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PERFORMANCE AND EVALUATION OF DISC TILLAGE TOOL FORCES ACTING ON STRAW INCORPORATION SOIL

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Straw cover protects soil from erosion caused by wind and water. For this purpose, small amount of straw is needed be incorporation into soil. Tillage was done by disc in a soil-bin filled with paddy field soil with straw cover (100 g.m^{-2}) at three speeds and depths to study forces acting on disc, burial straw rate of different lengths of straw (7,13, and 19 cm), soil disturbance and change in bulk density. Results showed draft, vertical and side forces of the disc increased from 533 to 1236, 243 to 632, and 418 to 1063 N. Disc tillage tool brought 47 to 86% of the straw buried in the 0-15 cm layer having smallest straw length (7cm) share of 39 % as maximum. Further soil bulk density was improved from 8.5 to 26.9 % as depth and speed was increased. Moreover, soil disturbance area was highest at 15 cm while lowest at 5 cm. Forces of disc, burial straw, soil disturbance area and bulk density were highly significantly ($p<0.05$) at higher speed and depth. Present research indicated that powered disc has provided constant and horizontal flow of furrow wedge to the side with more soil disturbed area.

Keywords: Disc tillage tool, transducer, burial straw rate, soil disturbance area and soil bulk density

INTRODUCTION

Tillage is the mechanical manipulation of soil to improve soil conditions for better crop production, weed and disease control (Olatunji, 2007). The interaction of tillage tool with soil and straw (used as mulch, Pervaiz *et al.,* 2009; Hesham, 2007) changes the physical properties of soil by its mechanical disturbance which affects the movement and incorporation of crop residue (Colvin *et al.,* 1986; Muqdadas *et al.,* 2005). The intensity of movement and incorporation of crop residue varies with different tillage tools hence effect its burial status (Hanna *et al.,* 1995). For heavy and hard soils like clay disc tillage implements are often used due to its rolling motion which cut through the soil and provides rapid decay of burial residues resulting in shallow incorporation and improve surface mulch which offer better ridging effects with less compaction as a result of improve soil workability and hence disc implements are considered important for conservation and reduced tillage practices in clay soils (Munir *et al.*, 2012; Kepner *et al.*, 1978; Rehman and Chen, 2001; Tice and Hendrick, 1992; Cannell, 1987). The draft requirement of disc implements have linear relation with speed as compare to mould broad ploughs which have quadratic relation (Summer *et al.,* 1986). Disc plough required more draft force and specific draft as compared to other tillage implements (ASAE, 2002; Sheruddin *et al.*, 1992a; Grisso *et al.,* 1996). Even after all these researches, still there is space to be filled by the evaluation of the forces acting on disc tillage tool working in straw, soil environment. Similarly burial status of straw at different plowing depths and speeds need to be evaluated.

Therefore, present research was intended to study the performance of powered disc tillage tool in the soil-bin with incorporation of straw to examine the behavior of reaction forces under controlled conditions for disc, to study the burial status of straw after plowing and show the changes of soil bulk density and soil disturbance area caused by the passage of disc tillage tool.

MATERIALS AND METHODS

The study was conducted in soil-bin available at Soil Mechanics Lab, Department of Agricultural Mechanization, College of Engineering, Nanjing Agricultural University. Soil bin was 2.5 m wide, 6 m long and 0.78 m deep and was filled with locally available paddy field soil which was sun dried and grinded with electrical hammer before filling.

Soil-bin was equipped with carriage track system to allow the movement of tillage tool along its length. A vertical support was connected for attaching and controlling the vertical movement of the tillage tool. A variable high speed motor was connected to the soil-bin carriage for controlling the tool forward speed. Similarly, plowing depths and tool angle were controlled by adjusting the vertical position of the rectangle tool leg on the frame.

***Soil Preparation*:** After determining the soil moisture, calculated amount of water was sprayed on the entire length of soil to achieve desired experimental soil moisture of 18 % then it was tilled at a greater depth than the experimental depth to allow uniform loosening of the subsurface soil then rotary tiller was run at the slowest forwarded speed to open the soil then it was leveled to achieve smooth surface and uniform water distribution. Soil was again tested for moisture content to confirm that the desired moisture content was achieved throughout the soil.

