Australian Journal of Crop Science AJCS

AJCS 9(9):812-818 (2015) ISSN:1835-2707

# Tractor performance and corn crop development as a function of furrow opener and working depth in a Red Latosol

**Rafael Scabello Bertonha[1*], Carlos Eduardo Angeli Furlani[1], Vicente Filho Alves Silva[2], David L. Wright[3]**

**[1]Department of Rural Engineering, Universidade Estadual Paulista – UNESP/FCAV, Prof. Paulo Donato Castellane Access way, 14884-900 – Jaboticabal, SP – Brazil**
**[2]Federal Rural University of Amazonia – UFRA, Brazil**
**[3]North Florida Research and Education Center – NFREC/IFAS – University of Florida, USA**

*** Corresponding author: rafaelbertonha@gmail.com**

**Abstract**

To use a no-tillage system, the producer must know the ideal tool for each condition encountered in the soil. In seeding, the function of the furrow opener is loosening and disturbing the soil, but if the opener lacks the specific geometry for a specific soil condition, the furrow opening angle could be incorrect, leading to compaction due to mirror formation on the walls of the furrow. The aim of this study was to analyze three hoe-type furrow openers of planters at different working depths, evaluating the area of disturbed soil, tractor performance, and corn crop yield. The experiment was conducted in areas of the UNESP/FCAV, Brazil on a soil classified as a Eutroferric Red Latosol. A randomized block design with factorial scheme 3 × 5 (three shanks: FO1, FO2, and FO3, and five depths: WD1, 6.0; WD2, 9.5; WD3, 10.5; WD4, 12.0; and WD5, 13.5 cm), with four replications was used. The results showed that the soil disturbance was highest at working depths of WD3, WD4, and WD5. With WD1 and WD2, the emerged seedlings began the crop cycle in fewer quantities (72839 and 73380 plants $ha^{-1}$, respectively). The final stand of the crop, corn-grain yield, and biomass were not affected by the treatments. The opener with greatest tip angle (29°) showed a lower traction power demand and fuel consumption than openers with 27° and 17° at working depth WD5, and in general, incurred higher fuel consumption per volume of soil disturbance. Opener geometry and soil type directly affect soil disturbance, machine performance, and crop development. However, in this study, we suggest the opener with a rake angle of 27°, working at greater depth, because this combination provided better fuel consumption per volume of disturbed soil and no reduction of crop productivity.

**Keywords:** agricultural machines, disturbed area, grain yield, groove loosening, shank, *Zea mays* L.
**Abbreviations:** FO_furrow opener; WD_working depth of the openers; SMRP_soil mechanical resistance to penetration (MPa).

**Introduction**

A no-tillage system (NTS) is a farming system that aims to maintain permanent soil cover, reduce soil disturbance and erosion during the rainy season (Garcia and Righes, 2008). It is also characterized by a lower intensity of tillage and lower frequency of machine traffic on soil, leaving more plant material on the soil surface than conventional tillage (Furlani et al., 2007), and may restore soil structure, keeping a productive agricultural system, being considered as conservation system (Streck et al., 2004). The function of the furrow opener in an NTS is disturbance and/or soil loosening, to a technically stipulated depth and extent (Cepik et al., 2005). These actions promote highest soil disturbance with fewer traction force, and allow greater working depths, than double-disk tilling (Mion and Benez, 2008), by reducing mechanical resistance to penetration (Koakoski et al., 2007). The evaluation of planter mechanisms is important for the scientific community and for farmers seeking optimal efficiency of tools (higher productivity and improved machine performance) according to the types of soil to be worked. Several studies have investigated this efficiency using furrow openers (Altikat et al., 2013; Furlani et al., 2013; Troger et al., 2012; Akbarnia et al., 2010). There are two major variables in the selection of appropriate geometries for specific tillage implements: depth/width and angle of inclination (Godwin, 2007). Germino and Benez (2006) evaluated two types of planter furrow openers at four working depths (0.12, 0.23, 0.28, and 0.33 m) in a Distroferric Red Nitosol and concluded that at the recommended depth (0.13 m) there was no difference in opener performance, but that below the critical depth the differences between the openers increased. The combinations of opener mechanisms for deposition of fertilizers and seeds in an NTS are limited by the desire of manufacturers and producers to find the "best" setting for a specific situation (Gohlke et al. 2010). This can increase the cost of seeding operation and soil compaction. Information from the evaluation of furrow opener mechanisms of no-till planters assists companies in the design of tools for soil opening that incur lower energy costs (Mion et al., 2009). According to Conte et al. (2011), shanks are used to promote an appropriate soil physical condition, and, in case of soil compaction problems, shanks are used more frequently and at deeper layers of the soil profile. However, to them this deeper use causes greater draught and does not appropriately disturb the soil because narrow shanks have limited depth performance ("critical depth"). The traction force required for the horizontal motion of a precision planter, including machine rolling resistance, on a good seedbed, ranges from 900 N ± 25% per row seeding (Asae, 1999). Levien et al. (1999) found that values of traction force from 3.24 to 3.64 kN per row seeding in clay soil did not differ between conventional, minimum, and no tillage. They also found that the drawbar power required for seeding operation in a conventional tillage system was 19.9 kW. Mello et al. (2003) verified that a furrow opener mechanism showed greater capacity to disturb the soil and reduced soil bulk density and resistance to penetration, as well as increasing macroporosity. According to these authors, the use of hoe-type furrow openers increased corn yield by 11.3% relative to a double-disk-type furrow opener. Altuntas et al. (2006), evaluating the effect of three types of opener mechanisms, claimed that the characteristics of the shank influence the germination and emergence of crops under different soil conditions. They added that the shape of the shank requires factors that affect the performance, promoting the quality of operation. The aim of this study was to evaluate the performance of three hoe-type furrow openers of precision planters at five working depths, with respect to area of disturbed soil, tractor performance, and corn-grain yield.

