Operational performance of crop residue cutting discs in the no-tillage system

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Abstract: The objective of this study was to evaluate the operating performance of crop residue cutting discs with distinct cutting edges in the no-tillage system, in relation to the travel speed of the tractor/tool holder set. The experiment was carried out in an experimental area, the soil classified as Paleudalf. The experiment consisted in a factorial arrangement of 4×4, totaling 16 combinations of treatments and three replications, composed by the interaction of the factors: crop residue cutting discs (plain flat disc, wavy disc, rippled disc, and helical wavy disc coulter) and travel speed (1.11, 1.67, 2.22 and 2.78 m s^{-1}). It was used a mobile tool holder structure for the coupling of the active organs, which was pulled by a farm tractor. For the collection of data on traction force and hourly fuel consumption, it was used electronic instrumentation; as for the measurement of the soil mobilization variables, it was used a microprofilometer. The cutting disc factor showed significant influence on all the variables. The travel speed factor only did not provide significant difference for mobilized soil area. The average requirement of traction demand for the wavy disc, rippled disc, helical wavy disc coulter and plain flat disc was 1.35, 1.27, 1.25 and 1.15 kN, respectively, being increased with the increase in speed. The use of discs with edges that provide larger contact area with the soil, in addition to increasing the traction force demand, makes the process more sensitive to sudden increases in speed, possibly caused by soil impositions. The wavy cutting disc showed the highest hourly fuel consumption. As for the mobilized soil area, it was proven the greater mobilization 42.84 cm^2 for the wavy disc and the lowest 20.62 cm^2 for the plain flat disc. For all the variables in the study, the highest values were obtained when using the wavy cutting disc and the lowest values when the plain flat disc was used.

Keywords: Field trial, agricultural machinery, machine-soil ratio, planter, agricultural Engineering

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1 Introduction

The dimensional and design variations in the development and in the views of the elements on soil/machine employed in planters are capable of causing influence on the efficiency of the operation, since the design of these mechanisms cannot be restricted to a single setting. Thus, these differences, when significant, may compromise the quality of the seeding process.

According to Zeng and Chen (2018), the conservation sowing included the use of soil cover with crop residues (straw), but these residues cause obstruction in the seeding equipment. This way, crop residues have to be cut into smaller fragments, which complicates the attachment of the element in the subsequent operation. This material is partially mixed with the soil for rapid decomposition, while an essential amount is maintained on the soil surface for protection.

Thus, it has become inevitable the use of elements in the planter machine which are able to perform the shear

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of this material, without moving it excessively, and perform a small crack in the soil, starting the process of mobilization only in the seeding line, for further action of the other elements. This way, it is provided a favorable environment for the subsequent deposition of fertilizers and seeds.

The tool responsible for this function is the cutting disc, which can be found in different diameters and shapes of the cutting edge. As for the shape, the most common types are plain flat, fluted, rippled, wavy and notched. Siqueira and Casão Junior (2004) point out that the fluted and rippled discs have grooves on the disc, smooth and sharp edge, providing the increase in the disc adherence to the soil and reducing its slipping. The wavy ones 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.

Thus, Alonço et al. (2006) point out that the users of agricultural machinery face a series of decisions related to the requirements at the time of selection, acquisition, operation and maintenance, which configures the need for credible information that can be provided from studies, tests, assessments and/or trials. This way, in order to meet these requirements, Francetto (2017) highlights that the weighing of the performance of sowing tools in these processes of evaluation has as intrinsic purpose the analysis of the mechanized set ability to perform the operation and the estimation of the changes on the soil, being necessary to measure, mainly, qualitative and quantitative alterations.

One of these performance variables is the mobilized soil area, which, according to Francetto et al. (2016), consists of the area between the original profile and the furrow bottom. In the studies of Dickey and Jasa (1983), it is stated that the wavy discs increase tillage area in the row when compared to elements with a smooth edge, a fact also proven by Silva et al. (2012) and Francetto et al. (2016). Likewise, Mion et al. (2009), when analyzing the mobilized soil area, obtained the results of 40.78 cm^2 mobilized soil for the wavy disc, 15.05 cm^2 for the plain flat disc and 14.14 cm^2 for the rippled disc.

