



Determination And Comparison of Soil Deformation Areas, Stubble Burial Rates and Stubble Quantities of Single-Acting Disc Harrow Driven by The Tail Shaft and Single-Acting Disc Harrow That Takes Its Movement from The Soil

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HIGHLIGHTS

- The effects of the single-acting disc harrow moving from the tail shaft and the single-acting disc harrow moving from the soil on the soil deformation area were determined and compared.
- The effects of the single-acting disc harrow driven by the power take-off shaft and the single-acting disc harrow driven by the soil on the stubble residue were determined and compared between applications.
- Stubble embedding rates of the single-acting disc harrow moving from the power take-off shaft and the single-acting disc harrow moving from the soil were determined and a comparison was made between the applications.

Abstract

In this study; soil-driven single-acting disc harrow and PTO-driven single-acting disc harrow machines were used. The single-acting disc harrow, which moves from the soil, was tested with two different disc diameters (610 mm and 660 mm) and three different direction angles (16°- 23° and 30°), while the single-acting disc harrow, which moves from the tail shaft, was tested with two different disc diameters (610 mm and 660 mm), three different direction angles (16°- 23° and 30°) and three different disc speeds (104.97-119.97 and 143.96 min⁻¹). As a result of the treatments, the effects on soil moisture retention, deformation area, stubble burial rate and stubble amount were compared for both machines. It was determined that the cutting width and working depth increased with the increase in disk diameter and direction angle, and the deformation area increased accordingly. The lowest amount of stubble was obtained from D1N3Y3, D1N3Y2 and D2N3Y3 treatments as 20.67 g m⁻², 22.67 g m⁻² and 25.33 g m⁻², respectively. The highest stubble burial rate was 87.30%, 86.07% and 84.02% in D1N3Y3, D1N3Y2 and D1N2Y3 treatments. While the lowest u/v ratio was obtained from D1N1Y1 with 3.03, the highest u/v ratio was obtained from D2N3Y3 with 4.63, the lowest skidding rate was obtained from D1N3Y1 with 3.17% and the highest skidding rate was obtained from D2Y3 with 11.99

Keywords: Deformation Area, Angle of Direction, Disc, PTO, Stubble

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1. Introduction

This study aims to determine the appropriate structural and operational characteristics for the use of a single-acting disc harrow driven from the PTO to ensure that agricultural activities are carried out on time, soil and plant residues are broken and mixed with the least number of passes, and the engine power of the tractor is used more effectively and efficiently.

Wan et al. (2017) reported that when the hydraulic-driven disc harrow and passive disc harrow were compared in terms of soil cutting, the hydraulic-driven disc harrow discarded a larger amount of soil, the ploughing depth was deeper. They also reported that the soil was worked more effectively and the good throwing effect was more favourable for subsequent agricultural works.

Nalavade et al. (2010), operating the tillage disk with an external power has a significant effect on the processing of soil volume and hence on the forces acting on the disk. The free rotating disk is unable to till the soil properly. An increase in the disk angle increases the volume of soil to be cultivated, resulting in higher soil reaction values. Finally, it was concluded that the externally powered disc is advantageous over the free-rotating tillage disc in terms of reduced tractive power consumption, energy use, easy soil volume processing and lateral displacement.

Çelik and Malashlı (2016), according to the average values of the depth of the furrow, it was determined that the depth of furrow increased as the disk direction angle increased.

Keçecioglu and Gülsoylu (2002) stated that the furrow base of disc harrows is not flat like the furrow base of eared plows and that disc harrows form ridges and grooves on the furrow base. The height of the ridges formed is affected by the diameter of the discs, their angles, working depth and the distance between the discs. Especially the disk angle and the working depth of the disk have a significant effect on the size of the contact area of the disk with the soil. Working by arranging the discs in batteries ensures that the soil areas the discs grasped overlap.

Raper (2002) found that implements with disked tillage implements buried significantly more residue at different tillage depths than implements with chisel-type tillage implements. He also stated that the time of year of tillage did not affect the percentage of residue cover or the total mass remaining on the soil surface.