**Results and Discussion**

***Soil mechanical resistance to penetration***

The highest mechanical resistance to penetration before seeding was in the 10 to 20 cm soil layer (Fig. 1). The openers worked at a depth close to that layer, but without going below it, owing to the resistance of the soil to furrow opening. According to Tardieu (1994), root systems are less well developed in compacted than in non-compacted fields, indicating that under a long-term no-tillage system, plants and ears may not develop owing to soil resistance. Canarache (1990) reported that values starting from 2.5 MPa can restrict the full root growth of most plants and Rosolem et al. (1999) reported that a SMRP around 1.3 MPa reduces by half the growth of adventitious seminal roots of corn. Sene et al. (1985) considered critical values of SMRP to be around 2.5 MPa for clayey soils, as did Assis et al. (2009).

***Soil disturbance***

There was no difference between openers with respect to soil disturbance, but operation at the working depths WD3, WD4, and WD5 increased soil disturbance relative to WD1 (Table 1). Thus, deeper penetration of openers caused increased disturbance, but it should be noted that increasing the working depth from WD3 to WD4, and WD5 did not result in higher areas of disturbed soil. Thus, WD3 is the critical working depth, i.e., from the same has not gained with soil disturbance and may provide greater traction force. The same results were observed for furrow width as for working depth. The higher area of disturbed soil produced by the hoe opener can be attributed to the higher working depth obtained, the greater width of the opener tip (Conte et al., 2009), and its geometry, designed to allow fertilizer deposition and soil disruption in more highly compacted layers. It was also observed that the furrow openers did not exceed the 13.1-cm depth and that it was expected to approach 19 cm in treatment WD5. This result was due to soil resistance to penetration measured at seeding. Despite the greater soil disturbance at the higher working depth, the furrow width may be reduced, leading to more uncovered soil. The absence of straw on the soil may hinder crop development, owing to high temperature and low humidity resulting from the absence of these residues. A mechanism in the planter for returning straw to the closed furrow is thus essential.