In addition, the estimated tractor effort is essential to understand the estimated energy cost of the operation, and the variables tractive force and hourly fuel consumption are among the most used for this. The first is defined as the amount of force required to pull or push a particular tool. Silva et al. (2012) and Francetto et al. (2015), evaluating straw cutting mechanisms, found that the wavy discs require greater horizontal force to overcome soil resistance when compared to the plain flats discs, possibly because of the edge shape, for their dynamic action in the soil and contact area are different. Concerning the hourly fuel consumption, it can be defined as the ratio of the volume consumed per unit of time. Levien et al. (2011) mention that the use of distinct mechanisms provide variations in hourly fuel consumption, which was verified by Francetto et al. (2015) when studying the different configurations of cutting discs and furrow openers.

Thus, the objective of this study was to evaluate the operating performance of crop residue cutting discs with different cutting edge profiles, working on different tractor set/tool holder travel speeds, with respect to energy requirements and mobilization of soil.

2 Material and methods

The experiment was conducted in an experimental area at the Federal University of Santa Maria (UFSM), municipality of Santa Maria (State of Rio Grande do Sul/Brazil). As soil cover it was observed the presence of crop residues of wheat (*Triticum spp.*), associated to various weed species, resulting in the amount of 55.78 g m^{-2} of dry matter on the soil surface, quantified by the oven method.

The physical characterization of the soil was accomplished by sampling the field, in depths of 0 to 0.20 m, following the methodology proposed by EMBRAPA (1997). For the soil density, it was found a mean value of 1.55 g cm^{-3} while the water content remained at 15%. The textural characterization of the soil is comprised of 20.40% clay, 47.90% silt, and 31.70% sand, and soil classified as Paleudalf, with loamy texture according to the Vettori method (Vettori, 1969). The soil resistance to penetration was measured using an electronic penetrometer, brand Falker, model PLG 1020, obtaining an average value of 1591.48 kPa, with data collection performed in the depth of 0 to 0.40 m, with acquisition of a sample every 0.010 m.

The degree of compaction and the optimum water content for this was 1.69 g cm^{-3} and 18%, respectively. They were obtained by compaction tests, according to ABNT 6457 (2016) and ABNT 7182 (2016).

The experiment was composed of two interacting factors, which were: crop residue cutting mechanisms (Factor 1, with four levels) and the travel speed of the mechanized set (Factor 2, with four levels). The former consisted of four cutting discs, which were: plain flat disc (PD); wavy disc (WD); rippled disc (RD) and helical wavy disc coulter (HD), as characterized in Table 1 and illustrated in Figure 1. The second factor was composed of the displacement speeds of 1.11, 1.67, 2.22 and 2.78 m s^{-1}.

Table 1 Characteristics of crop residue cutting discs

Description	Specification			
	PD	WD	RD	HD
Diameter (m)	0.46	0.46	0.46	0.46
Thickness (m)	0.0050	0.0050	0.0050	0.0050
Cutting depth (m)	0.06	0.06	0.06	0.06
Number of waves	-	18	45	25
Distance between waves (m)	-	0.077	0.049	0.023


(a) Plain flat disc


(b) Wavy disc


(c) Rippled disc


(d) Helical wavy disc

Figure 1 Crop residue cutting discs

The tests were conducted in portions with an area of 180.0 m^2 each, 3.0 m wide and 60 m long, resulting in a total area of 2880.0 m^2, not considering the maneuvering area. The dimensions of the portions followed the recommendation of the project of standards on "Planters and distributors in line of fertilizers and correctives - Field trial" ABNT 04: 015.06-007 (1996).