After the preparation of soil, rice flat straw (100 $g.m^{-2}$) (Fig. 1) was spread on the soil surface. After the each experiment, straw was removed from soil surface and new straw was weighted out, and then applied to the soil surface. The above steps were followed for each soil preparation prior to any experiment test run.

(a)

(b)

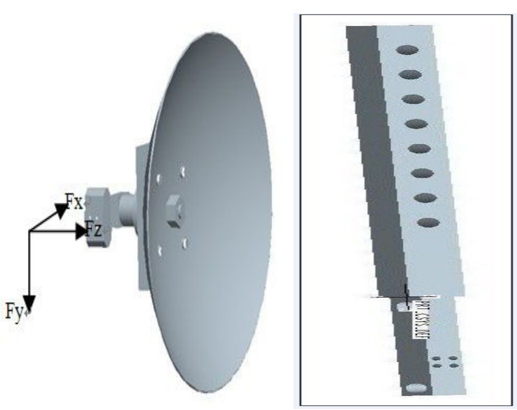


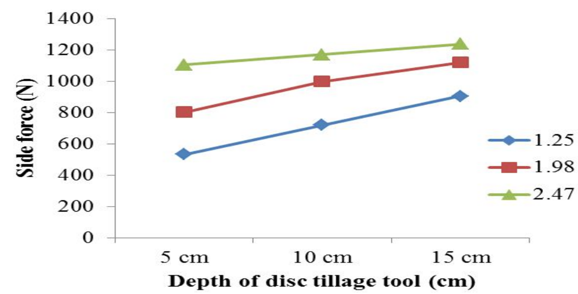
Figure 1. (a) Straw laid on soil-bin for experiment. (b) Schematic view of assemble leg and disc tillage tool

***Assembling of disc tillage tool and transducer placement*:** Disc tillage tool was assembled (Fig. 1b) with the rake angle of 25° in order to reduce negative suction of disc tillage tool for maximum penetration into the soil (Damora and Pandey, 1995; Godwin *et al.*, 2007).

Transducer was placed between disc and tool leg to detect the variations of forces. The transducer was fastened so as to measure the forces data such as draft (Fx), side force (Fz) and vertical force (Fy) simultaneously and continuously (Nalavade and Salokhe*,* 2010). The DEOR transducer was developed by referring different equations given by Godwin (1975), Godwin *et al.* (1993) and O'Dogherty (1996).

***Data acquisition system*:** Transducers (Fx, Fy and Fz) system was controlled by computer program through data acquisition (Fig. 2) and analysis unit. Data acquisition hardware comprised of Advantech PCI1710 data acquisition card, the interface board and the dynamometer was connected to the output line. Dynamometers were first calibrated and a program was developed in Lab View 8.2 software to record their input into graphical form in Microsoft Excel 2003.

(a)



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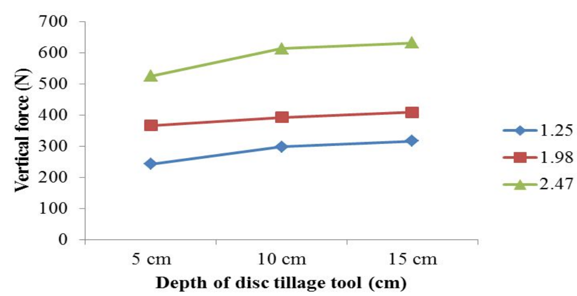

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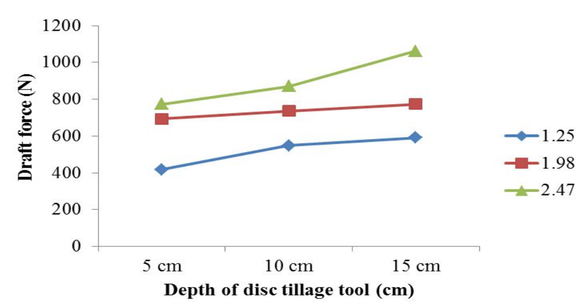

(c)

Figure 2. Forces reaction of disc tillage tool (a) side (b) vertical (c) Draft

***Burial straw measurements*:** Burial rate of three lengths (7,13 and 19 cm) of straw were studied using soil-bin experiments under two parallel passes of disc tillage tool at different speeds and depths. It was measured by a rectangular frame (18 x 18 cm^2) shown in (Fig. 3). Final position of buried straw was determined by measuring the depth of the center of the straw to the average soil surface.

