ANALYZING THE EFFORTS IN FURROW OPENERS USED IN LOW POWER PLANTERS

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ABSTRACT: The furrow openers for no-till system should be easy to penetrate the soil, generate low levels of soil mobilization and require a little traction force. Thus, the aim of this research was to compare six hoe-type furrow openers, four of industrial manufacturing and two handcrafted models, which were used in planters in the region of Pelotas, Brazil. The parameters for comparison among these furrow openers were the horizontal (F_h) and vertical (F_v) forces acting on the tip of the hoe and the cross-sectional area mobilized in the furrow. The experimental design was randomized, with six treatments (furrow openers) from T1 to T6, with four repetitions, constituted by their passage through plots of 20 x 3 m. The force data were collected by load cells and a signal conditioner. The determination of the mobilized area in the furrow was done by a micro soil profilometer. It was concluded that the furrow openers T1, T4 and T6 presented the lowest values of horizontal force (statistically equal and ranging between 1,034 and 1,230 N) and that T1 and T2 produced the highest vertical forces downwards (statistically identical and varying between 749 and 845 N). The furrow openers T1, T2, T4, T5 and T6 generated soil mobilization statistically equal and between 0.006993 and 0.008933 m^2.

KEYWORDS: hoe opener, traction demand, no-tillage.

ANÁLISE DOS ESFORÇOS EM SULCADORES EMPREGADOS EM SEMEADORAS--ADUBADORAS DE BAIXA POTÊNCIA

RESUMO: Os sulcadores de semeadoras de plantio direto devem ter facilidade de penetração no solo, gerar baixa mobilização de solo e demandar pequena força de tração. Nesse sentido, o presente trabalho objetivou comparar seis modelos de sulcadores tipo facão, quatro de fabricação industrial e dois artesanais, todos utilizados em semeadoras adubadoras na região de Pelotas - RS. Os parâmetros para comparação entre os sulcadores foram as forças horizontal (F_h) e vertical (F_v) atuantes no sulcador e a área de secção transversal mobilizada no sulco. O delineamento experimental utilizado foi o inteiramente casualizado, composto por seis tratamentos (sulcadores) de T1 a T6, com quatro repetições, constituídas pela passagem do conjunto por parcelas de 20 x 3 m. Os dados de força foram coletados por meio de células de carga e condicionador de sinais. A determinação da área de solo mobilizada deu-se por meio da utilização de um microperfilômetro. Concluiu-se que os sulcadores de T1, T4 e T6 apresentaram os menores valores de força horizontal (estatisticamente iguais e variando entre 1.034 e 1.230 N) e que T1 e T2 produziram as maiores forças verticais para baixo (estatisticamente iguais e variando entre 749 e 845 N). Os sulcadores T1, T2, T4, T5 e T6 geraram mobililizações de solo estatiscamente iguais entre 0,006993 e 0,008933 m^2.

PALAVRAS-CHAVE: sulcador de haste, demanda de tração, plantio direto.

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INTRODUCTION

In a planter for no-tillage system, furrow openers elements are the most important components regarding the proper furrow opening aiming at the deposition of seed and fertilizer, but the furrow openers are also the mechanisms that consume the largest share of energy necessary to carry out the sowing operation.

Generally, the hoe-type furrow openers are preceded by a smooth coulter. According to GERMINO & BENEZ (2006) the presence of the disc did not aggregate values for vertical or horizontal force neither in the furrow openers tested to a depth of 0.12 m, with a significant effect only in the depth of 0.33 m.

The planters produced to meet the needs of family farming are generally of low cost, lightweight and pulled by animals or low-power tractors. Even with these features, they should open the furrow with the same quality and performance of larger planters used in large areas.

Evaluating sixty models of hoe-type furrow openers, ARAÚJO (2009) concluded that for medium textured soils with clay, the best results in terms of traction demand and soil mobilization the following characteristics were obtained with a furrow: rake angle of 20°, the hoe width of 20 mm and the hoe thickness of 13 mm. However, due to the large number of factors that influence the energy performance of motomechanized sets such as tractor/planter and the complexity of their interactions, there is a need of specific studies in order to identify the energy demands of the various components and mechanisms of action (BORTOLOTTO et al. 2006).