Damanauskas et al. (2019) reported that the rate of mixing plant residues into the soil ranged between 0.80 and 0.96 in their study with an individually bedded disc harrow.

Nalavade et al. (2013) reported that the notched cutting edge of the tillage disc provided better cutting of weeds and crop residues in the harrow with a disc moving from the tail shaft, while the free-rotating disc harrows could not cut the residues properly despite the use of a notched disc. They carried out a study to determine the stubble embedding rates for the PTO and free-rotating disc harrows operated at different feed rates and the plant residue rates after three different speeds in the PTO disc harrows. As a result of this study, they reported that 86.98%, 92.03% and 89.29% stubble burial rates were obtained with the disc harrows moving from the tail shaft, while the free-moving disc harrow buried only 69.32%, 66.81% and 65.66% of the plant residues at three different feed rates.

It is stated that the presence of coarse and insufficiently broken stems in the soil interrupts the contact between the seed and the soil and this event may adversely affect germination (Önal and Aykas, 1997).

Zeng et al. (2021) investigated the soil shear forces, soil overturning, stubble residue cutting and mixing performances of three discs of different shapes at two different working depths and dry maize stalks were used in the experiments. They reported that the working depth of the discs was more significant in affecting the tillage performance than the disc type. Increasing the working depth resulted in an increase in soil shear forces, soil tillth and residue mixing.

Upadhyay and Raheman (2020a) found that both stubble burial rate and soil clod fragmentation increased with an increase in speed rate.

Dursun et al. (1999) reported that the rate of stubble burial increased by 8% for the ear plough and 13% for the disc plough when the working depth increased from 15 cm to 25 cm. In addition, they determined that the stubble burial rate increased by 8.6% with an increase of 40 in the angle of repose and by 12% with an increase of 100 in the angle of repose with disc plough, and the stubble burial rate increased by 12.7% with an increase of 160 to 240 in the angle of repose with disc plough. They reported that the most uniform stubble distribution along the tillage depth was achieved with a disc plough.

Unger (1984) reported that the stubble embedding rates of eared and disc ploughs were 90%, disc plough, offset and tandem disc harrow were 50%, chisel was 25%, weeder and cultivator were 10%.

Göknur and Özarslan (1995) examined the effect of tractor travelling speed on the burial rate of surface residues and stated that the highest burial rate was obtained at travelling speeds between 3.69 km.h⁻¹ and 5.92 km.h⁻¹.

Raper (2001) determined that at high working depths, disc tillage machines were more effective in burying plant residues compared to chisel.

Singh et al. (1978) reported that a decrease in directional angle and an increase in working speed had opposite effects on the working depth of the disc harrow. They reported that a decrease in the directional angle of the disc harrow at a constant working speed resulted in shallow working, whereas an increase in the working speed at a constant angle resulted in deeper working.

This study was carried out in field conditions to compare the stubble embedment rate, the amount of stubble remaining on the surface after tillage, and the soil deformation of the single-acting disc harrow moving from the PTO and the single-acting disc harrow that takes its movement from the soil.

2. Materials and Methods

A sheet metal plate with a thickness of 5 mm, a length of 1000 mm and a width of 600 mm, lime, a digital camera and a fiji- imagej image processing programme were used to determine the deformation area. Canon Eos 1300D digital camera was used to take the photographs. In order to determine the deformation area of the discs, after passing the machine, a sheet metal plate was immersed in the soil at the tillage depth perpendicular to the direction of movement and the soil in front of it was cleaned and the sheet metal plates were removed (Figure 1). Afterwards, the treated areas were calcified and the regions were determined (Topakcı, 2004; Marakoğlu et al, 2010).

After the sheet metal was removed, a picture of the degraded soil mass was taken with a digital camera from the front façade. For the determination of the deformation area, labels with an area of 1 cm² were placed on the side of the disturbed soil sample before the picture was taken as a reference. The images taken with the camera were saved as image format in the computer environment.



Figure 1. Crude horse oil (solid-liquid)

Imaging software was used to digitize the deformation area. The photographs captured by the imaging software were opened in JPG format, the boundaries of the deformation areas were determined, and the determined areas were painted. The same procedure was followed for the 1 cm² area used as a reference.

