.32 times greater than that F_1.

Table 3 shows that significantly greater root length of plants was observed at method M_2 than that at method M_1. The roots length in M_2 method was 1.05 times greater than at M_1 method. This supports the fact that since extensive cultivation during soil preparation with conventional method (M_2) caused the soil loose that reduced soil bulk density in the root zone, therefore, roots penetration increased to more depth. Table 3 also shows that significantly greater (α=0.05) root length of plants was achieved at irrigation level I_3 followed by I_2 and I_1. Root length at irrigation level I_3 was 1.69 times greater than that at I_2 and 2.50 times greater than that at I_1. The irrigation interval I_3 (4 days) was half of irrigation level I_1 (8 days) which might have caused the root zone wet for easy penetration of roots to greater depth. The effect of fertilizer levels on root length shows that significantly greater (α=0.05) root lengths of plants were observed at level F_1 (98.8 kg/ha) than those at F_2 (123.3 kg ha^{-1}) and F_3 (148.2 kg ha^{-1}) respectively. The root length of the plants at F_1 was 1.25 and 1.55 times more than those at F_2 and F_3 respectively. This could have been due to more minerals available in close vicinity of plants under F_1 which restricted elongation of roots under F_2 and F_3 fertilizer level.

It can be seen from Table 3 that method M_1 produced significantly greater shoot length of plants than those observed under method M_2. The shoot length under method M_1 was 1.64 times greater than that under method M_2. Since no extensive tillage was done under method M_1, therefore, previous crop residue was saved which reduced soil water evaporation, made the soil cool and conserved soil resources for growing crop. These facts might had helped in timely providing required plant necessities resulting in 1.64 times more shoot length under method M_1. The shoot lengths at irrigation level I_3 (after 4 days) was 1.14 times significantly greater (α=0.05) than shoot lengths at I2 (after 6 days) and 1.29 times greater than that at I_1 (after 4 days) respectively. Since irrigation interval at level I_1 (8 days) was double than those of I3 (4 days) as shown in Table 3. Therefore, timely plant requirements might have not been met at I_1 irrigation level that reduced shoot length. Effect of fertilizer level on shoot length presented in Table 3 indicated that significantly greater (α=0.05) shoot lengths were observed at fertilizer level F_3 than those observed at F_2 and F_1 fertilizer levels. Less value of shoot length at F_1 fertilizer level might have been due to insufficient availability of minerals to the roots of plants. The value of root length at F_3 fertilizer level was 1.18 and 1.34 times greater than those at F_2 and F_1 fertilizer levels.

The effects of planting method on root dry weight presented in Table 3 shows that method M_2 produced significantly greater (α=0.05) root dry weight under method M_1 than those observed under method M_1. This supports the results of greater root length under method M_2 discussed above. The root dry weight under method M_2 was 1.73 times greater than that observed under method M_1. It can be seen from the

Table 3 that irrigation level I_3 (after 4 days) produced significantly greater root dry weight than those observed under irrigation levels I_2 (after 6 days) and I_1 (after 8 days). I_3 produced 1.2 and 1.34 times greater root dry weight than those observed under I_2 and I_3.irrigation levels respectively. Since irrigation interval under I_3 was 2/3rd and half of those under I_2 and I_1, therefore, better soil environment helped more root establishment under irrigation level I_3. The effects of fertilizer levels on root dry weight in Table 3 shows that greater root dry of plants were observed at F_1 than those observed under F_2 and F_1 fertilizer levels. The root dry weight of the plants at F_3 was 1.68 times less than that at F_2 and 2.14 times less than that at F_1. This supports the root length pattern discussed above under three levels of fertilizer applications.

The statistically analyzed results indicated that significantly shoot dry weight of the plants were observed at M_1 than that observed at M_2 method as shown in Table 3. This could be because of cool and suitable soil environment produced by undisturbed previous crop residue this might have helped timely provision of plant nutrients. Shoot dry weight under M_1 was 1.68 times greater than that observed under M_2 method of planting as shown in Table 3. The statistically analyzed results presented in Table 3 indicated that shoot dry weight was significantly greater under irrigation I_3 than those observed under irrigations I_2 and I_1. Too low water availability under irrigation I_1 might have not helped timely provision of plant nutrients and therefore restricted shoot development. Shoot dry weight observed at I_3 was 1.16 and 1.48 times greater than those observed at I_2 and I_1 respectively. The results presented in Table 3 indicate that significantly greater shoot dry weight was observed at F_3 than those observed at F_2 and F_1 fertilizer levels. Low F_1 level of fertilizer might not be enough to make available required plant nutrients and therefore resulting in low shoot dry weight. Shoot dry weight at F_3 was 1.11 and 1.20 times greater than those observed under F_2 and F_1 fertilizer.