***Crop development***

Seedling emergence took 5.6 days on average and was not influenced by treatment. Emergence was also unaffected by the longitudinal distribution of plants, for which normal, flawed, and double spacing presented values of 61, 21, and 18%, respectively. The design of the openers and the working depths were able to ensure 61% of normal spacing. According to Coelho (1996), for planters with mechanical disk seed meters, the minimum acceptable value for normal spacing is 60%. The remaining 39% (the sum of flawed and double spacing) are possible consequences of the use of a double drill disc, given that it was working in a Red Latosol with high water content, which clay can accumulate in the disks and change the positioning of seeds. Another possible reason for variation in spacing is problems of the mechanical disk meter with the shapes of the seeds, which theoretically would not occur with a pneumatic meter. Reis et al. (2007) working with a planter with a mechanical meter in soybean, found a normal spacing of 68.8%, higher than found in the present work, but working at low speed (3.8 km $h^{-1}$). Altikat et al. (2013) reported higher percentages of seed emergence when using hoe-type furrow openers, compared with double disk mechanisms and a winged opener, again showing that this type of mechanism is effective for the localized disturbance of the soil in an NTS. The greater depth of the hoe-type furrow openers resulted in greater numbers of emerging seedlings (Table 2). Increasing furrow opener depth, with the purpose of breaking the compacted layers located on the surface, can stimulate root development and reduce the effects of soil compaction on grain yield (Conte et al., 2009). However, it was observed when the working depth was increased that the number of plants per hectare failing to survive was higher. Corn-grain yield did not differ between treatments, an important observation for the use of hoe-type furrow openers, because it shows that even with differences in soil disturbance resulting from deeper penetration of openers, grain yields did not differ. Experiments with working depths of hoe-type furrow openers also showed no difference for this variable (Furlani et al. 2013; Debiasi et al. 2010). The average yield of the corn crop was 7,137 kg $ha^{-1}$ with an initial stand of approximately 75,000 plants $ha^{-1}$, so the hoe-type opener promoted higher plant population. This type of mechanism is superior to the disk mechanism, favoring an increase in grain yield, according to Mello et al. (2003) and Kaneko et al. (2010). Arf et al. (2008), working with furrow opening mechanisms (double disk and shank) in bean, observed an increase, in two years, of 9.9% in grain yield using the hoe type. Crop-yield values found in this study were higher than the average yield in Brazil in the 2012–13 season, which was 5,149 kg $ha^{-1}$ (Conab, 2014). There was no statistical difference for biomass, which averaged 9,308 kg $ha^{-1}$.

***Tractor performance***

There were differences between all variables of tractor performance and significant interactions between treatments for average traction force and hourly fuel consumption (Table 3). In contrast, Reis et al. (2002) evaluating two planters, using mechanisms for hoe-type soil opening with four levels of soil moisture in a Red-Yellow Podzolic and an NTS, found no difference in the

**Table 1.** Analysis of variance of soil disturbance, furrow width and effective working depth.

| Furrow opener (FO) | Soil disturbance $cm^2$ | Furrow width cm | Working depth cm |
|---|---|---|---|
| FO1 | 139.1 | 24.9 ab | 10.3 |
| FO2 | 127.6 | 24.6 b | 10.0 |
| FO3 | 154.9 | 26.7 a | 11.0 |
| Working depth (WD) | | | |
| WD1 | 75.9 c | 20.9 c | 6.6 d |
| WD2 | 120.1 bc | 24.3 b | 9.2 c |
| WD3 | 145.7 ab | 25.7 ab | 10.8 b |
| WD4 | 169.1 ab | 27.3 ab | 12.4 a |
| WD5 | 191.6 a | 28.8 a | 13.1 a |
| F test | | | |
| FO | 2.07 $^{ns}$ | 3.56 * | 2.42 $^{ns}$ |
| WD | 13.29 ** | 14.37 ** | 50.66 ** |
| FO x WD | 0.92 $^{ns}$ | 1.40 $^{ns}$ | 0.73 $^{ns}$ |
| C.V. (%) | 28.9 | 10.9 | 11.3 |

Means followed by the same letter are not different by Tukey test at 5% probability; C.V.: coefficient of variation; **significant (P < 0.01). *significant (P < 0.05); ns: not significant.