The values of the total deformation area after coloring and the 1 cm² area taken as reference were calculated in square pixels and these values were converted to cm² to determine the total deformation area.

In determining the amount of stubble, the stubble in a 1x1 m² frame was collected from different parts of the experimental area before the pre-tillage trials and then weighed with the help of a precision balance. Weighing was carried out in three replicates in each treatment plot and the amount of stubble was determined as (g m⁻²).

After tillage, the amount of stubble remaining on the soil was determined by the same method and the stubble burial rate was found by using the following equation (Göknur and Özarslan, 1995)

$$F=(A-B)/A \times 100 \quad (1)$$

F: Stubble burial rate (%)

A: Stubble amount before tillage (g)

B: Stubble amount after tillage (g)

During the trials, two signaling apparatuses and a digital stopwatch were used to determine the running speed. Skidding was calculated by utilizing theoretical and actual speeds.

In order to determine the progress speed in the trials, the time taken to take the distance between the jalons placed at two points with a distance of 50 m during the work with the tractor in the field was measured in three replicates with the help of a stopwatch. According to this distance and measured time, the progress (actual speed) was calculated with the help of the equation given below.

$$v=L/t \quad (2)$$

v : Actual tractor travelling speed (m s⁻¹)

L : Distance between jalons (m)

t : Time taken for the distance between the jalons (s)

In order to find the skid ratio, the tractor drive wheel circumference and the distance travelled in one revolution were calculated. Then, the distance between the two jalons was divided by the distance that the wheel should take in one revolution and the number of revolutions that the tractor wheel will make in the specified distance was found. The theoretical speed was calculated with the following equation.

$$V_t = (\pi \cdot D \cdot n) / 60 \tag{3}$$

V_t = Theoretical speed ($m \cdot s^{-1}$)

D = Wheel diameter (m)

n = Wheel speed (min^{-1})

With the help of the data determined above, the skid rate is calculated by the following equation.

$$S = (V_t - V) / V_t \times 100 \tag{4}$$

S = Skid rate (%)

v = actual tractor travelling speed ($m \cdot s^{-1}$)

V_t = Theoretical speed ($m \cdot s^{-1}$)

3. Results and Discussion

The deformation areas of the trials are given in Figures 2 and 3 for both diameter treatments.

In D1 diameter disc treatments (Fig.2), the deformation areas varied between 154.59 -619.81 cm^2 . The minimum deformation area was obtained from D1Y1 with 154.59 cm^2 , while the maximum deformation area was obtained from D1N3Y3 with 619.81 cm^2 .

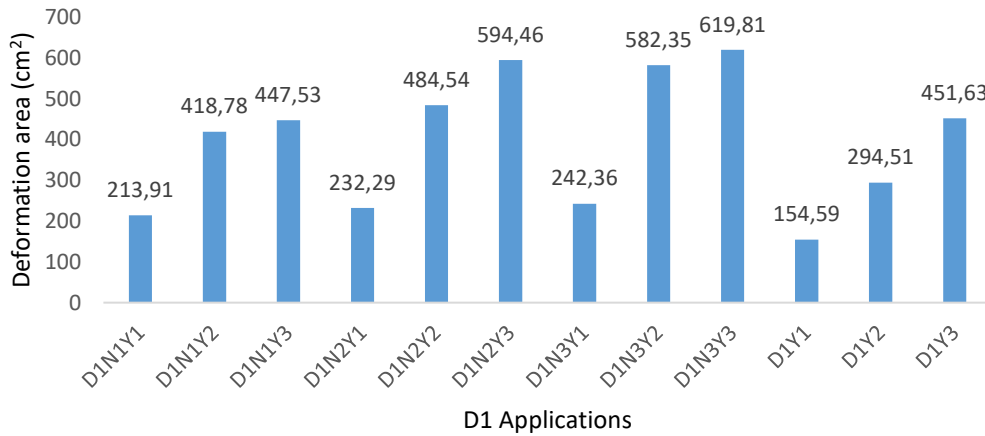


Figure 2. Deformation areas of the D1 applications

In D2 diameter disc applications (Figure .3), deformation areas varied between 187.8 - 903.71 cm^2 . While the minimum deformation area was obtained from D2Y1 with 187.8 cm^2 , the maximum deformation area was obtained from D2N3Y3 with 903.71 cm^2 .