Figure 3. Measurements of burial status of straw

The percentage weight of each length of rice straw was measured after each run of disc within its tillage depth (5, 10 and 15 cm). Burial rate of rice straw was calculated by following equation proposed by Dursun *et al.* (1999).

$$F = \frac{(A - B)}{A}$$

Where, F= Burial straw rate (%), A= Total weight of straw before tillage (gm), B= Buried weight of straw after tillage (gm)

***Soil bulk density and soil disturbance area measurements*:** The bulk density was maintained at 1.41 $g.cm^{-3}$ before each trial in the soil bin. After each run of the disc bulk density was measured at three random points on the run and average percentage was calculated to study the change in bulk density and soil disturbance area at 0-5, 5-10 and 10-15 cm depths, respectively.

***Experimental design*:** The disc speed and depths were considered for studying the performance of powered tillage disc tool. The disc depths considered for this study were 5, 10 and 15 cm ; while disc speeds were 50, 80 and 100 rpm (1.25, 1.98 and 2.47 $m.s^{-1}$). The concentration of rice straw was 100 $g.m^{-2}$ and three replicates were made for each test of 3 speeds x 3 depths x rice straw.

***Statistical analysis*:** This research was planned as a completely randomized design (CRD) with three replications. All data were analyzed through SPSS (ver. 16, SPSS, Inc., Chicago, IL, USA) mean ± 1 SD. Significance for differences between the treatment means was examined by one-way analysis of variance (ANOVA), with a probability ($p<0.05$).

RESULTS AND DISCUSSION

***Forces reaction of disc tillage tool*:** The side force of disc tillage tool acting on straw incorporated soil at different speeds 50, 80 and 100 rpm (1.25, 1.98 and 2.47 $m.s^{-1}$) with three depths (5, 10 and 15 cm) are presented in (Fig. 3a). By increasing the speed of tillage tool from 1.25 to 2.47 $m.s^{-1}$, depth from 5 to 15 cm, side force increased from 533 to 1236 N having highest value at a speed of 2.47 $m.s^{-1}$ while maintaining depth of 15 cm. It was observed that the effect of increasing disc tillage tool speed on side force was more dominant as compare to the increasing disc tillage tool depth whereas this force change reduced when disc tillage tool was run at greater depth. The increment in force observed was due to increase in surface area in contact with the soil as reported by (Schaaf *et al*., 1980). Difference in side force with respect to disc speeds and depths were statistically significant ($p<0.05$) only for higher disc tillage tool speed at 5, 10 and 15 cm, respectively.

Variation in average vertical force with speed and depth is represented in (Fig. 3b). These values are from 243 N to 632 N having maximum value at highest speed and depth. Here the effect of changing speed is again dominant than depth as observed in previous case whereas the relationship between force and depth is flatter than that of vertical force. This linear relationship was also reported by (Grisso and

Table 1. Experiment parameters of disc tillage tool and soil condition under soil-bin.

The main parameters plow and condition of soil	Units	Parameter values
Diameter of disc	cm	55.1
Tillage tool depth	cm	0-15
Tillage tool speed	$m.s^{-1}$	50, 80 and 100 rpm (Correspond 1.25, 1.98 and 2.47)
Texture	%	Silt clay soil(47 silt, clay 42 and 11 loam)
Angle from the soil angle	°	25
Soil moisture content	%	18
Soil bulk density	$g.cm^{-3}$	1.41
Soil internal frictional angle	°	32
Soil cohesion	kPa	6.86
Straw density	$g.m^{-2}$	100 per plot
Plot size	m^2	1.3x1.2
Straw mixture	cm	7,13 and 19

Table 2. Straw burial rate for rice straw at different depths under different speeds of disc tillage tool.

