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# Effect of applied loads on passive rolling coulters for cutting crop residues

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ABSTRACT

No-till system technology has created challenges for grain production in tropical regions, requiring alternative techniques for managing crops' residues during sowing. In context, this research aimed to relate the four straw-cutting discs effect under three vertical loads, analyzing the energy performance in corn brachiária consortium residues. A Soil Tillage Test Unit (STTU) was developed for controlled in-field tests. Three vertical load effects (2880, 3370, and 3860 N) applied to four models of cutting discs were evaluated: plain, turbo, notched, and bubble. The experimental design adopted was a Completely Randomized Design (CRD) 4 × 3 double factorial, with four cutting mechanisms and three vertical loads. The evaluations included mobilized soil, working depth, average drawbar force, horizontal force per area of mobilized soil, specific force, power demanded, hourly fuel consumption, and specific fuel consumption. Positive angular coefficients were obtained for all disc models, with linear adjustment between the increase in vertical loads and force demand. Determination coefficients of 0.99 and 0.97 for Plain and Turbo discs, respectively, in addition to 0.88 for Bubble and 0.90 for Notched discs. Turbo-type discs reached the soil depths lowest. The disc model determines soil effects by depth and soil mobilized. The Turbo disc reached the soil's lowest depths. Increasing the vertical load applied to the cutting discs results in greater disturbance to the ground.

## 1. Introduction

Conservation tillage techniques have significantly advanced in recent decades, particularly in Brazil, where agricultural systems permanently deposit soil crop residues. This research, which explores the effect of applied loads on passive rolling coulters for cutting crop residues, is a significant contribution to the field. The findings of this study can potentially enhance the efficiency of conservation agriculture, leading to increased productivity, reduced erosion, and minimized environmental impacts [1–4].

Passive rolling cutting coulters cut previous crops' remains and facilitate subsequent tillage. The coulters were historically used to facilitate the plow's work, reducing biomass and incorporating crop residues, with a thin mulch layer formed by decomposing residues. Today, in conservation soil management systems, the cutting blades of a mower come in four different patterns: smooth, mainly used in clean fields, and notched, turbo, and bubble, all of which work in fields covered with large amounts of residues [5].

In addition to soil preparation operations, passive cutting discs are used in planting and seeding machines in straw-covered soil conditions. Soil disruption efficiency during sowing promotes adequate initial plant development [6], depending on how vegetation cover is cut [7]. The disc model directly influences the furrow opening actions for planting and cutting dense straws [8,9]. The sowing realization on corn straw and the high fibrous material accumulation in topsoil reduces the machine's efficiency [10].

Therefore, further studies on disc efficiencies in different field conditions are necessary since, in addition to the coulter cut discs, the straw's characteristics can affect the machines' energy performance and the furrow opening's quality [11].

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Controlled trials support mathematical modeling and encourage the development of sustainable agricultural models. This study compares coulter cut disc performance under controlled conditions. In addition, three static loads affect corn and brachiária residues.

## 2. Material and methods

### 2.1. Site of study

The research was conducted at the Lageado Experimental Farm, Faculty of Agricultural Sciences of the São Paulo State University "Júlio de Mesquita Filho" (FCA/UNESP), Botucatu – SP. According to Köppen, adapted by [12], the region's climate is classified as Cwa, with dry winters and hot, rainy summers.

A representative soil, characteristic of most Brazilian productive regions, was chosen for the study's grain-producing scenario. According to soil taxonomy [13], it is classified as a Typic Hapludox or Red Yellow Latossol according to the Brazilian Soil Classification System [14].

The soil density analysis was performed using the standard volumetric ring method. The soil's water content was determined using the standard weighing methodology through pre- and post-drying in a forced circulation oven at 105 °C for 24 h [15]. Soil granulometric analysis was conducted, determining soil particles in silt, clay, and sand (Table 1).

The vegetation was desiccated within 15 days before tests began with Diquate herbicide, a dose of 2 L ha$^{-1}$ and a spray volume of 200 L ha$^{-1}$. The soil's total dry matter mass was determined using the methodology proposed by [16].

The Soil Penetration Resistance (SPR) in the area before the tests was determined by a mechanical penetrograph, model *Soil Control* SC-60, equipped with a metal rod conical tip 2 (12.83 mm in diameter and 30º angle). SPR data were collected at six random points up to 150 mm deep within a 50 mm interval (Table 2).

### 2.2. Soil tillage test unit

A specific test unit with unitary disc models was developed for the controlled experiment. The Soil Tillage Test Unit (STTU), built in a metallic structure with a total weight of 2275 N and dimensions of 1240×980×1280 mm in length, width, and height, respectively, had a tool holder bar attached to fix different cutting tools (Fig. 1). An agricultural tractor drawbar pulled the structure.

As shown in Fig. 1, the traction bar was connected to a coupling structure at the rear of the tractor, using a load cell with a capacity of 10 tons as support, arranged transversely between the tractor's traction bar and the STTU. The load cell allowed the reading of the force demanded by the tools during mechanized operation.

The STTU was coupled to a John Deere tire tractor, model 6600, with 4 × 2 TDA traction and 88.9 kW of power. During the tests, the tractor developed a constant speed of 5.5 km $h^{-1}$ in gear C1 with the engine at 1700 rpm.