For the coupling of the active organs, it was used a mobile tool holder structure (THS) designed and built by Gassen (2011), with the power supply of a tire tractor, brand Valmet, 62 id Sincro-O-Mático, with 40 kW of power and mass shipment of 2300 kg.

The mechanized set was equipped with electronic instrumentation for the collection of variable data: traction force and hourly fuel consumption. For the acquisition and storage of data collected by electronics devices, it was used a measurement and control module (*data logger*) brand Campbell Scientific, model CR1000.

To determine the traction force it was used a load transducer (load cell) type S, installed between the coupling device of the tool holder and the tractor drawbar in a retractable support. The implement required force for its operation, denominated as rolling resistance, and this was measured by the load cell, via electrical signals emitted according to the intensity and deducted from the final value.

The average traction force was determined based on Equation (1), using the data of the instantaneous traction force and rolling resistance.

$$F_t = F_i - R_r \tag{1}$$

where, F_t - average traction force, kN; F_i - instantaneous traction force, kN; R_r - rolling resistance, kN.

As for the measuring of the fuel flow, it was used a flowmeter brand Oval M-III, model LSF41, the data were obtained through electrical pulses emitted by the rotation of its inner workings, later being sent and stored by the *datalogger*, so that, using Equation (2), it is calculated the consumption in liters per hour.

$$Hfc = Pu \times 1.8 \tag{2}$$

where, Hfc = hourly fuel consumption, L h^{-1}; Pu = electrical pulses generated by the flowmeter.

The variables of soil mobilization were determined using a microprofilometer to obtain soil profiles. These were performed for each repetition in two phases, namely: obtaining the natural profile and the mobilization profile (after the manual removal of the soil in the furrow). The profiles were marked in A2 graph paper, and later photographed in a fixed position (x, y, and z) and inserted into the computer program Auto Cad (1:1 scale) in order to draw the contour lines of the profiles and finally obtain the soil mobilization area.

After the acquiring of the data, the normality of errors and homogeneity of variances were tested, using the Kolmogorov-Smirnov test to the first, and Cochran, for the second, both through the use of Minitab software, version 17.1. Subsequently, it was performed the statistical analysis of variance and the verification of the significance of factors through the F-test. For the differentiation between treatments it was applied the Tukey analysis test at 5% error probability.

3 Results and discussion

It was observed normality of errors and homogeneity of variances. The analysis of variance (ANOVA) of variables, with their respective averages, levels, and the results of F tests, are presented in Table 2.

Table 2 Summary of the analysis of variance with the average of the factors, their levels and F test results

Factors	Variables		
	F_t (kN)	*Hfc* (L h^{-1})	Mobilized Area (cm^2)
CUTTING DISCS			
PD	1.15 c	3.37 c	20.62 c
WD	1.35 a	4.18 a	42.84 a
RD	1.28 ab	3.71 b	29.03 bc
HD	1.25 bc	3.62 bc	36.02 ab
SPEED			
1.11 m s^{-1}	0.97 d	2.37 c	23.27 a
1.67 m s^{-1}	1.07 c	3.79 b	31.99 a
2.22 m s^{-1}	1.25 b	3.89 b	34.07 a
2.78 m s^{-1}	1.73 a	4.53 a	30.18 a
CV and TA			
Coefficient of variation (CV) (%)	7.14	7.76	32.94
Total average (TA)	1.26	3.72	32.13
F test			
Cutting disc (F1)	9.96 **	16.68 **	9.70 **
Speed (F2)	171.51 **	84.94 **	0.27 ns
F1×F2	2.40 *	1.13 ns	2.27 *

Note: Means followed by the same letter in column are not significantly different from each other Tukey test (p<0.005).
^{NS}: Not significant (P>0.05); *: Significant (P<0.05); **: Significant (P<0.01); F_t: Traction force; *Hfc*: Hourly fuel consumption.