MAMMAN & ONI (2005) by studying the influence of various parameters on the tractive effort required for work tools on the ground in soil bin, have concluded that in the range between 5 and 20°, increases in the rake angle is directly proportional to the horizontal force measurement . Similar results are described by GODWIN (2007), for which both the horizontal and the vertical force increases to variations in the rake angle between 22.5 and 67.5°. The author adds that for narrow hoe traction force increases in proportion to the width.

The basic geometrical parameters to guide the study of the forces acting on the hoe set are presented, among others, by MACHADO (1992). The key parameters are identified in Figure 1.

From the point of view of the environment, the soil and the vegetation cover, there are several factors that affect the demand for power required by a hoe-type furrow opener. Among those cited are: soil texture, soil water content, apparent density, vegetation cover and soil penetration resistance (BORTOLOTTO et al., 2006; CONTE et al., 2007; ARAÚJO, 2009).

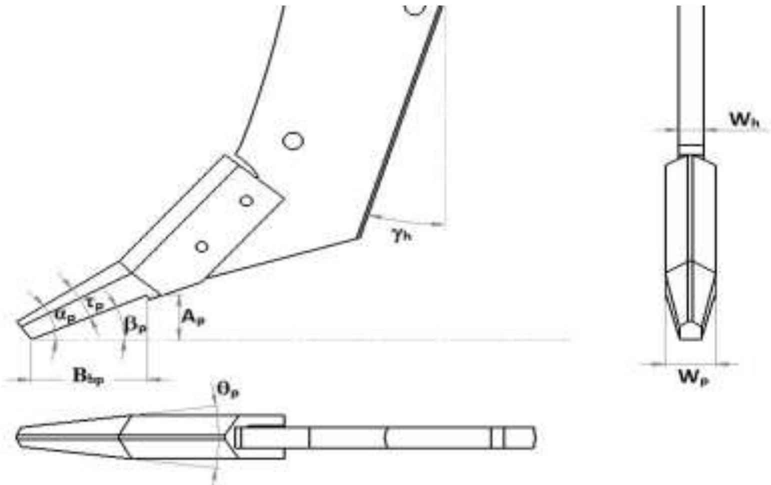

FIGURE 1. Basic geometric parameters of a hoe opener set, where W_p - maximum hoe thickness; θ_p - point angle; β_p - suction angle; τ_p - shank penetration angle; α_p –rack angle; W_h - shank thickness; B_{bp} - hoe bottom base length; A_p – free hoe height and; γ_h - hoe inclination angle.

Although there are a large number of studies searching for determining the geometric parameters that maximize the performance of all hoe openers for planters for no-tillage, no one can say that the design of these sets, regardless of the technological level of the manufacturer, use the parameters identified as ideal. A large discrepancy has also been noticed between the survey data and those published by planter manufacturers regarding to the traction demand, as verified by MACHADO et al. (2007). According to these authors, the values of the draft reported by manufacturers are up to 172% higher on average than those established by research. Likewise, there are planters with seeding line configurations very similar but with distinct tractor power. It is believed that these events can be partly explained by the actual arrangement of the hoe set in the machine sowing row during operation, which may differ from the geometrical parameters recognized as ideal.

Therefore, the aim of this study was to identify, through field trial among a few hoe openers models of no-till planters, which are the best for low power machines in terms of efforts demand (horizontal and vertical).

MATERIAL AND METHODS

The experiment was conducted in a flat area owned by EMBRAPA in Capão do Leão - RS, Brazil, at coordinates 31 º 49 '1.8" south latitude and 52 º 27' 58.3" west longitude and altitude of 17 m, which had been fallow for two years. The soil mapping unit belongs to Pelotas, called Hydromorphic Planosol (Albaqualf), with a density of 1.66 kg dm^{-3} and having the following particle size distribution: 0.444 kg kg^{-1} of sand, 0.301 kg kg^{-1} of silt and 0.255 kg kg^{-1} of clay. It was used rectangular plots measuring 3 x 20 m.