The signals from the traction test were collected and stored using a sophisticated data acquisition system. This system was installed in the tractor cabin and directly connected to the load cell. It was developed on the Arduino Pro Mini platform, which included a 10-bit digital-analog converter, 16 MHz clock, 32 kB of flash memory, 2 kB RAM, and 1 kB of EEPROM memory. The system was equipped with an HX711 signal converter module, which was crucial for connecting to the load cell (Fig. 2).

**Table 2**
Soil Penetration Resistance (SPR) for 0 to 150 mm deep.

| Depth (mm) | (MPa) |
|---|---|
| 0–50 | 1.49 |
| 50–100 | 2.45 |
| 100–150 | 2.94 |

### 2.3. Field test procedures

Tests were conducted in an area with Brachiária vegetation cover and corn straw on the surface. Random work tracks were determined depending on different discs and applied loads. The vertical loads adopted were 2880, 3370, and 3860 N (L1, L2, and L3, respectively); these loads were applied by metal ballast bars directly to the STTU structure on the discs and were selected based on standard load values in seeders- fertilizer machines, simulating the machine empty (L1), partially filled (L2) and at maximum load (L3), proportionally stipulated for a sowing unit.

The cutting discs used were plain, turbo, notched, and bubble. Table 3 describes the technical characteristics of each model.

The random study tracks were 20 m long and 5 m wide. Four replications were carried out for each treatment, totaling 48 experimental plots. The response variables obtained from the tests were working depth, forces imposed on the drawbar, and specific fuel consumption.

### 2.4. Working depth and mobilized soil area

The cutting discs' working depth was determined by a ruler with a precision of 0.0001 $m$ ± 0.5 mm from the surface to the base of the groove. The soil mobilized (cm$^2$) area was measured with a rod profilometer with 37 metal rods 0.5 m long, spaced at 0.015 m. The equipment was positioned before passing the disc (natural profile) and after passing the cutting discs, with sum of mobilized areas (Fig. 3). The markings were made on a 420×297 mm sheet of paper, and the readings were carried out on a digitizing table.

### 2.5. Drawbar force

A Sodmex load cell, model N400, with a capacity of 100 kN and sensitivity of 2.156 mV V-1, was installed to determine the traction force imposed on the tractor. According to Eqn 1, data were recorded with four repetitions.

$$DF = \sum_{i=1}^{n} (IF/N)x\ 9.81 \tag{1}$$

where DF is drawbar force (N), IF is instant force (kgf), N is the number of recorded data, and *9,81* is a gravity acceleration constant.

### 2.6. Force per soil mobilized area and specific force

The horizontal force per area of mobilized soil was calculated using the relationship between horizontal traction force and area of mobilized soil in cm$^2$ by Eqn 2.

$$FSMA = DF/SMA \tag{2}$$

Where *FSMA* is a force per soil mobilized area (N cm$^{-2}$), *DF* is a

**Table 1**
Experimental area soil characterization.

| Depth | Silt | Clay | Thin Sand | Medium Sand | Course Sand | Total Sand | Bulk Density | Soil Moisture | Dry Mass |
|---|---|---|---|---|---|---|---|---|---|
| cm | g kg$^{-1}$ | | | | | | kg $m^{-3}$ | % | Mg ha$^{-1}$ |
| 0–20 | 64 | 261 | 377 | 198 | 99 | 675 | 1,84 | 19,3 | 12.9 |

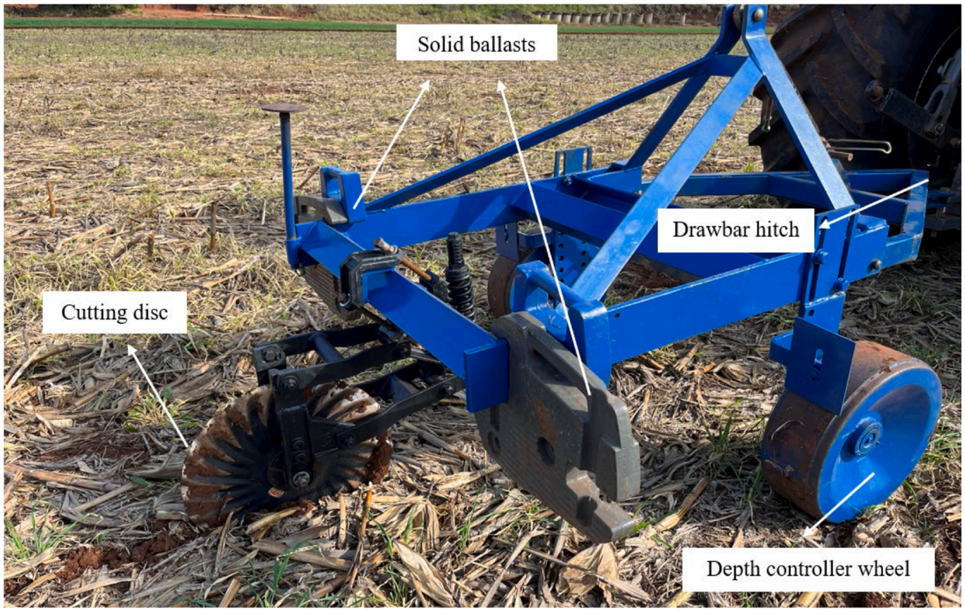


**Fig. 1.** Soil Tillage Test Unit (STTU). Steel chassis coupled to agricultural tractor for individual disc coulter testing. Solid ballasts apply controlled static loads.