The cutting disc factor showed statistically significant influence for all the variables in the study, at the level of 1% probability. Concerning the speed factor, it did not statistically differ for the variable mobilized soil area, but had a significant influence on traction force, considering that its effect on this variable is not assigned in isolation, but by the interaction with the cutting disc factor. There was no interaction between the factors on the variable hourly fuel consumption, but, when evaluated separately, they influence it significantly.

Moreover, the variables traction force and hourly fuel consumption showed a coefficient of variation value of 7.14% and 7.76%, respectively, gauging a high experimental precision in the obtaining of these variables, corroborating the data obtained by Francetto (2017). As for the variable mobilized soil area, it showed a 32.94% coefficient of variation, this increase may be linked to the variability of the physical characteristics of the soil that composes the area used in the experiment.

3.1 Traction force

It was found the highest energy demand for the WD, followed by the RD, with their average value of 1.35 and 1.28 kN, respectively, both not statistically different. The lowest demand occurred when using the PD, followed by the (HD, both in comparison to the WD reduced traction force of 14.81% and 7.41%, respectively.

Figure 2 illustrates the traction force demand in function of the travel speed for each cutting disc in the study.

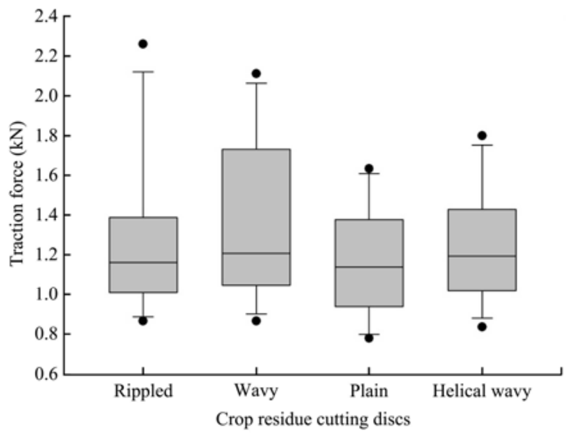

Figure 2 Performance of the cutting discs in traction force

For the rippled and wavy discs the increase in travel speed provided a greater extent in the demand for traction, which indicates their increased sensitivity to the increase of this factor. This shows that the use of discs with edges that provide increased contact area with the soil, in addition to increasing the traction demand, makes the process more sensitive to sudden increases in speed, possibly caused by soil impositions.

The performance of the demand for traction for all cutting discs due to the increase in travel speed may be seen in Figure 3.

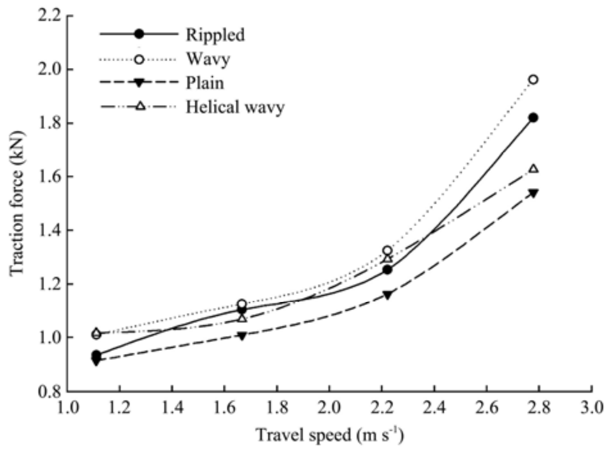

Figure 3 Influence of travel speed on the traction force

For all the crop residue cutting discs studied occurred the increase in the traction demand with increasing travel speed. This happens due to the fact that the increase in speed demands an increase in force to move the disc on the frictional resistance imposed by the soil. The highest average values were obtained when using the WD, for presenting a larger contact area with the ground, providing a higher friction.

The mean values of traction demand due to the interaction of the factors cutting discs and travel speed are shown in Table 3.