The treatments consist of six sets of rod and their hoes, selected from among the models of planters available in Pelotas - RS, managing to include not only models from manufacturers with high technological level, but also those who produce their models in an almost artisanal way. Figure 2 shows the six sets of rod and hoes that form the treatments and in Table 1 the values of the basic geometric parameters of each ones as described in Figure 1.

The sets 1; 2 and 5 are used in low-power planters produced by traditional companies in the sector, the T4 set is manufactured by a new medium-sized company, working over 15 years, and the treatments 3 and 6 are made by small businesses to attend manufacturing machinery needs or to replace parts from other manufacturers.

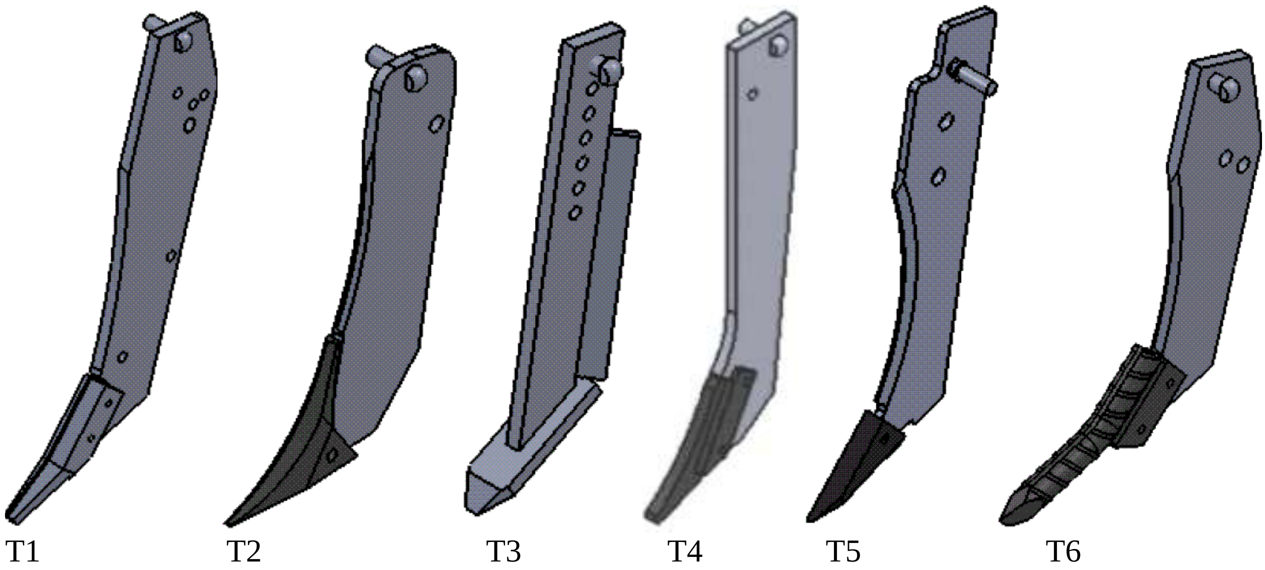

FIGURE 2. Perspective view of the hoe-type sets tested, with T1, T2, T4 and T5 being produced industrially and the others handcrafted.

TABLE 1. Basic geometric parameters of hoe furrow openers' sets.