**Fig. 2.** Data acquisition system.

drawbar force (N) and *SMA* is soil mobilized area ($cm^2$).

According to Eqn 3, the specific horizontal force was calculated by determining the relationship between horizontal force on the drawbar and working depth.

$$HSF = DF/D \quad (3)$$

Where *HSF* is a horizontal specific force ($N\ mm^{-1}$), DF is a drawbar force (N) and *D* is a soil depth (mm).

### 2.7. Drawbar power and hourly fuel consumption

Equation 4, proposed by [17], was used to determine the power the drawbar demands depending on the cutting discs and vertical load.

$$PD = DFx\,S \quad (4)$$

**Table 3**
Coulter discs description.

| Cutting disc | Specifies | | |
|---|---|---|---|
| | Diameter (mm) | Tilt angle (°) | Characteristics |
|  | 508 | 29.2 | Plain Disc (PD): presents a narrow width on furrow, approximately 10 mm. |
|  | 508 | 27.3 | Turbo Disc (TB): larger work width, reaching up to 40 mm, removing crop residue to sowing furrow |
|  | 508 | 27.0 | Notched Disc (ND): largest surface contact area, used in heavier crop residues, e.g. sugarcane residue |
|  | 508 | 26.5 | Bubble Disc (BD): This tool can be used to break up the surface compacted layers on the top and sides of the sowing furrow. |

Where *PD* is a drawbar power (kW), *DF* is a drawbar force (kN), and S is the Speed of FTTU (m $s^{-1}$).

Hourly fuel consumption was measured in each experimental plot using the methodology adapted from [18]. In this way, a 2000 mL test tube was installed at the inlet of the injection pump to supply the tractor in each work range. The fuel return from the engine was directed to the supply cylinder. The initial and final volumes were recorded in each experimental plot, and the hourly consumption was calculated from Eqn 5.

$$HFC = (V2 - - V1 / \Delta t)x3.6 \tag{5}$$

Where *HFC* is Hourly fuel consumption (L $h^{-1}$), *V2* is the recorded volume in the test tube at the beginning of the installment (mL), *V1* is a recorded volume in the test tube at the end of the installment (mL), *Δt* is the time taken to go through the experimental plot (s), *3.6* – Conversion factor from mL $s^{-1}$ to L $h^{-1}$.

### *2.8. Experimental design and statistical analysis*

The experimental design adopted was a Completely Randomized Design (CRD) 4 × 3 double factorial, with four cutting mechanisms, three vertical loads, and four replications each, totaling 48 experimental plots arranged in randomized parallel strips. The collected data were subjected to analysis of variance, and when differences were found, means were compared using the Tukey test at the 95 % significance level ($P \leq 0.05$). Regression analysis of means was applied depending on the different loads on the cutting discs. The results were analyzed using the statistical RStudio software version 4.4.1.

## 3. Results and discussion

### *3.1. Drawbar force*

Drawbar force is an important evaluation for agricultural devices, with a positive relation between traction requirements, fuel consumption, and tractor preparation. The results showed that the increased applied loads directly affected mechanized assembly force demand, regardless of the disc model used (Fig. 4). Unlike our results, [19] obtained variations in energy demand in analyses of different cutting discs, where the highest energy demand occurred with wavy discs and the lowest with plain discs. In our research, corrugated discs can be compared to the turbo disc design, but with variations to the number of corrugations and disc size.

Positive angular coefficients were obtained for all disc models (Fig. 4), with linear adjustment between the increase in vertical loads and force demand. Determination coefficients of 0.99 and 0.97 for Plain and Turbo discs, respectively, in addition to 0.88 for Bubble discs and 0.90 for Notched discs. According to [20], Notched discs have the capacity for greater penetration into rigid soils, but their cutting capacity is lower compared to Plain discs. Applied effect loads were less intense on the turbo disc due to the low angular coefficient obtained in the regression analysis. This fact is evidenced by the less intense growth of the regression line with the turbo disc compared to the other types of discs evaluated.

Our findings have significant practical implications. At low loads (L1), the Bubble disc demonstrated the highest force demand at 964 N (Fig. 4D), followed by the Turbo disc at 778 N (Fig. 4B). The Plain and Notched discs, on the other hand, exhibited the lowest force demands at low loads, with 732 and 611 N respectively (Fig. 4A and 4B). This suggests that the elevated structures (bumps) in the Turbo and Notched discs, which present greater resistance in the surface soil, could be beneficial in certain soil conditions. These structures create a larger contact area with the loose soil on the surface, necessitating a higher force demand.

At medium loads (L2), the Plain Disc with 1164 N expressed the highest energy demands, followed by the Notched Disc with 1110 N, the Bubble Disc with 1065 N, and the Turbo Disc with 877 N (Fig. 4). Therefore, in medium load conditions, the turbo disc presented the lowest force demand, indicating that the mobilization caused by the model's angled ribs may affect the mechanized assembly's greater groove opening and lower traction demand. Our results are supported by [11], where a relationship was found between lower force demand and an increase in ripples number on the discs.