Table 3 Summary of the analysis of variance with the average of the factors, their levels and F test results

Cutting disc	Cutting disc × Speed				Mean (kN)
	Speed (m s^{-1})				
	1.11	1.67	2.22	2.78	
PD	0.91 aC	1.01 aBC	1.16 aB	1.54 cA	1.15
WD	1.01 aC	1.12 aBC	1.32 aB	1.96 aA	1.35
RD	0.93 aC	1.10 aBC	1.25 aB	1.82 abA	1.27
HD	1.02 aC	1.07 aC	1.29 aB	1.63 bcA	1.25

Note: Means followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other;

PD: plain flat disc; WD: wavy disc; RD: rippled disc; HD: Helical wavy disc coulter.

For all cutting discs, no significant difference ocurred between the speeds 1.11 and 1.67 m s^{-1}, the same case occurred for RD, WD and PD between the speeds 1.67 and 2.22 m s^{-1}. Between the speeds of 2.22 and 2.78 m s^{-1}, there was an average increase in traction demand of 72.75% for all discs, providing statistically significant difference. There was also significance at speeds of 1.67 to 2.78 m s^{-1} for all discs, which was found at the speed of 2.22 m s^{-1} for the HD, due to the increased traction demand in 0.23 kN.

With the occurrence of the interaction between factors, the traction demand will be affected when there is a change in the proportion of any of the variables. The lowest value observed 0.91 kN was at the lowest speed, using the PD, this fact is explained by the flat lower surface of the disc providing a smaller contact area of the tool with the soil, thus the demand of traction has a tendency to be lower. However, when using the wavy disc blade, the highest traction force values are verified, with an average of 1.35 kN, since its waves cause a larger contact area with the soil, confirming the assumptions by Silva et al. (2012) and Francetto et al. (2015).

Analyzing the speeds of 1.11, 1.67 and 2.22 m s^{-1}, it was observed that there was no significant difference among the evaluated discs. However, for the highest travel speed it was observed that the WD required the greatest traction force (1.96 kN), not significantly differing from the RD (1.82 kN), both obtaining significance when compared to the PD, which required the lowest traction force (1.54 kN). The HD obtained average of 1.63 kN and did not statistically differ from the plain flat disc and the rippled disc.

3.2 Hourly fuel consumption

It was shown that the WD showed the highest hourly fuel consumption at all speed levels studied, this difference was of 0.47 L h^{-1} in comparison to the RD, which showed the second highest consumption (3.71 L h^{-1}). This situation occurs due to their larger contact area with the soil, thus requiring an increase in the traction force demand to overcome the friction generated between the tool and the soil, consequently causing the increase in consumption. The PD had the lowest hourly consumption (3.37 L h^{-1}), followed by the HD (3.62 L h^{-1}), both not significantly different. Francetto et al. (2015), by associating cutting discs to furrow openers found no difference, because the highest demand for fuel was set on the furrow opener and not on the disc, which did not provide a complete understanding of the action of the mechanism.

The hourly fuel consumption showed the influence of the cutting discs and travel speed, but there was no interaction among the factors studied. Figure 4 illustrates the results.

The performance of the hourly fuel consumption for all cutting discs in relation to the increase in travel speed may be seen in Figure 5.

