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Soil mobilization in function of sowing speed in maize

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Abstract

The sowing process can be affected by constructive differences related to the seeder, morphological and climatological conditions, and depending on the working speed used. The performance of the furrow opening components of the seeders is essential for obtaining good yields and productivity of maizecrops. This work aims to evaluate maize sowing with a Massey Ferguson tractor model MF 7370 with power of 125 kW pneumatic seeder-fertilizer as a function of its behavior at the different displacement speeds. The statistical design used was randomized blocks, with six displacement speeds, approximately (V1=2.0; V2=4.7; V3=6.5; V4=8.1; V5=10.3 and V6=12.3 km h^{-1}), for the maize crop, with four replications, totaling 24 experimental plots. Soil mobilization parameters were evaluated: furrow width and depth, furrow mobilized area, and furrow opening angle. As agronomic traits were evaluated: the number of days for sowing emergence, initial and final sowing population, and grain yield. The mobilized area, angle, and depth of the furrowing fitted the quadratic regression model, while sulcus width had an increasing linear effect. Intermediate speeds V4 (8.1 km h^{-1}) showed the highest values of the mobilized area and furrow depth and the lowest furrow angle value, whereas V3 (6.5 km h^{-1}) presented the highest yield (8902 kg ha^{-1}).

Keywords: furrow angle, agronomic characters, furrowing rod.
Abbreviations: MA_mobilized area; FA_furrow angle; NDE_number of days to emergence after sowing.

Introduction

The process of sowing or seeding plays a crucial role in achieving high productivity and profitability for farmers. The most important factors related to the performance of seeder fertilizers are efficient cutting of crop residues, furrow opening, and proper placement of seeds and fertilizer at correct depths and in contact with the soil (Francetto et al., 2015).

In addition to this, the use of conservation systems, including no-tillage, has led to changes in the manufacture of seeders used in this production system, making them robust, heavy, and with active soil attack components capable of breaking compacted soil layers caused by heavy machine traffic, requiring tractors with greater power to pull them (Silveira et al., 2013).

The no-tillage system is characterized by disturbance only in the sowing line, maintenance of crop residues from the previous crop, and crop rotation to form a suitable bed for receiving seeds. Seeder fertilizers use furrow-opening mechanisms to promote the formation of furrows and enable the deposition of seeds and fertilizer into the soil at suitable depths for each crop, providing ideal conditions for germination and initial plant development.

Therefore, the sowing process can be affected by variations in equipment design, soil morphological conditions, climatological characteristics, and the working speed employed. According to Ormond et al. (2019), among these parameters affecting sowing, seed metering systems stand out due to their ability to achieve regular seed distribution and working speed, which can influence all the stages carried out by a seeder, including furrow opening for fertilizer and seeds.

The furrow-opening process, which follows the cutting of the straw, can be achieved through double discs or furrow-opening tines. However, Mialhe (2012) highlights that, in no-till seeders, characteristics related to the behavior of furrow opening mechanisms isolated from other components are relatively under-studied.

Using furrow-opening tines for depositing fertilizers instead of double discs has become increasingly popular among farmers. Furrow-opening tines, working at a cutting depth of 80 mm, provide higher field germination percentages, plant populations, and greater seed deposition depth (Souza et al., 2019). The possibility of locally breaking compacted surface soil layers has led farmers to use furrow-opening tines that can reach greater depths, sometimes exceeding 0.20 m (Bertonha et al., 2015).

Thus, the performance of the furrow-opening components of seeders is critical for achieving high yields and productivity in maize crops, a globally important crop with the United States as the largest producer, with 383 million tons, followed by China with 272 million tons (USDA, 2021). In the national scenario, in the 2020/2021 agricultural year, second-crop maize production was estimated to be up to 96.4 million tons (CONAB, 2021).

Studies on the influence of speed on the shape of furrow openings for seed placement still need to be made available. Therefore, the objective of this study was to evaluate the sowing of maize with a pneumatic seeder-fertilizer about its performance at different displacement speeds of the tractor-seeder unit analyzed.

Results and discussion

All evaluated variables presented normality for the analyzed data. For the mobilized soil area, angle, depth and width of the furrow, graphs were constructed to demonstrate and facilitate the discussion of the opening mechanism of the furrow at different analyzed speeds (Figure 1). The mobilized area, angle, and depth of the furrow were adjusted to a quadratic regression model with R^2 of 0.67, 0.71, and 0.78, respectively (Table 1). This indicates that about 70% of the variation in these variables can be explained by the change in speed, while for the width of the furrow (R^2 = 0.92), there was a linear increasing effect.