Parameters	T1	T2	T3	T4	T5	T6
Maximum hoe thickness (W_p) - mm	26.2	25.0	38.0	23.7	20.0	26.8
Point angle (θ_p)	14.0°	16.0°	49.0°	90.0°	73.0°	35.0°
Hoe suction angle (β_p)	29.0°	11.0°	27.0°	21.0°	12.0º	21.0º
Shank Penetration angle (τ_p)	10.0º	24.0º	30.0º	24.0º	35.0º	10.2º
Hoe rake angle (α_p)	39.0º	35.0º	57.0º	45.0º	47.0º	31.2º
Hoe front area - mm^2	2,751.5	2,403.9	4,525.2	2,431.4	1,880.9	2,832.7
Shank thickness (W_h) - mm	12.8	10.0	12.5	13.0	10.0	12.8
Hoe inclination angle (γ_h)	12.0º	2.5º	10.0º	0.0º	10.0º	12.0º
Free Hoe height (A_p)	30.2	23.0	56.3	19.1	25.4	n.a.
Hoe bottom base length (B_{bp})	63.0	121.0	125.0	53.0	121.0	n.a.

Key: n.a. - not available.

The geometrical parameters were obtained in two ways: by direct measurement on the seeder with the help of a square, plumb line and protractor (T3, T4, T5, T6), with the hoe simulating the desired working depth (0.12 m) or provided by the manufacturer also having the working depth of 0.12 m (T1 and T2), because for these sets, a new or used machine could not be found in Pelotas - RS, to perform the direct measurement.

As the research includes low-power planter for no-tillage system, it was used a smooth coulter for cutting the vegetation cover mounted ahead of the furrow opener, trying to avoid the accumulation of plant material during the essays and simulating the real work situation in the field. The smooth coulter used in this essay had a diameter of 420.0 mm, thickness of 4.3 mm and sharpening angle of 6°.

It was used a completely randomized design for the experiment. For each treatment, four repetitions were made, which consisted in the passage of the tool by the 20 m of the plot. Both the order of the experiment execution and the repetitions description of the plots were previously assorted.

The data collected in the field were classified as direct and indirect response variables and control response variables. The direct response variables are: horizontal traction force on the hoe (N); vertical force on the hoe (N); cross section area of mobilized soil (m^2). The indirect response variables determined from the results obtained in the direct variable is the specific traction force (kN m^{-2}). The control variables are: working depth (m), soil water content (%), cone index (kPa), dry mass of vegetation (kg ha^{-1}).

Statistical analysis, as to response variables as to control variables, was done by mean calculation and coefficients of variation and was also done analysis of variance among treatments to determine the F value at a significance level of 5%. When the analysis of variance showed differences among treatments, the means were compared using the Tukey test also at a significance level of 5%.

To measure vertical and horizontal forces induced by the tool on its displacement in the soil was used the device developed by ESPÍRITO SANTO et al. (2010). To enable the assembly of the different rods in the device, it was necessary to split each one in two parts. One of which is permanently assembled on the device and the other where is fixed the hoe, is screwed to the first by a flange (Figure 3). The joining has been designed so to not interfere with the operation of the set in test. The arrangement allows the fast exchange of the hoe set to the essays realization, enabling the execution of the entire experiment in one day.

FIGURE 3. Force measuring device assembled in the row with the hoes attachment detail.

The acquisition of the signals of the forces acting on the hoe of the furrow openers that comprise the treatments was carried out using an apparatus of signals collector of the brand LYNX Electronic Technology, consisting of A/D converter with 16-bits and 16 input channels configurable by software, operating with a signal sampling frequency of 50 Hz per channel and a computer. These and other auxiliary equipment are coupled to a tool bar frame (Figure 4) assembled on a Ford tractor model 4600, with an output of 46.3 kW and weight of 24.5 kN. The essay was conducted with the tractor operating at reduced first gear, with engine in 1,000 rpm and speed of 1.1 km h^{-1}.

To keep the working depth and to adjust the inclination angle for each hoe were installed in the row a system of threaded extension arm (angle control) and depth gauge wheels near the furrow opener, as shown in Figure 4. The depth and the angle of inclination of the hoes were regulated before the beginning of each treatment, to such a template has been previously developed which allowed the fast adjustment in the field.

FIGURE 4. Tool bar frame with force measuring device and hoe set, where: (A) regulatory arm of the inclination of the hoe, and (B) wheel depth control.