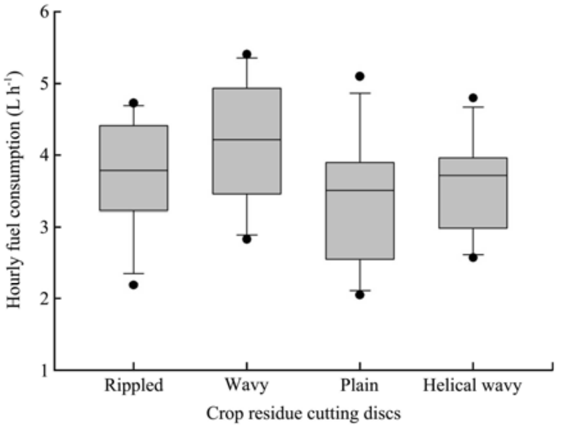

Figure 4 Performance of cutting discs in hourly fuel consumption

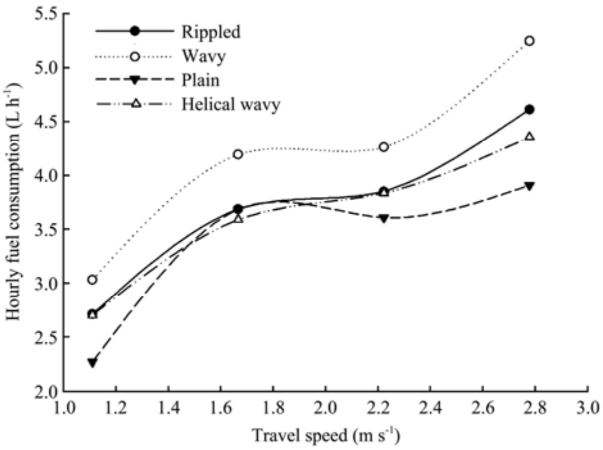

Figure 5 Influence of travel speed on hourly fuel consumption

There was an increase of 52.3% in fuel consumption with the increase of speed from 1.11 to 2.78 m s^{-1}. The speed levels of 1.67 and 2.22 m s^{-1} did not significantly differ among themselves, however, both of them showed significant differences with the speeds 1.11 and 2.78 m s^{-1}. Silveira et al. (2013), when evaluating the requirements of a seeder according to the travel speed, identified increased hourly consumption when the speed was altered from 1.11 to 1.67 m s^{-1}.

3.3 Mobilized soil area

It was observed an effect with statistical differentiation of the type of cutting edge profile of the discs in the mobilized soil area, wherein the WD caused greater movement, with 42.84 cm^2, followed by the HD and the RD, which moved 36.02 and 29.03 cm^2, respectively. The PD moved 48.13% less than the wavy disc, with 20.62 cm^2. This situation was due to the differences between the dimensional characteristics of the elements that interfere in the cutting stress, shear and compaction they cause on the soil, as cited by Hasimu and Chen (2014). According to Francetto et al. (2016), and Zeng and Chen (2018), the contact area of the disc has a greater effect in the lateral displacement of the soil, compared to the disc geometry, as its width and the number of waves.

The obtained values confirm those found by Silva (2012) and Mion et al. (2009), the latter when assessing the mobilization promoted by cutting discs, found significant differences, with 15 cm² values for PD and 41 cm² for the WD. According to Francetto (2016) and Zeng and Chen (2018), the higher aggressiveness of the wavy disc in the mobilized soil area is attributed to its larger contact surface, directly affecting the sides of the furrow.

Besides this, the differences among the technical conformations of the discs used in this experiment, as well as the contrasts between soil densities, penetration resistance and other physical characteristics of the studied soils may have caused different effects on the processes of cutting, shearing, compaction and flow in the behavior of the soil.

Figure 6 illustrates the mobilized soil area in relation to the travel speed for each cutting disc in the study.

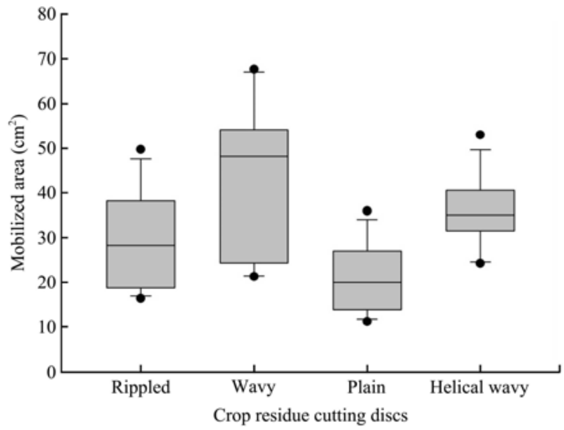

Figure 6 Performance of the cutting discs in the mobilized soil area

The use of different travel speeds of the mechanized set did not influence on the mobilized soil area, which presented an average of 29.87 cm^2, indicating that this factor is not limiting for adequate mobilization in the furrow for the no-tillage system, indicating the possibility of use of speeds of up to 2.78 m s^{-1} without causing reduction of tillage. These results are consistent with those found by Silva et al. (2012) evaluating the performance of straw cutting mechanisms and with

Francetto et al. (2015), analyzing the performance of associations between cutting discs and furrow openers. This effect may be associated with the friable consistency of the soil at the time of the experiment.