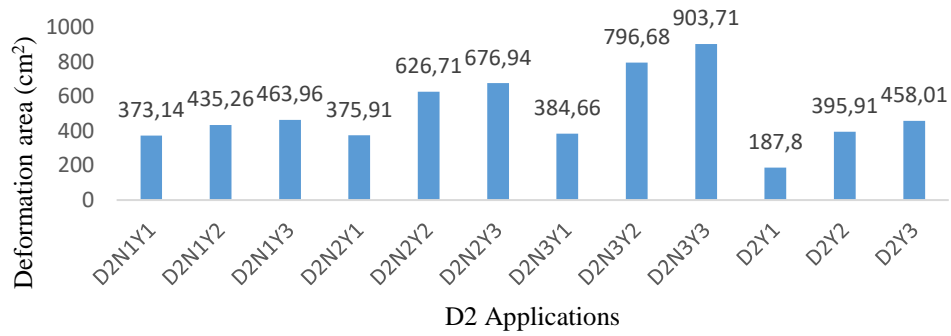


Figure 3. Deformation areas of the D2 applications

When Figures 2 and 3 are examined, it is seen that the deformation areas also increase when both disc diameter (D), same speed (N) and disc direction angle (Y) increase. Depending on the increase in disc diameter and disc direction angle, the increase in the cutting width and a working depth of the disc caused an increase in the deformation area.

While the highest deformation area was obtained from the D1N3Y3 application, the lowest deformation area was obtained from the D1N1Y1 application with the increase in disc speed of the PTO moving disc harrow with D1 disc diameter. Similarly, Nalavade et al. (2010) reported that when the disc harrow disc is driven by any power source, it has a significant effect on the processing of soil volume and thus on the forces acting on the disc and at high disc direction angles, it increases the volume of the processed soil.

Stubble quantities of the experiments are given in Figures 4 and 5 for both diameter treatments. The average stubble amount per square meter before tillage obtained from different points was 162.67 grams.

The lowest amount of stubble per unit area was obtained from D1N3Y3 with 20.67 g m⁻² in D1 diameter disc treatments, followed by D1N3Y2 with 22.67 g m⁻² and D1N2Y3 with 26 g m⁻². The highest amount of stubble was obtained from D1Y1 with 45.33 g m⁻², followed by D1Y2 with 42.67 g m⁻² and D1N1Y1 with 34.67 g m⁻².

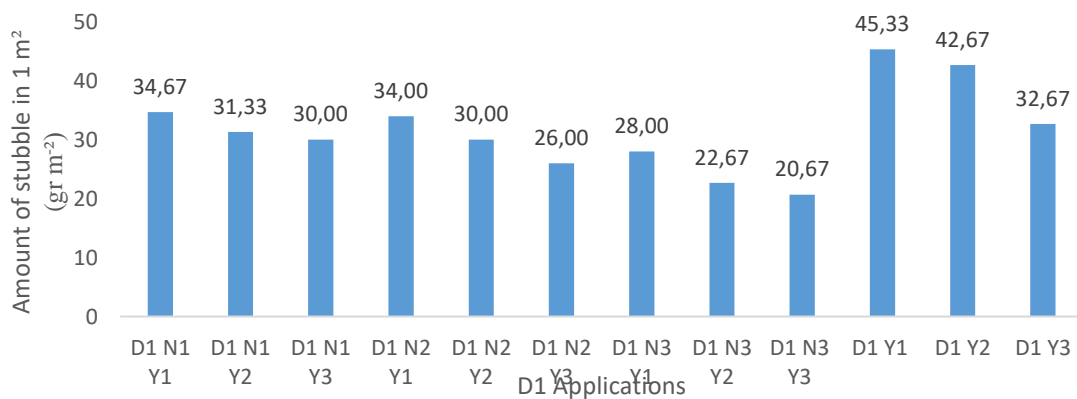


Figure 4. The amount of stubble in 1 m² for D1 applications

In D2 diameter disc treatments, the least amount of stubble was obtained from D2N3Y3 with 25.33 g m⁻², followed by D2N3Y2 with 30.67 g m⁻² and D2N2Y3 with 31.33 g m⁻². The highest amount of stubble was obtained from D2Y1 with 72 g m⁻², followed by D2Y2 with 50 g m⁻² and D2Y3 with 42 g m⁻².