		Burial Straw		
Speed (m.s^{-1})	Depth cm	7 cm	13 cm	19 cm
1.25	5	22.00±3.00^{c}	16.00±1.00^{b}	9.00±1.00^{c}
1.98	5	26.00±3.00^{b}	18.33±3.51^{ab}	11.00±3.00^{b}
2.47	5	30.33±3.51^{a}	19.00±2.00^{a}	13.00±2.00^{a}
1.25	10	26.00±3.00^{c}	17.00±2.00^{a}	11.33±1.53^{c}
1.98	10	34.33±3.51^{b}	23.00±2.00^{a}	16.00±1.00^{b}
2.47	10	39.00±2.00^{a}	26.33±2.52^{b}	21.33±1.53^{a}
1.25	15	23.67±1.53^{b}	19.00±2.00^{b}	9.00±2.00^{c}
1.98	15	28.00±3.00^{ab}	21.00±2.00^{b}	14.00±1.00^{b}
2.47	15	33.00±2.00^{a}	26.00±1.00^{a}	19.00±1.00^{a}

*Different superscript words in a same column indicate significantly different ($p < 0.05$) between the treatments.

Perumpral, 1985; Fielke and Riley, 1989). It was revealed that the vertical force component of powered disc was acting downward and it resulted because of the weight of soil volume sliding over the disc surface. When forwarding speed was high, the vertical forces have increased because a part of dynamic force required in the process of throwing the soil slice increased with increased the depth from 5 to 15 cm respectively. It means that at higher speed tendency to penetrate increased as reported by (Morrison *et al.,* 1996) and these disc needed an additional force for penetration (Godwin *et al.,* 2007). Furthermore relationship between vertical force and speed has been found to be linear in many studies in both clay and sandy loam soils by (Owen, 1989). Difference in vertical force with respect to disc speeds and depths were statistically significant ($p<0.05$) only for greater disc tillage tool speed at 5, 10 and 15 cm, respectively.

The draft force of disc tillage tool acting on straw incorporated soil during current research increase from 418 to 1063 N with the increase in depth and speed (Al-Janobi and Al-Suhaibani, 1998) and are presented in (Fig. 3c). In another similar experiment (Nalavade *et al.*, 2010) reported that the variation was from 620 to 860 N under similar conditions except the straw. Effect of speed and depth were the same as previously observed in horizontal force and vertical force. Force changing trend with depth at speeds of 1.25 and 2.47 m.s^{-1} were almost same in case of horizontal and vertical force but in draft case this trend is different whereas at speed 1.98 m.s^{-1} was almost same in all three cases. Although the increasing response of draft observed with tillage depth and speed is in agreement with (Harrigan and Rotz, 1994). According to Kepner *et al.* (1987) increasing the speed would help to improve the soil penetration which improve the draft force. Difference in draft force with respect to disc speeds and depths were statistically significant ($p<0.05$) only for greater disc speed at 5, 10 and 15 cm, respectively.

***Effect of disc tillage tool on burial straw rate*:** Results showed that when speed of tillage tool increased from 1.25m.s^{-1} to 2.47 m.s^{-1}, the percentage of buried straw also increased from 47 to 62 at 5 cm tillage depth, 51 to 78 at 10 cm tillage depth and at 15 cm tillage depth from 54 to 86. Individual burial status of three straw lengths used against tillage depth and speed was presented in (Fig. 4). It was observed that the smallest size straw has maximum burial status (22 to 39 %) in all trials whereas the 19 cm length has its least contribution (9 to 21%) in overall burial status of straw in all trials.

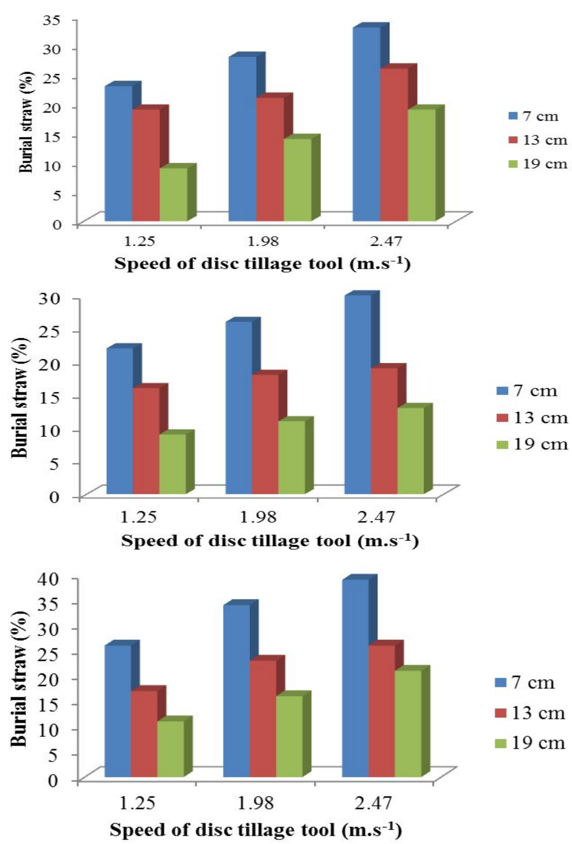

Figure 4. Influence of disc tillage tool on different length of burrial straw status at 5, 10 and 15 cm.