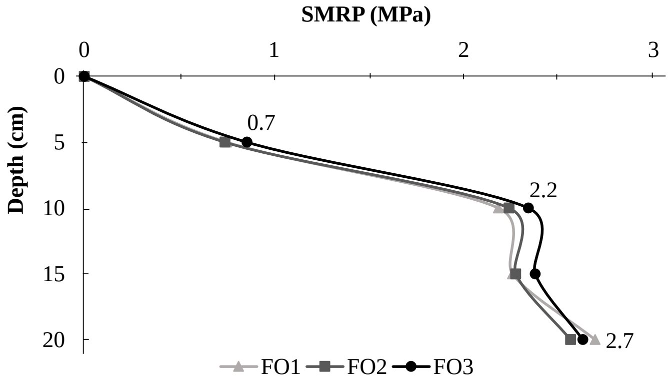


**Fig 1.** Soil mechanical resistance to penetration (SMRP) evaluated before seeding for each furrow opener (FO).

**Table 2.** Analysis of variance of crop initial and final stand, corn-grain yield, and biomass.

| Furrow opener (FO) | Initial Stand | Final Stand | Grain yield | Biomass |
|---|---|---|---|---|
| | ----------- plants $ha^{-1}$ ----------- | | ----------- kg $ha^{-1}$ ----------- | |
| FO1 | 75185 | 72222 | 7279 | 8935 |
| FO2 | 75093 | 71482 | 7003 | 9501 |
| FO3 | 74490 | 71157 | 7128 | 9490 |
| Working depth (WD) | | | | |
| WD1 | 72839 b | 70756 | 7175 | 9511 |
| WD2 | 73380 b | 70602 | 6847 | 9230 |
| WD3 | 75772 a | 72222 | 7096 | 9371 |
| WD4 | 76466 a | 72917 | 7205 | 8964 |
| WD5 | 76157 a | 71605 | 7360 | 9466 |
| F test | | | | |
| FO | 0.50 $^{ns}$ | 0.27 $^{ns}$ | 0.49 $^{ns}$ | 0.45 $^{ns}$ |
| WD | 2.03 * | 0.51 $^{ns}$ | 0.55 $^{ns}$ | 0.12 $^{ns}$ |
| FO x WD | 1.59 $^{ns}$ | 0.86 $^{ns}$ | 0.35 $^{ns}$ | 1.32 $^{ns}$ |
| C.V. (%) | 5.5 | 6.6 | 12.3 | 23.2 |

Means followed by the same letter are not different by Tukey test at 5% probability; C.V.: coefficient of variation; **significant (P < 0.01). *significant (P < 0.05); ns: not significant.

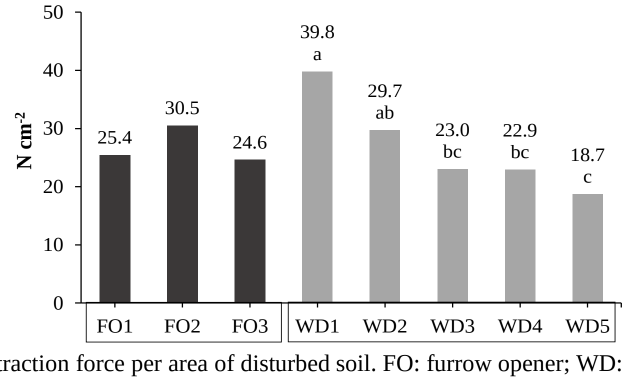


**Fig 2.** Analyses of variance for traction force per area of disturbed soil. FO: furrow opener; WD: working depth. Means followed by the same letter do not differ by Tukey test at 5% probability. Coefficient of variation: 10.4%. Significance threshold: 1% for working depth factor.

**Table 3.** Analysis of variance of tractor requirements as average traction force (TFaverage), traction force peak (TFpeak) and hourly fuel consumption.

| Furrow opener (FO) | TFaverage | TFpeak | Fuel consumption |
|---|---|---|---|
| | ------------- kN | -------------- | $L\ h^{-1}$ |
| FO1 | 11.9 | 13.6 b | 7.8 |
| FO2 | 14.0 | 16.4 a | 8.2 |
| FO3 | 13.2 | 14.8 b | 7.6 |
| Working depth (WD) | | | |
| WD1 | 11.6 | 11.7 c | 7.5 |
| WD2 | 13.6 | 14.8 b | 8.1 |
| WD3 | 12.4 | 14.6 b | 7.6 |
| WD4 | 14.2 | 17.0 a | 8.1 |
| WD5 | 13.4 | 16.5 ab | 7.9 |
| F test | | | |
| FO | 7.51** | 11.46** | 7.82** |
| WD | 4.10** | 15.26** | 2.95* |
| FO x WD | 4.84** | 0.65 ns | 7.52** |
| C.V. (%) | 13.5 | 11.5 | 6.4 |

Means followed by the same letter are not different by Tukey test at 5% probability; C.V.: coefficient of variation; **significant (P < 0.01). *significant (P < 0.05); ns: not significant.