The cross section of tilled soil was measured by a micro profilometer. The equipment consists of 96 brass hoes of 1.7 mm of diameter distributed equidistantly from one another by 4.0 mm (center to center). Its measurement capability in width mobilized profile is of 0.383 m and to until 0.39 m of deep. For the reading of the mobilized profile to be done, a sheet of graph paper was placed behind the sticks. In each plot two determinations were made positioned randomly, totaling eight samples of soil profile by treatment.

The working depth was verified by a ruler for measuring tractor tire lug, which acts similarly to a depth caliper consisting of two parts, a graduated scale in mm and a bracket that rests horizontally over the surface. Five determinations were made per plot (one every 4 m, with manual removal of the soil until it found the bottom of the furrow), totaling 20 samples per treatment.

To determine the characteristics of the soil, samples were collected at a depth of 0.0 m to 0.12 m, and one sample per plot for determination of particle size, water content and density.

The cone index was determined by taking the penetration resistance at each point in the range from 0.0 to 0.20 m, using a portable electronic penetrograph Falker ® brand, model PLG 1020 with cone of 12.83 mm in diameter and records every 0.01 m. Throughout each plot, three points have been established for determining the soil resistance to penetration, and made five determinations per point. A place in the center of the plot of 20 m and two other distant 5 m either side. From the penetration resistance values obtained at each point in the depth range, it was calculated the cone index in the range of 0 to 0.12 m.

It was used a wooden frame in the dimensions 0.5 x 0.5 m, to limit the vegetation collection area, which was completely removed with grass shears. The samples were dried at 65 °C to constant weight. The frame was released randomly to the ground in two positions of each parcel, totaling eight samples per treatment.

RESULTS AND DISCUSSION

The analysis of variance of the control variables soil water content and cone index showed that, at a significance level of 5%, there were no differences between the mean values in these treatments within the experimental area. Therefore, mean values of these parameters were: water content in the soil of 13.3%; cone index of 1,077 kPa between 0 and 0.12 m deep.

The average amount of dry plant cover per treatment in the test area, are shown in Table 2. Analysis of variance showed difference between treatments, with the highest amount of average mass (2,645.1 kg ha^{-1}) is observed in the plots of T3, which differs statistically from T1 and T5. The lowest amount of dry mass is observed in areas where T1 was tested (1,901.7 kg ha^{-1}), which is statistically equal to T2, T4 and T5. The analysis of these differences together with the data of forces, presented below, did not allowed to identify any interaction between them.

TABLE 2. Mean values of dry mass of vegetation for each treatment.

	Treatments					
Results	T1	T2	T3	T4	T5	T6
Average(kg ha^{-1})	1,901.7 a	2,188.5 ab	2,645.1 b	2,125.5 ab	1,709.4 a	2,420.8 b
C. V. (%)	7.3	15.8	9.6	6.8	16.6	18.5

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test.

The analysis of variance of the operation depth means of the rod-hoes set showed a significant difference between treatments (Table 3). However, it is noteworthy that the least significant difference (lsd), in 5% probability by Tukey test, was only 0.009 m (7.5% for the adjusted depth in the essay rig), which is a small difference when considering the operation of furrow openers. The possible effects of these differences on the mean forces are discussed below.

TABLE 3. Mean values of furrow depth (m) for each treatment.

Parameter	Treatment					
	T1	T2	T3	T4	T5	T6
Mean (m)	0.115 b	0.125 a	0.125 a	0.117 b	0.113 b	0.112 b
C.V. (%)	6.1	4.0	2.9	2.1	1.2	6.4

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test.

The analysis of variance of the variable mobilized soil area showed that the treatment means differ from a significance level of 5%. Table 4 shows the results with the respective statistical analysis.

The largest mobilization of soil occurred with the set T3, differing significantly from the other treatments. The width of the T3 hoe, as well as its shape, unlike the others, may explain the higher average.

TABLE 4. Mean values of mobilized area for each treatment, in m^2.