Table 4 Cost and man-h for planting one-hectare maize in rice stubble field

Machines/ Implements	Field Capacity (ha/h)	No. of passes of implement	Man h ha^{-1}	Operational cost (USD h^{-1})	(USD ha^{-1})*
A. Seed drill with land preparation					
Tractor MF-375, (75 HP)	-	-	-	8.85	-
Disc Harrow (18 discs)	1.21	2	1.66	0.45	15.59
Cultivator (13 tines)	1.21	2	1.66	0.15	15.20
Sohaga (3,050 mm)	1.42	3	2.10	0.01	16.69
Sub Total	-	-	5.42	-	47.48
Wheat drill (13 tines)	1.42	1	0.70	0.08	6.61
Total	-	-	6.12	-	54.09
B. zone disc tiller drill without land preparation					
Tractor MF-375, (75 HP)	-	-	-	8.85	-
Zone Disc Tiller Drill	1	1	1	0.28	8.17

Note: * Implement operational cost including tractor operational cost

3.2 Cost analysis of zone disc tiller drill with conventional sowing machinery

The cost and man hour for the preparation of seed bed and planting of maize with ZDTD and conventional sowing is shown in Table 4. The cost of tillage operations was USD 54.08 per hectare and planting cost with conventional seed drill was USD 6.61 per hectare. The time required for seed bed preparation with conventional methods was found to be 5.42 hours per hectare and with conventional seed drill it was 0.70 per hectare.

The cost of sowing maize with ZDTD on an area of one hectare was USD 8.17 per hectare which was 500% less than the conventional methods. Similarly, only one hour is required for sowing maize on an area of one hectare with the ZDTD which was 512% less than the conventional method. There was a direct saving of USD 47.48 per hectare for eliminating the conventional tillage operations by using ZDTD. The use of ZDTD not only facilitates early plating of maize in a rice stubble field but it also saves time, fuel and operational cost. The early planting of maize helped to increase the yield per hectare. The ZDTD quickly and easily off-sets the conventional energy consuming practices of sowing maize in a rice stubble field. It is also a resource conservation technology because it is a minimum tillage of minimum tillage plus accurate line sowing.

4 Conclusions

In this study, design modification in old ZDTD is made, and the effect of three irrigation levels, three fertilizer levels on crop parameters was observed by using newly developed ZDTD and conventional method (tillage + drilling). The cost analysis of newly developed ZDTD and old machine was also done. The following conclusions were drawn from the study;

The improved machine is lighter in weight compared to old one. The weight of old machine was 800 kg and the weight of newly developed machine is 750 kg. Similarly, it was concluded from the cost analysis that cost of sowing maize with ZDTD on an area of one hectare was USD 8.17 per hectare which was 500% less than the conventional methods.

It’s concluded that crop parameters like ERI, shoot length and shoot dry weight increases with irrigation levels from I_1 to I_3, while remaining parameters like root length, root shoot ratio, root fresh weight, root dry weight and shoot fresh weight decrease with increase in irrigation levels from I_1 to I_3.

It’s concluded that crop parameters like ERI, shoot length and shoot fresh weight increases with fertilizer levels from F_1 to F_3, while remaining parameters like root length, root shoot ratio, root fresh weight, and root dry weight decrease with increase in fertilizer levels from F_1 to F_3.

The seedling ERI was greater under ZDTD machine planting method as compared to conventional sowing method.

It was concluded that maize crop parameters under conventional sowing methods show the unsatisfactory results due improper placement of seed, less availability of minerals and less availability of water to the roots of plants as compared to sowing with ZDTD which improves the crop parameters for efficient germination and growth.

Overall, the comparison of sowing method in this study shown that ZDTD has better results in crop production and residue handling as compared to the conventional sowing methods. The use of newly developed ZDTD not only facilitates the early plating of maize in a rice stubble field but it also saves the time, machine cost, improve the crop parameters and soil physical properties as compared to other conventional sowing. Our findings further clarified that newly developed ZDTD could be an effective machine for crop sowing in semiarid regions of Pakistan to increase crop production. In future, we are working on the development of new seed metering device for sowing multiple seed and installed on a common shaft to make it as compact unit.

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