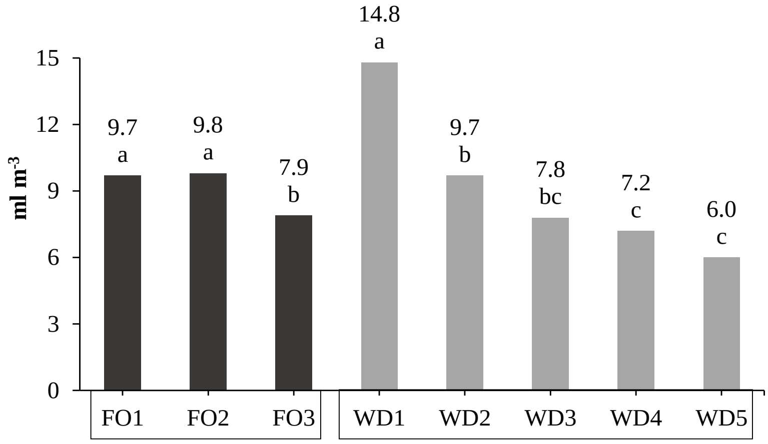


**Fig 3.** Analysis of variance of fuel consumption per volume of disturbed soil. FO: furrow opener; WD: working depth. Means followed by the same letter do not differ by Tukey test at 5% probability. Coefficient of variation: 12.6%. Significance thresholds: 5% for openers and 1% for working depth factor.

**Table 4.** Interaction effect of furrow opener and working depth factors on average traction force (kN).

| Openers (FO) | Working depths | | | | |
|---|---|---|---|---|---|
| | WD1 | WD2 | WD3 | WD4 | WD5 |
| FO1 | 8.7 Bc | 12.0 Bab | 11.1 Aab | 13.3 Aa | 14.4 Aa |
| FO2 | 15.3 Aa | 16.2 Aa | 13.2 Aab | 13.9 Aab | 11.7 Bb |
| FO3 | 10.8 Bb | 12.6 Bab | 12.9 Aab | 15.4 Aa | 14.0 Aab |

Means followed by same letter, upper case in the column and lower case in rows, are not statistically different by Tukey test at 5% probability.

**Table 5.** Interaction effect of furrow opener and working depth factors on hourly tractor fuel consumption ($L\ h^{-1}$).

| Openers (FO) | Working depths | | | | |
|---|---|---|---|---|---|
| | WD1 | WD2 | WD3 | WD4 | WD5 |
| FO1 | 7.1 Bb | 8.1 ABab | 7.2 Bb | 8.0 Aab | 8.5 Aa |
| FO2 | 8.9 Aa | 8.6 Aa | 8.2 Aab | 7.9 Aab | 7.3 Bb |
| FO3 | 6.6 Bb | 7.4 Bab | 7.6 ABab | 8.4 Aa | 7.8 ABa |

Means followed by same letter, upper case in the column and lower case in rows, are not statistically different by Tukey test at 5% probability.

hourly fuel consumption of the tractor. FO2 showed a higher traction force peak, and at higher working depths (WD4 and WD5) the requirement was 43% higher than for WD1. Palma et al. (2010) in evaluations of depths of a hoe-type furrow opener (100, 150, 200, and 250 mm) observed that when the opener tip worked in higher compacted layers of soil, the required traction force was greater than that of the opener tip working below these layers. The traction force peak per was 3.7 kN per opener, near the limit of 3.4 kN per line proposed by Asae (2003), and can be considered as falling within the recommended range because the evaluations were performed on a no-tillage system over eight years, and in conditions of higher SMRP than for a conventional tillage system. The drawbar power peak required by the planter was 25.6 kW. Furlani et al.

(2005), working with four seeding rows, a hoe-type opener with 8 cm of depth, and twice the displacement speed of the present experiment, found values of drawbar power of 25.1 kW in a no-tillage system. The FO2 showed higher traction force requirement at shallower depths than other openers (Table 4). This difference is explained by the angle of inclination and width of the opener tip, which is responsible for the disruption of the soil. Furlani et al. (2013) found lower values of traction force when they used openers with similar geometry. The FO2 yielded higher fuel consumption than the other openers at smaller working depths (Table 5). At WD5, this opener required less fuel for the tractor than did FO1. The traction force per area of disturbed soil (Fig. 2), was significantly different at different working depths. When the openers extended deeper into the soil, the force per cross sectional area of disturbed soil was lower. The increases from WD1 to WD3 and WD5 led to reductions of 16.8 and 21.1 N $cm^{-2}$, respectively. With respect to the fuel consumption of the tractor per volume of disturbed soil as a function of the openers and working depths (Fig. 3), the FO3 incurred lower consumption, owing to the higher opener tip width than the others and the angle of tip inclination less than that of FO2. Thus, FO3 was able to disturb the soil more and incurred less fuel consumption.