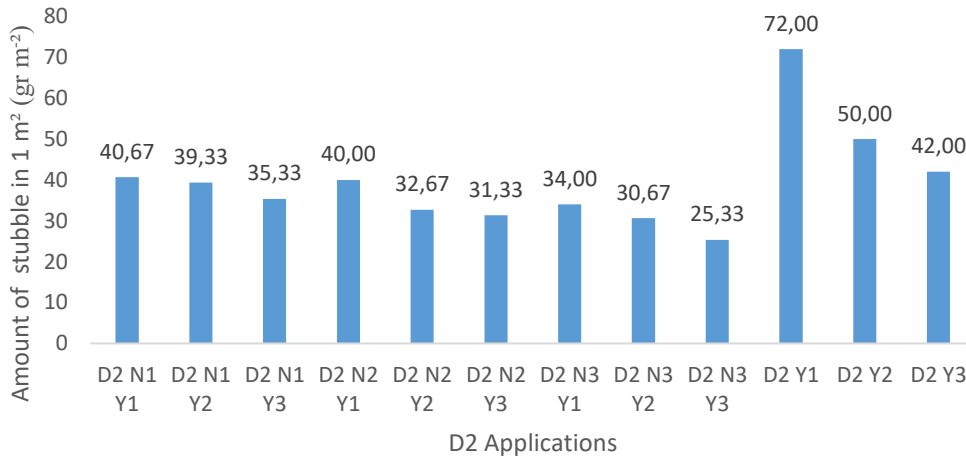


Figure 5. The amount of stubble in 1 m² for D1 applications

Stubble burial rates of the trials are given in Figures 6 and 7 for both diameter treatments.

In D1 diameter disc treatments, the highest stubble burial rate was obtained from D1N3Y3 at 87.30%, followed by D1N3Y2 at 86.07% and D1N2Y3 at 84.02%. The lowest stubble burial rate was obtained from D1Y1 at 72.13%, followed by D1Y2 at 73.77% and D1N1Y1 at 78.69%.

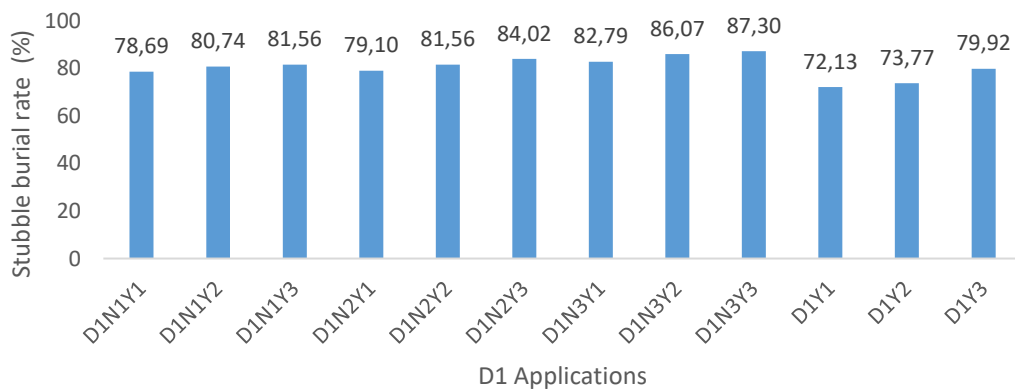


Figure 6. Stubble burial rate for D1 applications

In D2 diameter disc treatments, the highest stubble burial rate was obtained from D2N3Y3 at 84.43%, followed by D2N3Y2 at 81.15% and D2N2Y3 at 80.74%. The lowest stubble burial rate was obtained from D2Y1 at 55.74%, followed by D2Y2 at 69.26% and D2Y3 at 74.18%.