Soil vegetation covered with corn crop remains is resistant to the mechanized cutting process. This affects the group's energy demand and increases the need for machine power. Cutting resistance can be reduced by applying loads to the discs, but this process increases disturbances in the soil [21]. Therefore, in some farming conditions, adopting devices to crush straw before sowing is recommended [10]. Studies of [11] inferred that increased straw on the soil surface can increase the force demand for a mechanized sowing system.

For high loads (L3), there is greater force demand for Plain Disc 1519 N followed by Bubble Disc, 1503 N and Notched Disc, 1253 N (Fig. 4A, D, and C). The increase in force demand for these models for the Turbo disc occurs due to this model's groove and axial angle of attack. The Turbo disc tends to apply loads to the ground staggered, reducing the demand for energy and force necessary to break the ground. This is related to the construction and attack angle of this tool on the ground [9].

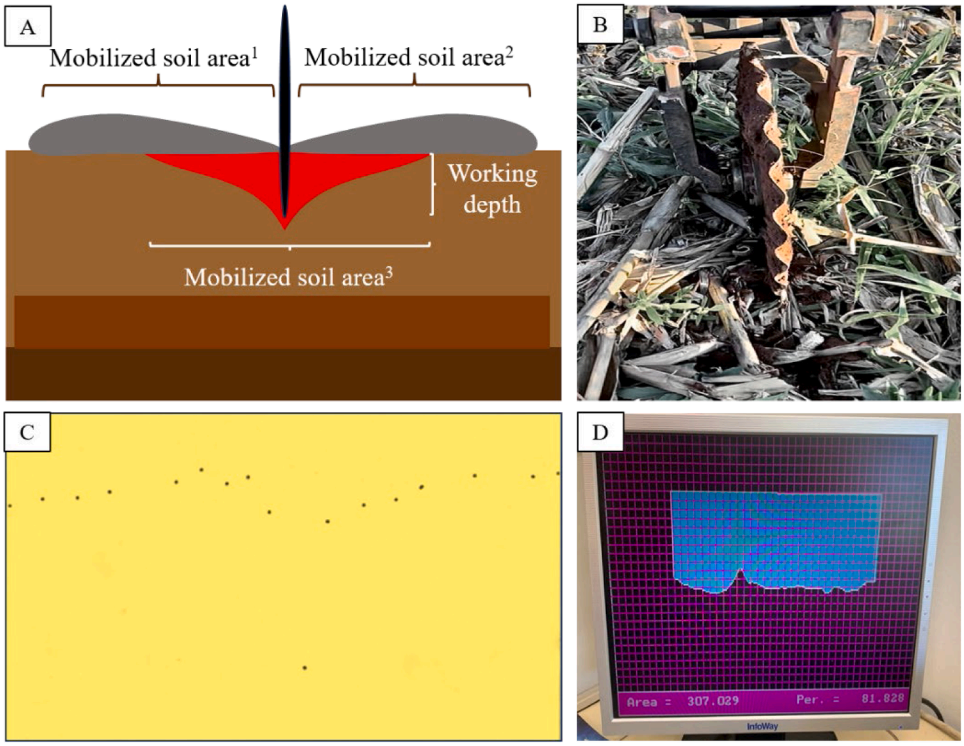


**Fig. 3.** Distribution profile of soil mobilized area and working depth on the tests (A), Field assessment (B), Data collect (C) and Data analysis (D).