Repetitions	Treatments					
	T1	T2	T3	T4	T5	T6
1	0.007638	0.006270	0.011031	*	0.009203	0.010982
2	**	0.007939	0.011564	0.008209	0.007139	0.008064
3	0.007671	0.008367	0.013543	0.009958	0.007915	0.007276
4	0.005670	0.006554	0.011947	0.007049	0.008539	0.009408
Mean (m^2)	0.006993a	0.007282a	0.012021b	0.008405a	0.008199a	0.008933 a
C.V. (%)	16.4	14.1	9.0	17.4	10.7	1.2

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test. * - Lost plot due to the presence of a strange object on the hoe. **- Lost plot.

The average results of the horizontal traction force acting on the hoe (F_h) of the furrow openers set are shown in Table 5 along with the results of analysis of variance. As can be seen, the differences between the means of the horizontal force (F_h) are distributed among treatments, with the lowest values being observed in T6, T4 and T1 and T2 and T3 the largest. The largest absolute value of F_h was measured in T3 (1,755 N), which corresponds to an increase of 69.7% compared to the force measured in T6 (1,034 N), which was the lowest average in numerical terms. This difference, in addition to being statistically significant, may influence the functioning of the planters intended for low-power tractors, which are limited in their ability to exert traction force and also drawbar power.

TABLE 5. Mean values of F_h for each treatment, N.

Repetitions	Treatment					
	T1	T2	T3	T4	T5	T6
1	1.067	1.620	1.862	*	1.189	943
2	1.378	1.530	1.607	1.346	1.238	1.064
3	1.155	1.514	1.701	1.089	1,322	1.082
4	1.318	1.452	1.850	1.173	1.569	1.049
Mean (N)	1.230 ab	1.529 cd	1.755 d	1.203 ab	1.329 bc	1.034 a
C.V. (%)	11.7	4.6	7.0	10.9	12.7	6.0

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test. * - Ditto.

Among all treatments, the rake angle of T6, which is the closest to the value considered ideal, according to CASÃO JÚNIORR & SIQUEIRA (2004), where the furrow opener whose rake angle (α_p) was 30.0º and the hoe thickness of 20.0 mm demanded the second lowest value of horizontal force (F_h), this being of 1,627 N. The same authors obtained a horizontal force value 186 N lower, using a furrow opener whose hoe has a α_p = 20.0° and 15.0 mm thickness, the rake angle of the furrower the lower average value of F_h, 33.3% smaller.

Although the results do not cause surprise, it is curious that the project with parameters so close to technically prescribed has been developed by a family company without a technical staff with academic background. On the other hand, T2, produced by a company technologically far superior, with engineering department, presented the highest values of F_h. It is believed that, in this case, the design presents hoe problems of assembly in the planter, as analyzing separately the hoe has optimized geometry, but when in the working position to operate in 0.12 m depth, the α_p value is 75% above what is described as ideal by CASÃO JUNIOR & SIQUEIRA (2004).

In general, the results obtained are below the values found by MACHADO et al. (2007) in researches of tractive effort in planters in Brazil (tractive effort of 2,680 N per line). However, we must consider that these studies were done with a full planter in several soils and the data from this study consider only the hoe set.

Searching for better interpretation of the results, analyzes were conducted taking into account the effect of the rake angle of the hoe (α_p) on F_h and the variations of the operation depth and specific traction force.

The horizontal force measured was directly proportional to the rake angle of the hoe as it can be seen in Figure 5. The linear regression analysis between these two factors was significant at 5% level of probability. Both the adjusted equation as the coefficient of determination (R^2) are shown in Figure 5, excluding the values related to T2 (α_p = 35°), which had values that did not fit with the other data. The R^2 shows a strong correlation between the variables.