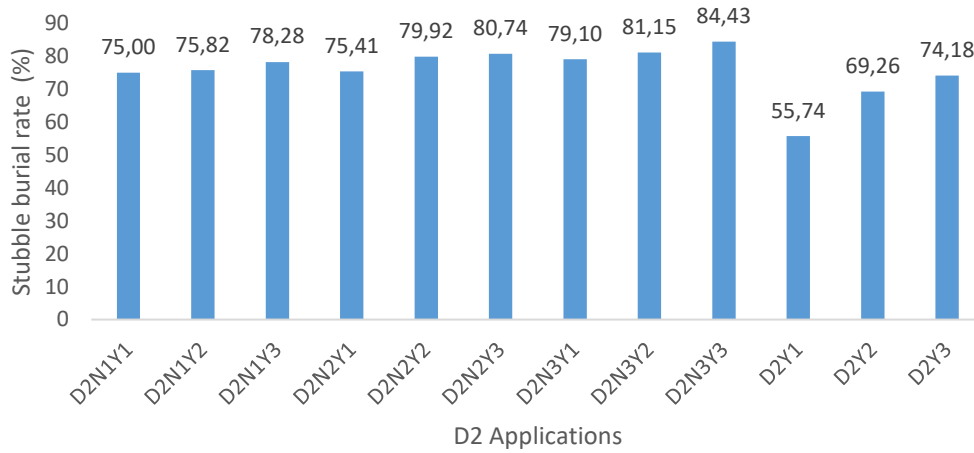


Figure 7. Stubble burial rate for D2 applications

As a result of the measurements and calculations made for the amount of stubble after tillage, it was observed that the amount of stubble on the soil surface decreased as the disc speed and direction angle increased in both disc diameters.

While the lowest amount of stubble in the disc harrow applications, which takes its movement from the soil in both disc diameters, was obtained from Y3 applications, the highest amount of stubble in all applications was obtained from Y1 applications. The fact that the working depth was lower in the applications where low disc speed and disc direction angle were used is seen as the reason why the stubble was not sufficient to be cut and mixed into the soil.

Increasing the working depth caused an increase in soil shear forces and soil and residue mixing (Zeng et al., 2021). It was observed that the treatments with the highest stubble burial rates were in the treatments with the lowest stubble amount. Upadhyay and Raheman (2020a) found that both crop residue embedding efficiency and pollination of soil clods increased with an increase in speed ratio (increase in disc speed and decrease in feed rate), and that there was a significant improvement in tillage quality when disc speed was increased from 95 to 133 min⁻¹ (Dursun et al, 1999) reported that the stubble burial rate increased at rates ranging from 82.9% to 87.6% with the increase in the state and direction angles of the disc in disc ploughing and that the stubble burial rate increased by 12.7% with the increase of the direction angle from 160 to 240 in disc stubble disturbance ploughing.

It is seen that the amount of stubble decreases as the speed increases at different disc speeds with the same disc direction angles. While the amount of stubble was 34.67 g m⁻² in D1 disc diameter, N1 speed and Y1 direction angle, it was 34 g m⁻² in the D1N2Y1 application and 28 g m⁻² in the D1N3Y1 application.

It was observed that increasing the disc diameter increased the amount of stubble at the same speed and direction angles. While the amount of stubble obtained from the D1N3Y3 application was 20.67 g m⁻², the amount of stubble obtained from the D2N3Y3 application was 25.33 g m⁻². The amount of stubble obtained from the D2N3Y3 application was 18.39% more than the amount of stubble obtained from the D1N3Y3 application.

It was observed that increasing the disc diameter at the same direction angle in the disc harrow applications, which takes its movement from the soil, caused an increase in the amount of stubble. While the amount of stubble was 45.33 g m⁻² in the D1Y1 application, it was 72 g m⁻² in the D2Y1 application.

Working speeds (v), disc peripheral speed (u) and u/v ratios for both diameter applications are given in Table 1.

Feed and disc peripheral speeds were determined separately for each application for PTO moving machine applications. Depending on the determined disc circumference speeds, the ratio of disc circumference speed to feed speed was calculated.

Table 1. Feed rates, disc peripheral speeds and u/v ratios of the applications.