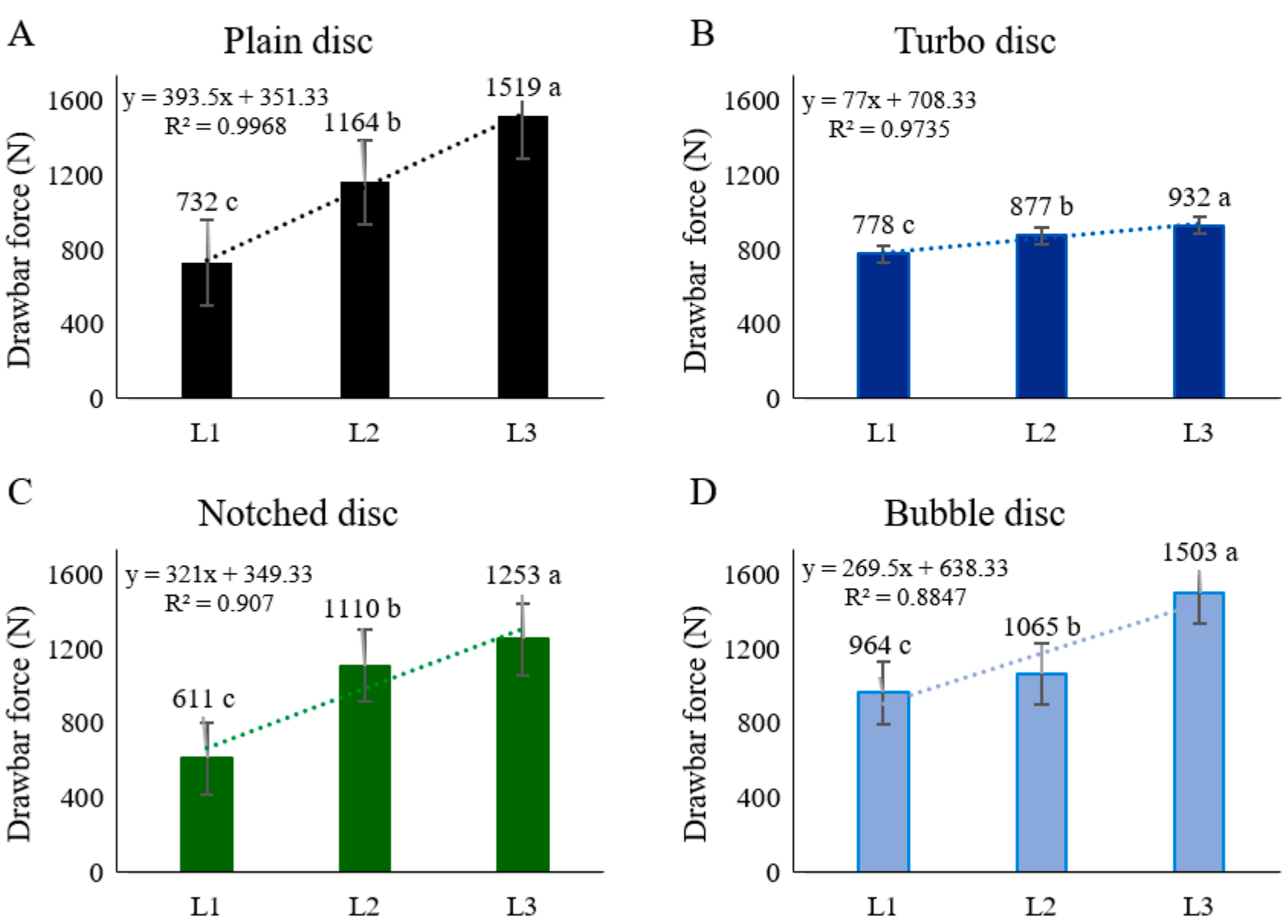


**Fig. 4.** Average force on the drawbar as a function of cutting mechanisms and applied load for Plain (A), Turbo (B), Notched (C) and Bubble (D) discs. Means associated with similar letters do not differ by Tukey test ($P \leq 0.05$).

### 3.2. Depth and soil mobilized area

Surface soil mobilization is an essential parameter of soil management. Since cover vegetation residues protect the topsoil and furrow sowing where seeds are deposited, this practice can improve initial crop establishment. For the variables of depth and mobilized soil, we did not obtain a significant difference between the treatments however, in absolute values, the lowest load obtained to Bubble and Turbo discs showed the greatest depths at 68 and 51 cm, respectively, followed by the Plain and Notched discs at 44 and 36 cm, respectively (Fig. 5 and 6).

The mobilized areas' characteristics were reflected in the force demand for the mechanized assembly presented in Fig. 6. Our findings allow us to infer that for the discs evaluated, depth directly affected the load demand of the mechanized assembly, which is also confirmed by [22]. It was found that the load increase on the discs tends to increase the working depth and, consequently, the mobilized area [9]. In addition, [20] described that the shape of the discs significantly impacts the straw-cutting effect, which reflects on the mobilized area as presented in this study.

The largest mobilized area was found in the turbo disc, which can reduce the amount of straw on the surface. However, this disc model can be suitable in areas with excessive residue on the surface to minimize the effect of poor seed placement in the soil and thus delay their germination [23,24].

### 3.3. Specific force and force per soil mobilized area

The physical characteristics of plant material effectively impact soil mobilization. In areas with a high amount of matter on the soil, as in this study, it may be necessary to increase the vertical load applied to the discs to cut the residues and form the sowing furrow effectively [10].

The Plain, Notched, and Bubble discs required greater specific forces to the turbo disc, especially the Plain, possibly due to the smaller cutting width among the models evaluated (Fig. 7). Similar to our study, [25] found that grooved discs, intermediate in width between plain and turbo discs, required 43 % and 67 % less torque than discs with plain and notched edges.

Among the discs with a plain edge, the cut one presented the lowest average values for the two variables analyzed in two of the three loads. This demonstrates that the disc has a low capacity to go deeper into the soil and a low mobilization capacity (Fig. 5 and 6). Because it has prominent edges, the disc has a concentration of force at the edges, reducing cutting capacity and increasing tool wear [5].

### 3.4. Power requirement

As well as drawbar force, from measuring power requirement, it is possible to preview fuel requirement for different tools, providing data to coulter disc chosen before sowing, optimizing process, and decreasing