It was also observed that speed had played positive role in increasing the burial percentage of straw irrespective of its length. On the other end depth and burial percentage also showed direct relationship. Similar increment in burial percentage with depth and speed was reported by (Dursun *et al.*, 1999). According to the study (Liu and Chen, 2010), results show that the longer length of straw was less buried after tillage practice than the shorter length of straw at the same tillage speed and also higher speed was buried more straw.

***Effect of disc tillage tool on soil bulk density and soil disturbance area*:** In this experiment bulk density of 1.41 $g.cm^{-3}$ was maintained in the start of each trial. Later the reduction in bulk density was observed in percentage and it was found that it was reduced from 8.5 to 26.9 % as a whole. By increasing the speed bulk density reduced from 8.5 to 12 %, 14.8 to 16.3 % and from 19.2 to 26.9 % at 5, 10 and 15 cm respectively, (Fig. 5-6).

Figure 5. Soil disturbance pattern after single pass of disc tillage tool

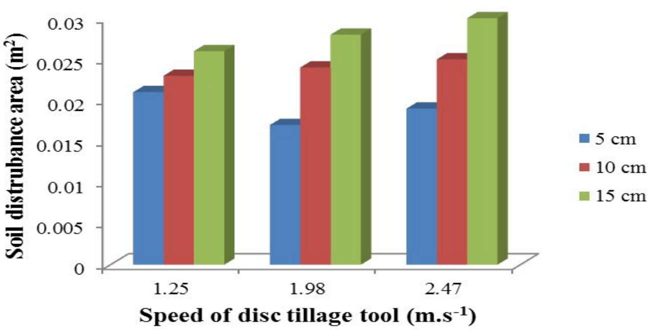

Figure 6. Soil disturbance area influenced by disc tillage tool at different speeds and depths

It was observed that the effect of changing disc tillage tool depth was more as compare to speed in order to reduce the bulk density as maximum change with speed was 7.7 % (at speed 2.47 $m.s^{-1}$) whereas with depth it was 14.9 (at 15 cm depth). Difference in soil bulk density with respect to disc tillage tool speeds and depths were statistically significant ($p<0.05$) only for greater disc tillage tool speed at 5, 10 and 15 cm respectively. These results were in agreement with Rahman *et al.* (2001) and Hulugalle *et al.* (1985) who reported the effect of speed and tillage depth on bulk density. The soil disturbed of cross sectional area with disc (551 mm) tillage of a single pass shown in (Fig. 12). It was observed that soil disturbance area increased with increase in tillage depth and vice versa. Increasing the speed of disc tillage tool from 1.25 to 2.47 $m.s^{-1}$, increase the soil disturbance of area from 0.018 to 0.030 m^2 at 5, 10 and 15 cm respectively. Maximum soil disturbance area was measured at 15 cm at 2.47 $m.s^{-1}$. The results regarding change in soil disturbance area with depth and speed were in agreement with the findings of Godwin (2007) and Vozka (2007).

***Conclusions*:** The study was conducted in soil-bin on straw cover soil at different depths and speeds of disc tillage tool under controlled conditions. Draft represented direct relationship with speeds and depths of disc tillage tool so in order to reduce draft for deep tillage (15 cm) at 1.25 $m.s^{-1}$ while higher at 2.47 $m.s^{-1}$. As a result, it showed lower values of vertical and side forces of disc tillage at lower speed and depth. Hence, its higher values of burial straw were observed that 7 cm length of straw had maximum share in burial straw as compare to 13 and 19 cm. Further soil disturbance area was larger when disc tillage tool speed and depth were increased. The greatest soil disturbance area occurred at speed of disc tillage tool 2.47 $m.s^{-1}$ and depth of 15 cm. Deep depth of disc tillage tool improves the bulk density to provide better platform for seed germination.

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