## Materials and Methods

### *Site characteristics*

The experiment was conducted in the experimental area of the Department of Rural Engineering, São Paulo State University - UNESP/FCAV, Jaboticabal-SP-Brazil, in the 2011–12 season. The average slope of the area is 4%, with an Aw (subtropical) climate, according to the Köppen classification, and the soil texture is classified as Eutroferric Red Latosol with 469 g $kg^{-1}$ of clay, 307 g $kg^{-1}$ of silt and 224 g $kg^{-1}$ of sand. The plot had been managed for eight years of a no-tillage system and the residue cover was approximately 50%. The cover crop residue left on the soil was from a soybean crop harvested 60 days before corn seeding.

### *Seed and machine materials*

Corn seeds (BG7049H; BioGene) were planted at 7.3 seeds $m^{-1}$. Seeding fertilization was performed based on the results of soil chemical analysis. A pantographic planter was used to plant, consisting of a mechanical seed distribution meter, a tool holder for the furrow opener and fertilizer spreader, a double-drill disk for seeding, and

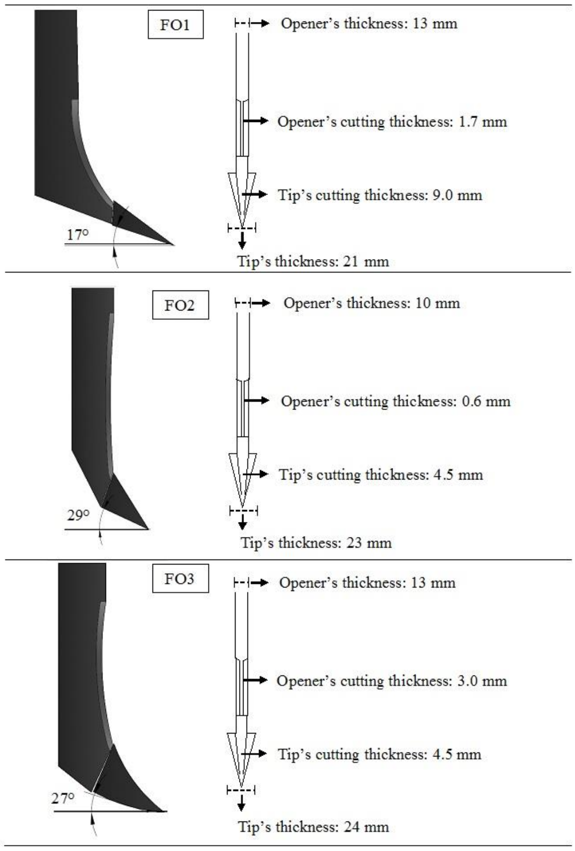


**Fig 4.** Characteristics and dimensions of hoe-type furrow openers, with side view (rake angle) and frontal view (dimensions).

double press wheels. The planter seeded four rows at 0.90 m spacing and was pulled with an Agco-Valtra BM125i tractor with 91.9 kW power at 2300 rpm. The average speed during seeding was 5.5 km $h^{-1}$.

### *Treatments*

A randomized block 3 × 5 factorial design was adopted, using three hoe-type furrow openers (FO1, FO2, and FO3), five working depths (WD1, WD2, WD3, WD4, and WD5) and four replications. The working depths (WD) of the furrow openers (Fig. 4) defined by furrow opening and fertilizer deposition were WD1, 50 mm; WD2, 90 mm; WD3, 125 mm; WD4, 160 mm; and WD5, 195 mm.

### *Corn evaluations*

The corn crop was evaluated by the following variables:
- longitudinal distribution of seed, determined as the distance between seedlings in 12 m of the two center rows, according to ABNT (1996).
-emergence of plants, determined by the daily counts from the first seedling emerging until stabilization of the corn seedling, adapted from Vieira and Carvalho (1994).
- initial and final stand: the number of plants in the usable area of the plot was counted at the beginning of the crop cycle, after stabilization, and at the end of the crop cycle, expressed as plants $ha^{-1}$.
- corn-grain yield: the ears of each plot were collected by hand and threshed with a mechanical thresher. The grain was separated and weighed, and weights were corrected to 13% moisture and expressed as kg $ha^{-1}$.

- biomass: plants were cut above the soil surface and then weighed. The weight of the grain was deducted. A sample for drying was placed in a forced-air oven for 72 h at 65°C to determine the percentage of water, and the yield of dry matter was then expressed as kg $ha^{-1}$.