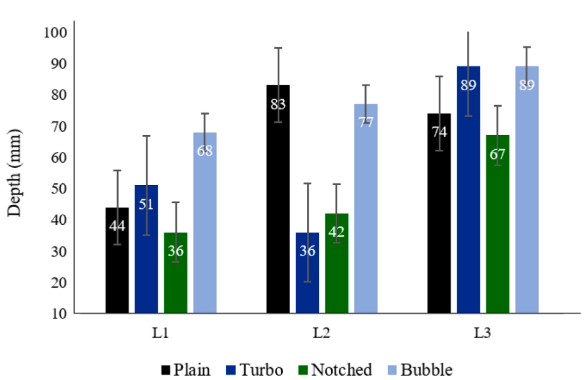


**Fig. 5.** Depth reached by each disc model. Means do not differ by Tukey test ($P \leq 0.05$).

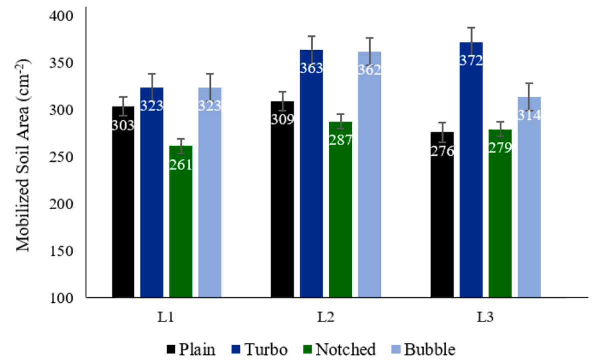


**Fig. 6.** Soil mobilized area by disc model. Means do not differ by Tukey test ($P \leq 0.05$).

fuel consumption. L3 load required greater demand to mobilize the soil due to the horizontal load exerted to pull the discs. Indicating that it is an excessive load if the waste cutting is carried out at lower vertical loads. For all disc models, the L3 load provided more significant power requirements (Fig. 8), except for the turbo disc, which presented higher values of power demanded in L2, a fact explained by the conformation and valuable disc area, as this requires more significant pressure to go deeper into the ground compared to the other discs.

The drawbar's power demand results indicate increased power required to pull the discs due to the increased load on the test unit. This is proven by the line slope describing the fuel behavior in a linear fit versus loads. The data can be based on the resistance from corn residues and their high mass, exceeding 12 Mg residues per hectare. It reinforces the need for studies with well-adapted and high-performance cutting discs to deal with the problems of excessive crop residues in no-till operations.

Analyzing the behavior of plain and wavy discs for different groove opening mechanisms, [26] confirmed that the wavy disc required 4.98 % more power. The result of this model's cutting width differs from the results presented in this research, in which, as shown in Fig. 6, the Turbo disc presented demands equal to or lower than the Plain, Notched, and Bubble discs. The positive results for the cut disc are explained by the dynamics exerted on the ground, in which the force exerted on the ground varies according to the smaller contact area of this disc, reducing the demand for horizontal and vertical force and, consequently, the power required [27].

Following the trend of the force data exerted on the drawbar, the cut disc presented the lowest average power required. This behavior can be explained by the smaller contact area of this disc due to its construction format. They presented edge characteristics along the edge, reducing the contact surface with the ground by half. In this line of research, [22] report that the 30-tooth cut disc required lower rates of vertical and traction force, demonstrating less lateral soil mobilization for covering rice and wheat in a rotation system.

### 3.5. Fuel consumption

The hourly consumption followed an increasing trend depending on the load applied to the plain, cut, and bubble discs, which may be related to the greater depth of action, as observed in (Fig. 5), corroborating to [28], which describes that increasing the working depth increases hourly fuel consumption. At the lowest load applied, the cut and turbo discs increased consumption compared to the others, while at the highest load, the plain disc showed the highest consumption during the tests at 9.6 L $h^{-1}$ (Fig. 9).

Monitoring agricultural activities, especially fuel consumption, is a significant factor in improving economic indicators on agricultural farms [29], as according to [30], research often focuses only on the effects of disk geometry.