D ₁ Uygulamalar	u (m s ⁻¹)	v (m s ⁻¹)	u/v	D ₂ Uygulamalar	u (m s ⁻¹)	v (m s ⁻¹)	u/v
D ₁ N ₁ Y ₁	3.35	1.11	3.03	D ₂ N ₁ Y ₁	3.63	1.09	3.31
D ₁ N ₁ Y ₂	3.35	1.09	3.08	D ₂ N ₁ Y ₂	3.63	1.08	3.36
D ₁ N ₁ Y ₃	3.35	1.07	3.13	D ₂ N ₁ Y ₃	3.63	1.07	3.39
D ₁ N ₂ Y ₁	3.83	1.11	3.45	D ₂ N ₂ Y ₁	4.14	1.10	3.76
D ₁ N ₂ Y ₂	3.83	1.10	3.49	D ₂ N ₂ Y ₂	4.14	1.09	3.79
D ₁ N ₂ Y ₃	3.83	1.07	3.57	D ₂ N ₂ Y ₃	4.14	1.07	3.87
D ₁ N ₃ Y ₁	4.60	1.11	4.13	D ₂ N ₃ Y ₁	4.97	1.11	4.47
D ₁ N ₃ Y ₂	4.60	1.10	4.17	D ₂ N ₃ Y ₂	4.97	1.10	4.53
D ₁ N ₃ Y ₃	4.60	1.08	4.28	D ₂ N ₃ Y ₃	4.97	1.07	4.63
D ₁ Y ₁		1.09		D ₂ Y ₁		1.08	
D ₁ Y ₂		1.06		D ₂ Y ₂		1.05	
D ₁ Y ₃		1.02		D ₂ Y ₃		1.01	

The lowest u/v ratio among the treatments was obtained from D₁N₁Y₁ with 3.03 and the highest u/v ratio was obtained from D₂N₃Y₃ with 4.63. The fact that the disc peripheral velocity was higher than the feed velocity and thus the u/v ratio was high, was effective in good soil cultivation and the plant residues were cut and shredded and mixed into the soil. Upadhyay and Raheman (2020b) recommended that the peripheral speed and feed rate ratio (u/v) of the discs should be kept between 3.0 and 4.0 to obtain the best performance. In terms of tillage performance index, Upadhyay and Raheman (2020a) recommended tillage at a forward speed of 4.55 km.h⁻¹ corresponding to a speed ratio of 3.09 and 133 min⁻¹ with a double-acting disc harrow with front discs driven by PTO and rear discs free moving, considering the overall performance.

The skidding rates of the trials are given in Figures 8 and 9 for both diameter treatments.

In D₁ diameter disc treatments, the lowest skidding rate was observed in D₁N₃Y₁ treatment with 3.17%. This was followed by D₁N₂Y₁ and D₁N₁Y₁ with 3.40% and 3.70%, respectively. The highest skidding rate was realised in D₁Y₃ treatment with 11.45%. This was followed by D₁Y₂ and D₁N₁Y₃ treatments with 7.89% and 7%, respectively.