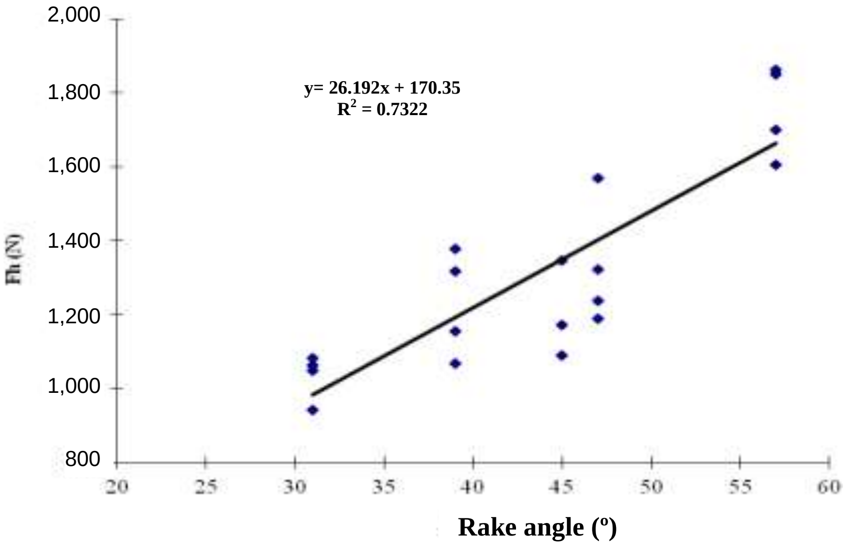

FIGURE 5. Linear regression analysis between the rack angle and the horizontal force at the hoe.

Comparing the values of F_h and the furrow depth in each treatment, we note that as the depth increases, the strength also increases regardless of the treatment. The linear regression analysis between these two factors was significant at 5% level of probability, although the coefficient of determination (R^2) is considered moderate. The graphical result of this analysis with linear equation adjusted and R^2, is shown in Figure 6.

Using the adjusted equation shown in Figure 6, it is found that F_h increases 556 N every cm (8.3% of difference compared to the adjusted - 0.12 m) of increase in the furrow depth under the conditions of this experiment. Thus, it can be said that part of the observed differences in the horizontal force are due to small variations in the working depth of the sets.

Analysis of variance of the specific traction force means showed that there are significant differences at 5% level of probability among the treatments (Table 6). The least significant difference was 71.5 kN m^{-2}. The lowest value was 119.4 kN m^{-2} for T6 and the largest of 213.4 kN m^{-2} for T2. The T2 furrow opener differs statistically from the T6, which in turn is statistically equal to the T1, T3, T4 and T5 planters.

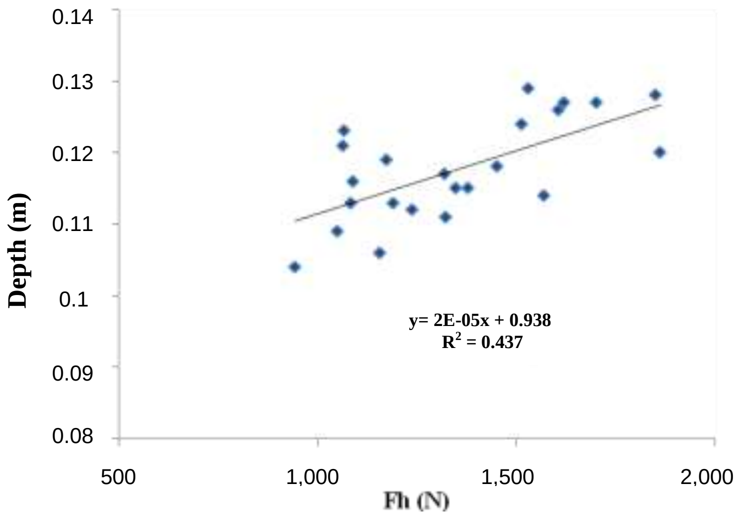

FIGURE 6. Linear regression analysis between the depth of the furrow and the horizontal force at the hoe.

TABLE 6. Mean values of specific force for each treatment in kN m^{-2}.