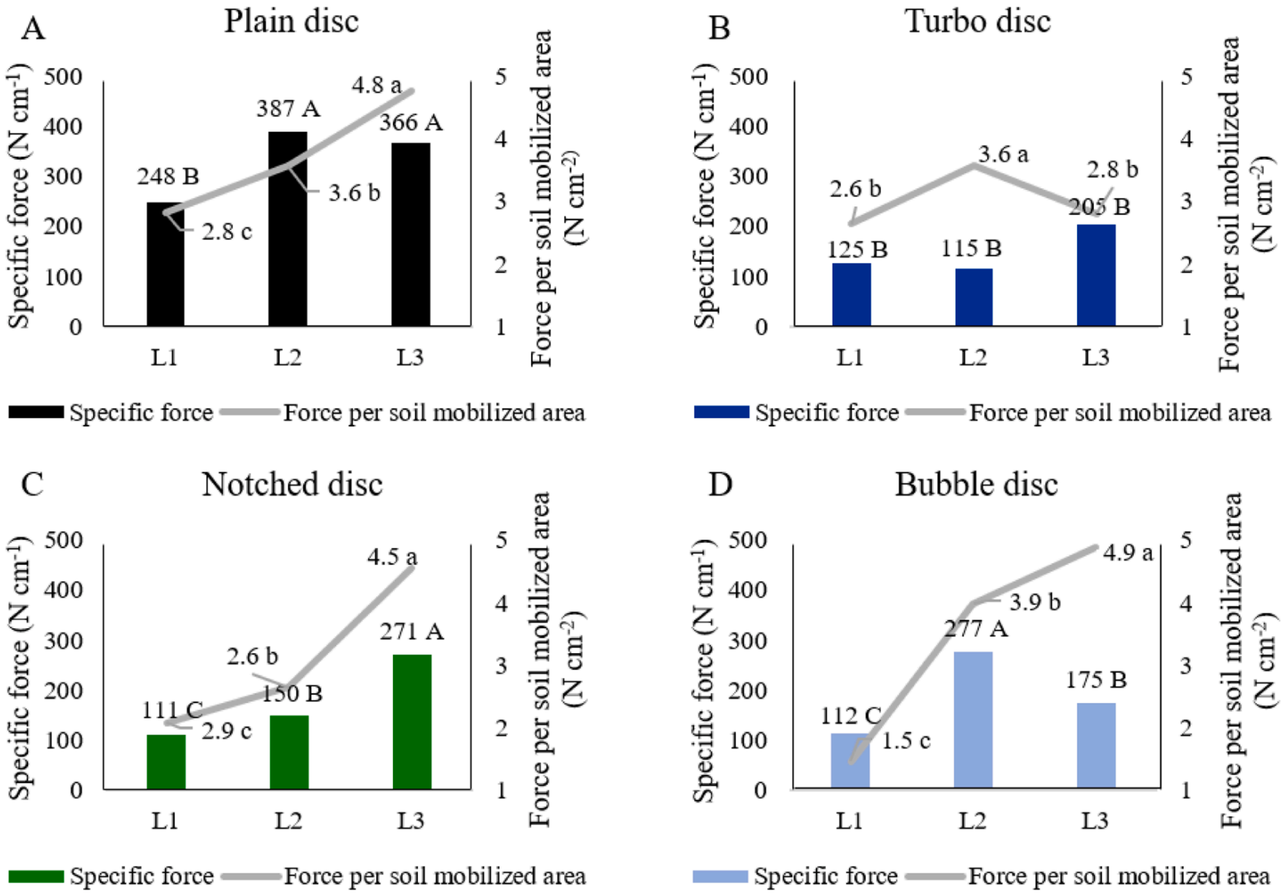


**Fig. 7.** Specific force and force per soil mobilized area depending on the cutting mechanism and load applied for the Plain (A), Turbo (B), Notched (C), and Bubble (D) discs. Means associated with similar letters do not differ by Tukey test ($P \leq 0.05$).

The turbo disc's fuel consumption showed stability due to increased loads. The findings showed that the fuel demand for this type of disc is more significant at low loads. Therefore, adjusting and applying high loads to turbo models in seeding operations is interesting. The turbo disc obtained the best cutting performance with reduced fuel demand.

The plain disc presented the best performance at low loads; however, when loads were increased, fuel consumption increased. The results collaborate with [31], where there was a reduction in fuel consumption with flat discs compared to bubble discs. However, the authors' results come from a virtual modeling system for specific soil conditions.

Our study provides practical insights by revealing the hourly fuel consumption required by the main cutting discs that equip direct planting seeders. This opens new frontiers and studies to determine the energy demand of various models of commercial fertilizer seeders. Our results directly address the need for more information in the scientific literature regarding the energy performance of cutting tools for seeders, making them highly relevant for agricultural researchers and professionals.

The findings highlight the need for advances in research into cutting discs action on waste. The characteristics and amount of soil residue, combined with direct planting seeder models, can increase fuel consumption by >70 % compared to conventional machines. This highlights the importance of ongoing research and the role of agricultural engineers and professionals in addressing these challenges [21].

## 4. Conclusions

In this study, an innovative device was developed to evaluate the individual performance of seeder-cutting discs. The device allowed the variation of vertical loads applied to each soil-breaking and straw-cutting tool in direct seeders; our main findings were:

a) The device made it possible to verify differences between disc types and soil disturbances.
b) The coulter disc model is crucial in determining soil effects at depth and soil mobilized.
c) The Turbo coulter disc reached the soil's lowest depths.
d) The increased vertical load applied to the coulter discs causes greater soil disturbance and energy demand.


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## Ethical statement

We declare that our research article complied with all relevant ethical guidelines, including approval/consent statements at the study institution. Our research did not involve studies with living subjects – human or animal – exempting ethics committee approval.

This ethics statement also informs that we did not use any artificial intelligence (AI) to compose the work, following institutional/national research ethics principles, as required for ethical research and submission.

## CRediT authorship contribution statement

**Arthur Gabriel Caldas Lopes:** Writing – original draft, Supervision, Software, Resources, Methodology, Investigation, Funding acquisition,