The mobilized soil area and furrow depth presented similar behavior, with the highest values at V4, approximately 146.87 cm^2 and 13.1 cm, respectively. There was a decrease of 46.30% and 40.8% for these parameters at higher speeds. Speeds higher than V4 indicate a reduction in the depth of furrow opening, resulting in a smaller mobilized area. Silveira et al. (2013) found that at the highest speed analyzed (7 km h^{-1}), there was a shallower furrow depth, which diverged from the results obtained in this study, where a decreasing quadratic effect was observed.

Similar results were found, but the speeds analyzed were lower than those in this study. Trogello et al. (2013) found significant differences in the mobilized area for different vegetation cover management at speeds of 4.5 and 7.0 km h^{-1}. The variation influenced the mobilized area in speed and depth. The results corroborate with Macedo et al. (2016) but differ from those found by Francetto et al. (2015), who did not find a significant effect and influence of speed on the mobilized area.

The adjustment of the sowing depth assumes great importance in achieving the correct initial population of the crop. Therefore, any furrow opening mechanism cannot be limited to a single configuration and must have several depth configurations that best suit the speeds employed and morphological conditions of the soil. Francetto et al. (2015), working with different mechanisms for furrow opening (harrow and disc), observed the influence of the type of furrow opener on the mobilized area. The harrow-type opener provided the greatest movement, with about 126 cm^2. This situation was due to the greater working depth used for the harrow, the differentiated action between the mechanisms for furrow opening, and the differences in the dimensional characteristics of the elements that interfere with the cutting, shearing, and compaction stresses they exert on the soil.

For the width of the furrow, an increase was observed from the lowest speed (V1=2.0 km h^{-1}) to the highest (V6=12.3 km h^{-1}), with the smallest width found is 18 cm for the lowest speed and 21.5 cm for the highest, representing an increase of approximately 16.5%. As shown in Figure 1, the depth of the furrow decreased from V4, while the width continued to increase with increasing speed, resulting in a decrease in the mobilized area. Brandelero et al. (2014) found that the action of furrow opening mechanisms depends on soil moisture and how the crop residue is managed and that differences in the mobilized area were due to greater depths and widths of the furrows.

For the angle of the furrow, the lowest angle (61°) was observed at V4 (8.1 km h^{-1}), with an increase of approximately 31% in angle values for speeds higher than this. This variable represents the soil zone where the seed can settle for subsequent germination and development. As the seeding speed increased, there was less soil mobilization and a larger furrow angle, indicating greater irregularity in the furrow shape.

The average number of days for sowing emergence showed a better fit to a polynomial regression model, with the linear decreasing model being the best fit, with an R^2 of 0.91 (Figure 2). V1 (2 km h^{-1}) had the longest average germination time of around six days, while as the speed increased, the average number of days decreased to 4 days for V6 (12 km h^{-1}). Weirich Neto and Lopes (2012) observed that all plants emerged between 5 and 10 days after sowing and that the shortest average number of days found was due to better soil/seed contact. The average number of days for sowing emergence differed from the results of Santos et al. (2019), who reported that deeper furrows were related to a longer number of days for sowing emergence.

For the initial plant population, the quadratic polynomial regression model best fits the analyzed data (R^2 = 0.75). V3 showed the highest initial plant population, with approximately 47,222 plants ha^{-1}, and there was a decrease of about 13% between V3 to V6 (Figure 3). Cortez et al. (2016) found that the sowing speed influenced the plant population, and the best speed was 5.5 km h^{-1}, which resulted in a quadratic adjustment model in the regression. The maize crop has low plasticity as a characteristic; therefore, maintaining an adequate plant stand is important to maximize crop yield.

For the final population (Figure 4), a similar behavior to that of the initial population was observed, with V3 presenting the highest number of plants per hectare (46666) and V6 the lowest final population with approximately 40000 plants ha^{-1}, representing a decrease of approximately 14.5% from V3 to V6. The survival rate of the initial population to the final population varied from around 4% for all analyzed speeds.

The productivity presented a polynomial regression model. The best fit was obtained with a quadratic function with an R^2 value of 0.83, indicating that approximately 83% of the existing variation is related to the employed speed. The V3 speed showed the highest productivity, around 8902 kg ha^{-1}, and as the speed increased, there was a decrease in productivity of about 29% (Figure 5). Similar results were

Table 1: Adjusted regression models for opening mechanism of the furrow in function of sowing speed.