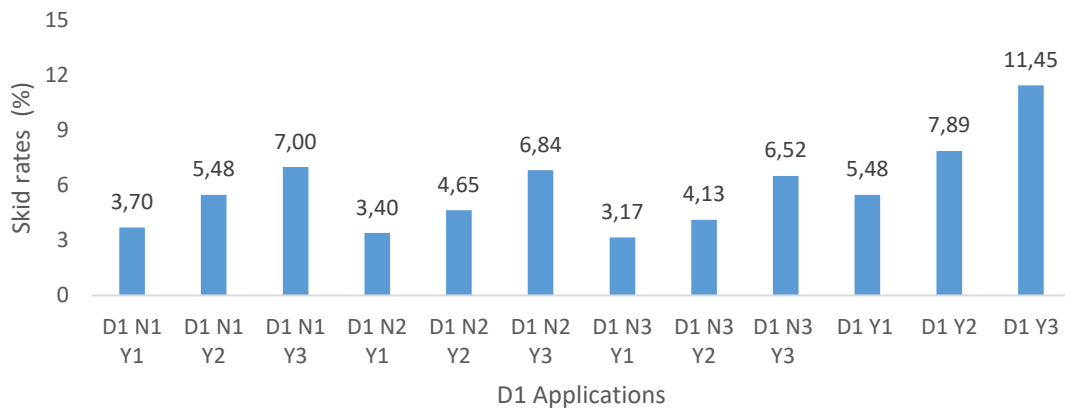


Figure 8. Skid rates for D1 applications

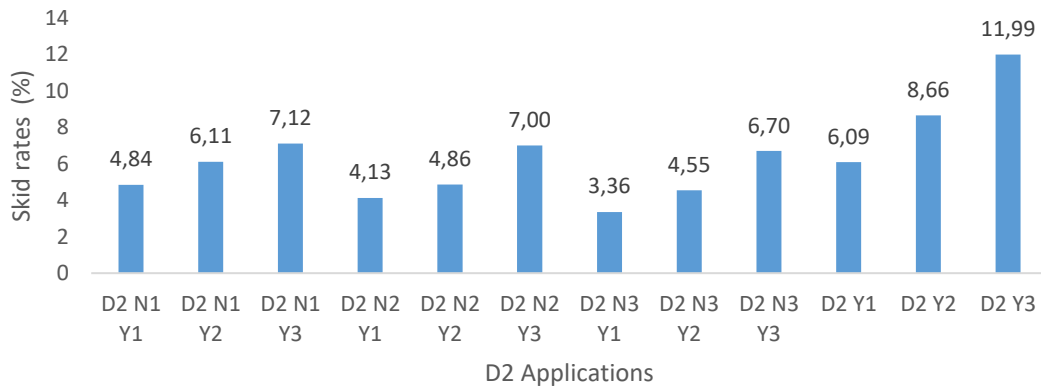


Figure 9. Skid rates for D2 applications

In all applications, it was determined that the increase in the directional angle caused the feed rate to decrease as a result of the effect of increasing working depth and as a result, the skidding rate increased. Similarly, Alamin (2017) reported that the effect of disc direction angle on the skidding rate of the tractor was statistically significant at $\alpha: 0.01$ level, and the skidding of the tractor increased with the increase in disc direction angle. Upadhyay and Raheman (2020b) determined that at disc speed of 95-150 min^{-1} , feed rate of 3.46-6.82 km.h^{-1} and working depths of 80-120 mm, tractive force requirement and wheel slippage were 47.8% and 69% less, respectively, for a double-acting disc harrow with front battery driven by PTO and rear battery driven from the soil compared to a disc harrow driven from the soil.

As a result of the deformation area measurements made after the trials, it was observed that the deformation area increased as the direction angle increased in both disc diameters. It was concluded that the reason for this was the increase in tillage depth as the direction angle increased and as a result, the volume of soil cut by the disc increased. It was determined that disc speed, disc diameter and disc direction angle were effective on the deformation area.

In all applications, increasing the disc diameter at the same disc speed and direction angle and increasing the direction angle and disc speed at the same disc diameter caused an increase in the stubble burial rate and a decrease in the amount of stubble on the surface.

The tillage depth of the disc harrow increased as the disc direction angle and disc speed increased. While the working depth of the machine was determined as 95 mm at minimum direction angles, it was observed that it increased up to 205 mm at maximum direction angles.

Single-acting disc harrow driven from the tail shaft provides a smooth soil surface, reduces penetration resistance, increases the content of clods with a total diameter of less than 15 mm, increases the stubble burial rate, reduces the need for towing power and skidding compared to the disc harrow that takes its movement from the soil.

Since the stalk residues of some crops cannot be broken into short or small enough pieces in the traditional tillage method, doubling or even tripling operations in the fields with clods are carried out to break the stubble or stalks of these crops. This situation enables the stubble or stalks to be broken down, although not sufficient, but in addition to this, harmful effects such as reducing the water retention ability of the soil by breaking down too much and forming a layer of cream after sowing also occur.

Mixing the stalks and stubble into the soil will also contribute to the sustainability of our agriculture by increasing the organic matter ratio of our country's soils, which are insufficient in terms of organic matter

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