The performance of the mobilized soil area for all cutting discs in relation to the increase in travel speed may be seen in Figure 7.

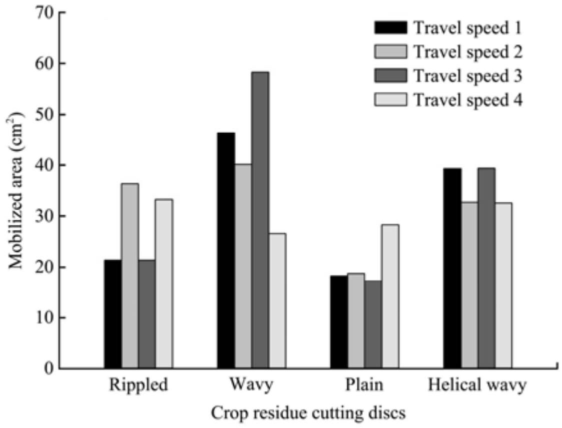

Figure 7 Influence of travel speed on the mobilized soil area

The average values of the mobilized soil area in relation to the interaction of the factors cutting discs and travel speed are shown in Table 4.

Table 4 Mean values of mobilized soil area in relation to the factors

Mower	Cutting disc × Speed				Mean (cm^2)
	Speed ($m\ s^{-1}$)				
	1.11	1.67	2.22	2.78	
PD	18.39 bA	18.72 aA	17.20 bA	28.29 aA	20.62
WD	46.32 aAB	40.17 aAB	58.30 aA	26.57 aB	42.84
RD	25.11 abA	36.38 aA	21.39 bA	33.28 aA	29.03
HD	39.35 abA	32.72 aA	39.41 abA	32.29 aA	36.02

Note: Means followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other. PD: plain flat disc; WD: wavy disc; RD: rippled disc; HD: helical wavy disc coulter.

For the RD, PD, and HD, the factor speed did not significantly influence the mobilized soil area, with means of 29.03, 20.62 and 36.02 cm^2, respectively. As for the WD, it was found the highest value in soil mobilization, 58.3 cm^2, at a speed of 2.22 $m\ s^{-1}$, this result did not differ from the lower speeds, but it presents a distinction from the highest.

When viewing the value found (26.57 cm^2) at a speed of 2.78 $m\ s^{-1}$ to the WD, it was verified a result relatively below what was obtained for the lower speeds, this difference may have been influenced by the variability in the physical characteristics of the location, such as soil density, penetration resistance and humidity.

The speed levels of 1.67 and 2.78 $m\ s^{-1}$ did not differ as to the cutting disc factor, but at the speed of 1.11 the mobilized area was not significant for the RD, WD, and HD, the same occurred among the plain flat, helical wavy, and rippled cutting discs. This latter case was also verified at the speed of 2.22 $m\ s^{-1}$.

4 Conclusions

Under the conditions and characteristics where the experiment was run, the edge profile of the crop residue cutting discs significantly influenced the traction force, the hourly fuel consumption and mobilized soil area, the amounts of these variables being higher when using the WD.

Increased travel speed provided a greater extent in the demand for traction and tillage for the discs with larger contact area with the soil, showing that the process is more sensitive to the increases of this factor.

The use of the HD was the most efficient in the use of traction by unit of mobilized soil.

It is not recommended the use of speed levels 2.22 and 2.78 $m\ s^{-1}$, regardless of the cutting edge profile of the disc used, because they demand higher traction force and hourly fuel consumption.

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