MA = $-1.577x^2 + 20.323x + 72.018$ $R^2 = 0.67$ F=9.17**	FA = $0.536x^2 - 6.086x + 80.6$ $R^2 = 0.71$ F=10.79**
Width = $0.364x + 17.367$ $R^2 = 0.92$ F=24.96**	Depth = $-0.114x^2 + 1.337x + 8.757$ $R^2 = 0.78$ F=15.81**

MA: mobilized area; FA: furrow angle

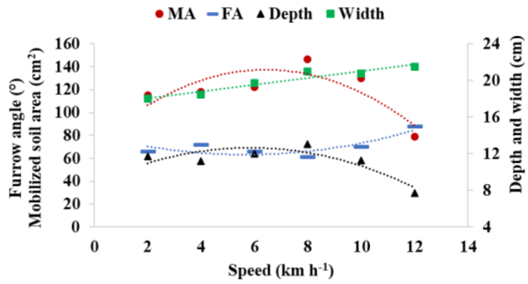

Figure 1. Opening mechanism of the furrow in function of sowing speed. Mobilized soil area (MA); Furrow angle (FA).

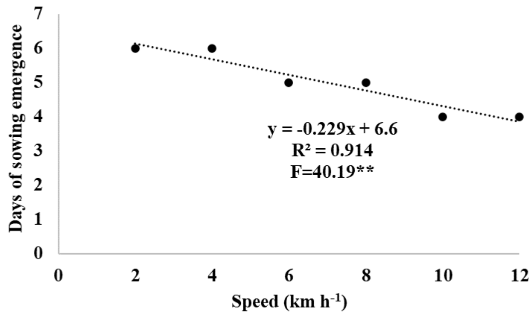

Figure 2. Days to emergence maize in function of sowing speed.

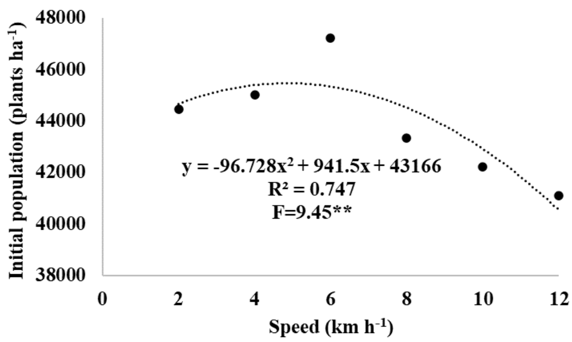

Figure 3. Initial plant population in function of sowing speed.

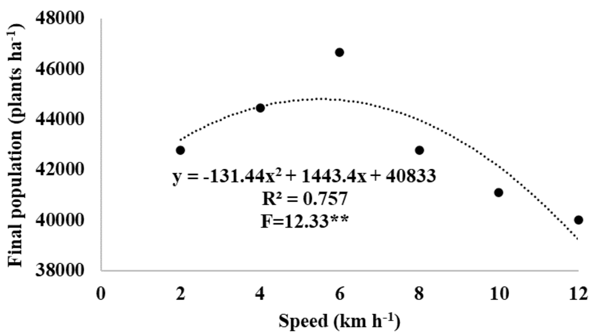

Figure 4. Final plant population in function of sowing speed.

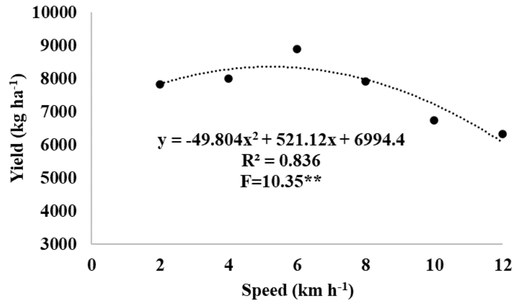

Figure 5. Maize yield in function of sowing speed.

found by Cortez et al. (2016) when evaluating soybean, who observed that speeds within the working range (5 to 7 km h^{-1}) favor higher yields, improving the number of pods per plant and not affecting the plant population. The increase in the furrows' depth caused by the planters' furrow opener to break down locally compacted layers on the surface is a way to stimulate root development and reduce the effects of soil compaction on maize yield (Müller et al., 2019). On the other hand, Modolo et al. (2019) reported that the disc-type furrow opener provided a 2.69% increase in grain mass compared to the blade-type furrow opener. The agronomic characteristics of the plant population and the mobilized soil area showed a similar behavior (quadratic effect) with intermediate speeds resulting in the best parameters, which also reflected in grain productivity. This fact can be explained by the greater soil disaggregation, improving conditions for proper seed germination, and adequate exposure to light, temperature, and humidity.