Repetitions	Treatment					
	T1	T2	T3	T4	T5	T6
R1	139.7	258.4	168.8	*	129.3	85.9
R2	*	192.7	139.0	164.0	173.4	131.4
R3	150.6	180.9	125.6	109.4	167.0	148.7
R4	232.5	221.5	154.9	166.4	183.7	111.5
Mean (kN m^{-2})	174.3 ab	213.4 b	147.1 ab	146.6 ab	163.4ab	119.4 a
C.V. (%)	29.0	16.2	12.8	22.0	14.5	22.6

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test. * - Lost plot.

The average results of the vertical force acting on the hoe (F_v) of the furrow opener sets, are shown in Table 7 along with the results of analysis of variance, which indicated that the treatment means differ for the significance level of 5%.

TABLE 7. Mean values of F_v for each treatment, N.

Repetitions	Treatments					
	T1	T2	T3	T4	T5	T6
1	655	814	763	*	494	443
2	854	869	607	613	516	518
3	729	815	636	632	533	514
4	758	879	635	738	677	433
Mean (N)	749 cd	845 d	660 bc	661 bc	555 ab	477 a
C. V. (%)	11.0	4.1	10.6	10.2	14.9	9.5

Means followed by the same letter do not differ from the significance level of 5%, by Tukey test. * - Ditto.

As it can be seen in Table 7, the differences between the average vertical force (F_v) are distributed among treatments, and the lowest values were observed in T5 and T6 and the highest in

T1 and T2. The largest mean value observed, T2 (845 N) is 77.1% higher than the average of T6 (477 N). In the same way as for the horizontal force, the magnitude of F_v can influence the operation of the planters intended for low-power tractors, since there are limitations such as the lift capacity of the hydraulic system, the planters should be light. Thus, the ability to open the furrow for fertilization and/or seeding will depend upon the downward vertical force exerted by the ground on the hoe. Thus, the greater the vertical force acting, lighter might be the planter. Therefore, the same T6 set that showed the lowest horizontal force, which is desirable also generated less vertical force, which in turn compromises the ability of penetration into the soil. Considering these two forces, T1 and T4 may be more advantageous, since they present F_h statistically equal to T6 and also the highest level of F_v.

It was not possible to correlate the F_v of the treatments with the geometric parameters of the sets (rack angle, suction angle, width and areas of the frontal and vertical projections of the hoes). Although the analysis of variance of the linear regression between the data of furrow depth and F_v might have been significant at 5% level of probability, the determination coefficient was only 0.238. Nevertheless there was a trend of increasing vertical force with increase of the working depth; the adjusted equation explains a very small portion of the data. GOODWIN (2007) in his study of summarization of the results of the research in this field makes it clear that this force increases in the same way that the horizontal force when the depth increases, however in a magnitude much smaller, since in this case the predominant influence of the rake angle is greater.

CONCLUSIONS

The furrow openers from treatments one, four and six were those with the lowest values of horizontal force (ranging between 1,034 and 1,230 N), being these results statistically equal among them.

The furrow openers from treatments one and two showed the highest values of vertical force down (ranging between 749 and 845 N), being these results statistically equal among them.

The furrow opener from treatment one presented simultaneously, the lower horizontal force and the highest vertical force, which are desirable features for the use in low power planters.

The results regarding to the demand of horizontal force, vertical force and mobilized area, shown to be independent of the level of technology from the manufacturers of the hoes sets tested.

Variations in the order of 7.5% around the adjusted working depth cause significant differences in the horizontal force induced by the passage of the hoe into the soil.

The increase in the rake angle present in the tested hoes, in the range from 31.2 to 57.0º, caused linear increases in the horizontal force measure when operating at 0.12 m of depth.

The furrow opener from treatment three promoted higher mobilization of soil, being less favorable for the no-tillage system, differing from all the other models.

The lowest index of specific force (119.4 kN m^{-2}) was obtained with the furrow opener from treatment six (handicraft manufacturing), differing significantly from the average of treatment two (industrial manufacturing - 213.4 kN m^{-2}).

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