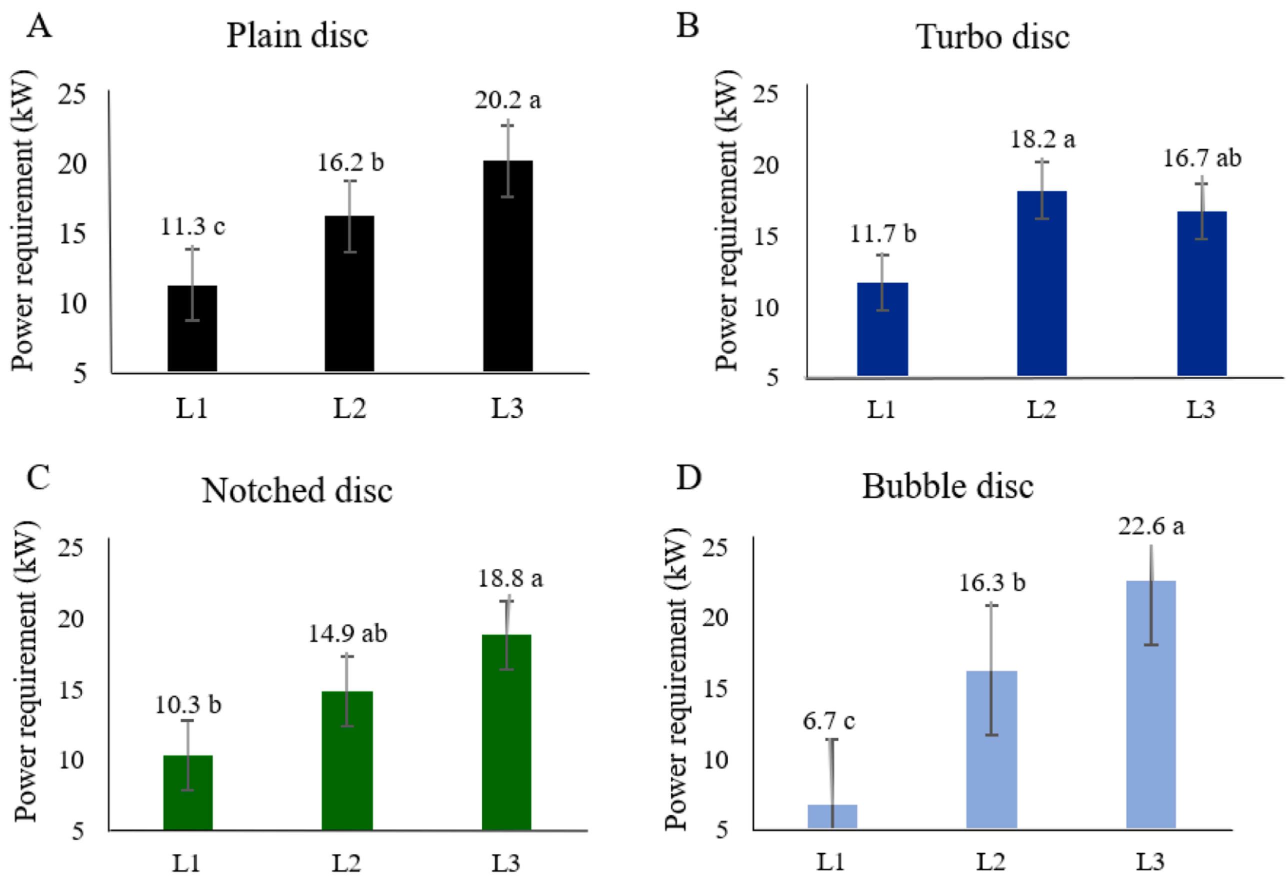


**Fig. 8.** Power demanded for each cutting disc depending on the applied load. Means associated with similar letters do not differ by Tukey test ($P \leq 0.05$).

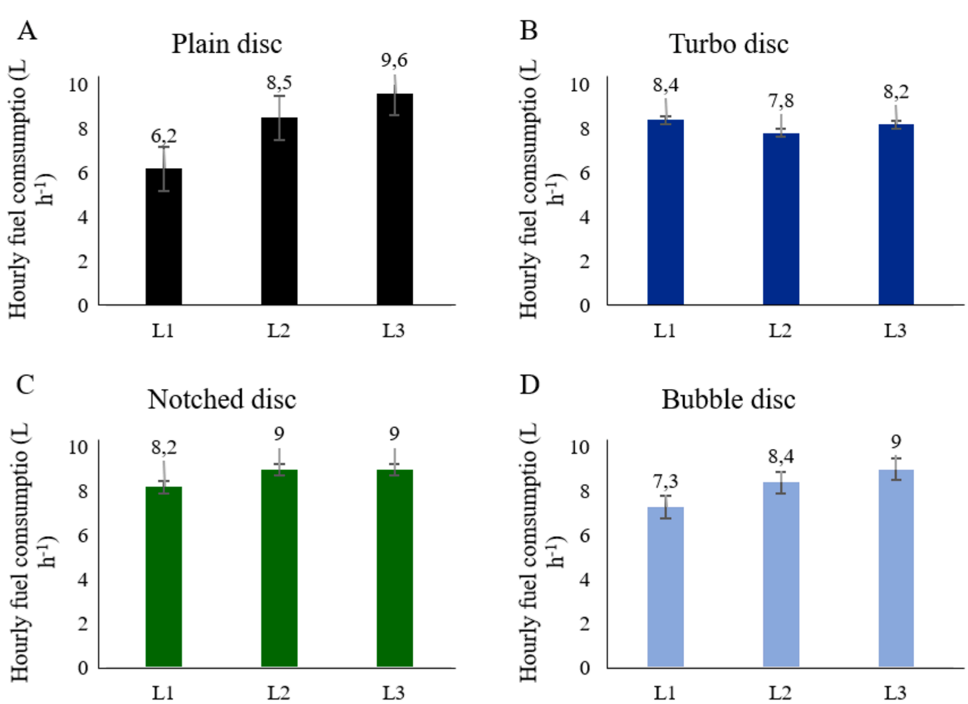


**Fig. 9.** Hourly fuel consumption for different cutting discs on the applied load. Means without associated letters does not differ by Tukey test ($P \leq 0.05$).

Formal analysis, Data curation, Conceptualization. **Aldir Carpes Marques Filho:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **Lucas Santos Santana:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology. **Murilo Battistuzzi Martins:**

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on correspondent author request.

## Data availability

Data will be made available on request.

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