Material and methods

Experiment location and soil properties

The experiment was conducted in an area located around the geodetic coordinates of 21°14'54" S and 48°16'51" W, with an average altitude of 568 m and an average slope of 4%. During the evaluated period, the total precipitation was 567.2 mm. The average maximum temperature during the period was 28.84°C, ranging from 25.92°C to 30.54°C, and the average minimum temperature was 19.02°C, ranging from 15.54°C to 23.06°C. The average relative humidity was 80.38%, ranging from 70.54% to 87.76%. The data were collected from the nearest meteorological station. The physical characterization of the soil was carried out by field samples taken at a depth of 0 to 0.10 m. The soil moisture content was around 22% at the time of sowing. The results of the soil granulometric analysis showed 48% clay, 23% sand, and 29% silt. The soil in the area was classified as a typical Eutrophic Red Latosol, with moderate A horizon, clayey texture, and smooth undulating relief. The maize crop (*Zea mays* L.) was implanted in an area with 12 years of no-tillage system. The presence of maize straw and weeds was observed, and approximately 247 g m^{-2} of dry matter was found on the soil surface using the oven method.

Plant materials

The simple hybrid 30F35YH was sown according to the characteristics of the region and sowing periods. Mineral fertilization was applied in the sowing furrow with a commercial formula (08-28-16) at a rate of 350 kg ha^{-1} based on soil analysis carried out in the area.

Description of machine and seeder

A Massey Ferguson tractor model MF 7370 with a power of 125 kW (170 hp) and a rotation of 2000 rpm was used to pull a Jumil model 3070 Exacta Air pneumatic prototype seeder with a spacing of 0.90 m. The seeder was configured with a smooth cutting disc of 17", a furrow opening mechanism, fertilizer deposition of the hoe type, double offset discs of 14" for dosing and seed deposition, respectively, and double V-shaped compactor-terracing wheels. The dosers were made up of 28-hole discs, aluminum distributors, plastic discs, and a chassis for heavier seeders. This seeder was configured with a smooth cutting disk of 17", a mechanism for opening the furrow and depositing fertilizer of the sulcus type, double unpaired disks of 14" for seed dosing and deposition, respectively, double compacting-terracing wheels in a "V" shape. The dosers were made up of 28-hole discs, aluminum distributors and plastic discs, and a chassis for heavier seeders.

Treatments and experimental design

The statistical design used was randomized blocks with six displacement speeds (V1=2.0; V2=4.7; V3=6.5; V4=8.1; V5=10.3 and V6=12.3 km h^{-1}) for the maize crop with four replications, totaling 24 experimental plots. The speeds were selected according to the gear ratio achieved by the tractor-seeder set. Three speeds above and three below the usual sowing speed were evaluated. The plots were 11 x 10 m for the evaluation of the mechanized set, and 5 m of the plot's two central rows (4.5 m²) were used.

Traits measured and Statistical analysis

To evaluate the variables of furrow soil mobilization, the furrow was manually opened until the compacted layer was located, and the furrow was modeled. The following were evaluated: furrow width and depth, mobilized area of the furrow, and furrow opening angle. These evaluations were carried out with the help of a profilometer consisting of 45 rods spaced 1 cm apart and with a maximum height of 30 cm. At the back of the profile meter, a horizontal line frame with a spacing of 0.5 cm was placed to facilitate the reading, which was analyzed by photographic images. The position of the rods' upper end copies the furrow's geometric shape, and readings can then be taken. The width was defined from the first to the last rod, which presented different measurements when they fell on the soil. The maximum depth was defined as the average of the three rods that presented the highest measurement. Mobilized area of the furrow: after the photographic images were read, the data was entered into an electronic spreadsheet of the Microsoft Excel® program, in which the area of the transverse section of soil mobilized by the sulcus type opener was obtained in cm2, resulting from the integral of the trapezoidal rule (Equation 1) proposed by Gomes-Ruggiero and Lopes (1996).