### *Tractor evaluations*

The operational performance of the tractor during seeding was evaluated by the following variables:
- traction force on the drawbar: a load cell was used, connected to a data acquisition system to compute the average traction force.
- traction force peak: data of average traction force were recorded in a spreadsheet and the four highest values collected by the data logger were identified and their average used in the statistical analysis.
- hourly fuel consumption: tractor fuel consumption was recorded with an Oval-III flow meter with 0.01 ml of precision, installed in the tractor and recording the difference between the measured amount of fuel in the input and output of the fuel injection pump, evaluated for all the experimental plots. The values were stored in a CR23X micrologger (Campbell Scientific Company). Hourly fuel consumption was calculated as Hc = C * 3.6/t, where Hc denotes hourly consumption (L $h^{-1}$), C fuel consumed by the tractor (ml), t travel time in the plot (s) and 3.6 a conversion factor.

### *Soil evaluations*

For the soil, the following variables were evaluated:
- soil mechanical resistance to penetration (SMRP): the data were collected with a penetrometer (PNT/Titan, DLG Company) at 1-cm intervals. Five points per plot were collected before seeding.
- soil water content: samples were collected with an auger at 0–10 and 10–20 cm and dried for 24 h at 105ºC. Water content was calculated on a dry basis (%).
- soil area disturbed, width and depth of furrow: the furrow was opened manually and these variables were analyzed as follows: furrow width (FW) and working effective depth (WED): using a profile meter with 45 rods, spaced of 1 cm. On the back was nailed a cardboard sheet with horizontal lines spaced 0.5 cm apart for easy reading and precision. The positions of the rods' upper ends copied the shape of the furrow. Images were recorded with a digital camera for computer analysis. FW was defined as the distance between the first rods that touched the ground inside the furrow, showing a change of height. WED was defined by the average of the first two rods that showed highest values.
- soil disturbance: the values from the profile meter yielded the transversal section of disturbed soil and the data were integrated by the trapezoidal rule (Equation 1) according to Ruggiero and Lopes (1996).

$$\int = \frac{h}{2}\{f(x_0)+2[f(x_1)+f(x_2)+\ldots+f(x_{m-1})]+f(x_m)\} \qquad (1)$$

where,
$\int$ = numerical integral of the area of disturbed soil,
h = distance between profile meter rods (1 cm),
*f (x)* = value of a rod reading (cm).

### *Energy demand per area of soil disturbance*

- traction force per area of disturbed soil: first, the traction force values was divided by the number of seeding rows and expressed in Newtons (N). They were then divided by the area of disturbed soil and expressed in N $cm^{-2}$.
- fuel consumption per volume of disturbed soil: the area of disturbed soil was transformed to the volume of disturbed soil per hectare ($m^3$ $ha^{-1}$). The fuel consumption values were transformed from liters to milliliters and divided by the volume of disturbed soil (ml $m^{-3}$).

### *Statistical analysis*

The statistical programs used were SISVAR (Ferreira, 2011) and ASSISTAT (Silva and Azevedo, 2006) to ANOVA, using the F test of Snedecor and, when significant, the Tukey test at 5% of probability ($p < 0.05$). When the values were asymmetric by the Anderson-Darling test, the transformation [X = log(x)] was applied.

## Conclusions

Soil disturbance was highest at working depths WD3, WD4, and WD5.
At WD1 and WD2, fewer plants began their growing cycle. The final stand of the crop, corn-grain yield and biomass were not affected by treatments. The opener with greatest tip angle (29°) showed less traction power demand and fuel consumption than openers with 27º and 17º at working depth WD5, and in general required higher fuel consumption per volume of soil disturbance.


## Acknowledgments

The authors thank the Coordination of Improvement of Higher Education Personnel - CAPES, for grants to authors.


## References


ABNT Brazilian Association of Techinal Standards (1996) Standard project: 04:015.06-004/1995. Precision planter: laboratory test - test method. São Paulo: Abnt, pp 21.

Akbarnia A, Alimardani R, Baharloeyan Sh (2010) Performance comparison of three tillage systems in wheat farms. Aust J Crop Sci. 4(8):586-589.

Altikat S, Celik A, Gozubuyuk Z (2013) Effects of various no-till seeders and stubble conditions on sowing performance and seed emergence of common vetch. Soil Tillage Res. 126:72-77.

Altuntas E, Ozgoz E, Taser OF, Tekelioglu O (2006) Assessment of different types furrow openers using a full automatic planter. Asian J Plant Sci. 5:537-542.

Arf O, Afonso RJ, Júnior AR, Silva MG, Buzettim S (2008) Furrow opening mechanism for nitrogen fertilizer application in common bean crop under no-tillage. Brag. 67(2):499-506.