∫f (x) =h2 {f(x0)+2[f(x1)+f(x2)+...+f(xm-1)]+f(xm)}   (1)
where,

∫ = numerical integral for the mobilized area of the soil,
h = distance between the rods of the profile meter (1 cm),
x = value of the readings of the rods (cm).

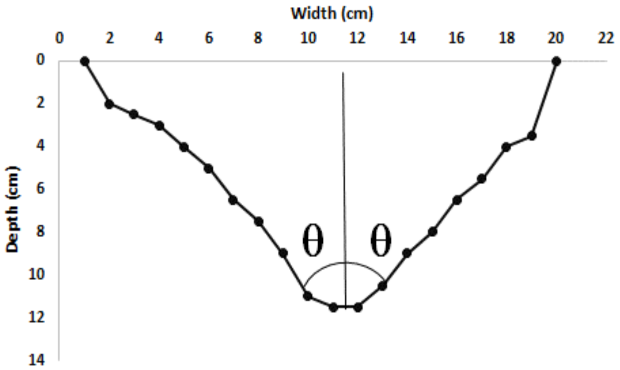

Figure 6. Composition of the furrow angle. Two angles considering the center of the furrow, the right and left angles. These two angles were added together to compose the angle of the furrow.

Furrow opening angle: to evaluate the angles of the furrow (right and left), the same images evaluated for the mobilized area of the soil were used. To find the furrow opening angle, it is first necessary to know that there are two angles considering the center of the furrow (Figure 6), that is, the right and left angles. Observing the images of the profile meter and taking as a basis the highest value of furrow depth (center of the furrow), the distance between the highest depth value and the (imaginary) point on the angle line is calculated. Next, the height value is found between the maximum depth point and the point where the imaginary line of the angle touches the tip of the rod. This forms a triangle below the angle. Using this triangle, it is possible to divide the opposite cathetus (a) by the adjacent cathetus (b), finding the tangent (α) and converting it to degrees. The angle (θ) is calculated as 90º minus the arctangent (in degrees) calculated. This method was created based on the proposal by Spoor and Godwin (1978), in which they suggest that the planting furrow should present two 45º angles, considering it ideal for crop implementation. Based on this premise, these two angles were added together to compose the angle of the furrow.
Agronomic characteristics evaluated: Average number of days to emergence: it was determined by daily counts from the first emerged sowing until the count stabilized, within ten meters of the two central rows, five meters on each row, in all plots, calculated according to the formula suggested by Edmond and Drapala (1958) (Equation 2):

$$NDE = \frac{\sum_{i=1}^{n} N_i G_i}{\sum_{i=1}^{n} G_i} \qquad (2)$$

where,
NDE = average number of days to emergence of sowings;
Ni = number of days elapsed between sowing and count i;
Gi = number of emerged sowings between counts i and (i-1).

Initial and final plant population: for these evaluations, the number of plants in the useful area of the plot was counted;

Yield: for this evaluation, ears were collected from each plot's useful area and threshed with a mechanical thresher's aid. The grains were separated and weighed, and the values were corrected to a moisture base of 13% and extrapolated to kg ha^{-1}. The data were subjected to the Anderson-Darling test, demonstrating that they presented normal behavior. Afterward, the results were subjected to analysis of variance by the F-test ($p < 0.05$), and when significant, mean comparison was performed by the Tukey test, at 5% probability and subjected to regression analysis to verify the behavior of the characteristics as a function of the sowing speeds, with the help of the statistical program AgroEstat (Barbosa and Maldonado, 2014).

Conclusions

The results obtained in this study showed that the intermediate speed V4 (8.1 km h^{-1}) presented the highest values for both the mobilized area and the depth of the furrow, as well as the lowest value for the furrow angle. These findings suggest that this intermediate speed may be more suitable for optimizing the planting process. It allows for greater soil mobilization and deeper furrow formation while maintaining a suitable angle for seed accommodation.
In addition, the V3 speed (6.5 km h^{-1}) showed the best agronomic characteristics, with higher plant populations and higher productivity. These results suggest that this speed may be optimal for achieving higher crop yields. However, it is important to note that other factors, such as soil moisture and texture, may also influence the performance of different planting speeds. Overall, the speed employed during planting significantly impacts the opening and conformation of the furrow for seed accommodation, as well as other agronomic parameters such as plant populations and yield. These findings highlight the importance of carefully selecting the appropriate planting speed to optimize crop performance and productivity.

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