Asae - American Society of Agricultural Engineers (1999) Agricultural machinery management. In: Asae Standards 1999: Standards engineering practices data. St Joseph Asae. 359-366.

Asae - American Society of Agricultural Engineers (2003) Agricultural machinery management data. In: Asae Standards 2003: Standards engineering practices data. St. Joseph, 373-380.

Assis RL, Lazarini GD, Lanças KP, Cargnelutti Filho A (2009) Evaluation of soil resistance to penetration in different soils with varying moisture contents. J Braz Assoc Agric Engineering. 29:558-568.

Canarache A (1990) Penetr - a generalized semi-empirical model estimating soil resistance to penetration. Soil Tillage Res. 6:51-70.

Cepik CTC, Trein CR, Levien R (2005) Draft and soil loosening by knife type coulter related to soil moisture and planter's working speed and depth. J Braz Assoc Agric Engineering. 25:447-457.

Coelho JLD (1996) Test and certification of machines for seeding. In: Mialhe LG (ed) Agricultural Machines: tests and certification. Piracicaba: Fealq, pp 551-570.

Conab - National Supply Company (2014) Historical series – Harvesting Season 2012/2013. Brasília: Conab. Available at: <http://www.conab.gov.br/conteudos.php?a=1252&>

Conte O, Levien R, Trein CR, Xavier AAP, Debiasi H (2009) Draft power requirement, soil mobilization in sowing lines and soybean yield in no tillage. Pesq Agropec Bras. 44:1254-1261.

Conte O, Levien R, Debiasi H, Stürmer, SLK, Mazurana M, Müller J (2011) Soil disturbance index as an indicator of seed drill efficiency in no-tillage agrosystems. Soil Tillage Res. 114:37-42.

Debiasi H, Levien R, Trein CR, Conte O, Kamimura KM (2010) Soybean and corn yield after soil winter covers and soil mechanical loosening. Pesq Agropec Bras. 45(6):603-612.

Ferreira DF (2011) Sisvar: a computer statistical analysis system. Ciên Agrotec. 35:1039-1042.

Furlani CEA, Lopes A, Silva RP (2005) Evaluation of the performance of a precision seeder working in three tillage systems. J Braz Assoc Agric Engineering. 25:458-464.

Furlani CEA, Pavan Júnior A, Lopes A, Silva RP, Grotta DCC, Cortez JW (2007) Operational performance of seeder in different forward speed and winter cover crop management. J Braz Assoc Agric Engineering. 27:456-462.

Furlani CEA, Canova R, Cavichioli FA, Bertonha RS, Silva RP (2013) Energy demand of a planter as a function of the furrow opener in corn sowing. Ceres. 60:885-889.

Garcia SM, Righes AA (2008) Vertical mulching and water management in no tillage system. Braz Soc Soil Sci. 32:833-842.

Germino R, Benez SH (2006) Comparative assay of two models of furrow opener drills for planters in no-tillage system. En Agric. 21:85-92.

Godwin RJ (2007) A review of the effect of implement geometry on soil failure and implement forces. Soil Tillage Res. 97:331-340.

Gohlke T, Ingersoll T, Roe RD (2010) Soil disturbance in no-till and direct seed planting systems. Agronomy technical note n.39, U.S. Department of Agriculture, Natural Resources Conservation Service, Portland, Oregon, pp 6.

Kaneko FH, Arf O, Gitti DC, Arf MV, Ferreira JP, Buzetti S (2010) Furrow opening mechanisms, inoculation of seeds and nitrogen fertilization in no tillage common bean crop. Brag. 69(1):125-133.

Koakoski A, Souza CMA, Rafull LZL, Souza LCF, Reis EF (2007) Performance of seeder-fertilizer using two furrow opening mechanism and three loads on soil firming mechanism. Pesq Agropec Bras. 42(5):725-731.

Levien R, Marques JP, Benez SH (1999) Performance of a precision seeder, in corn seeding (*Zea mays* L.) under different forms of soil management. 28th Brazilian congress of agricultural engineering. Pelotas, Sbea, CD-ROM 1999.

Mello LMM, Pinto ER, Yano EH (2003) Seed distribution and yield of corn as a function of seedding speed and seed box types. J Braz Assoc Agric Engineering. 23(3):563-567.

Mion RL, Benez SH (2008) Loads in furrow opening tools for seeders on no-tillage systems. Ciên Agrotec. 32:1594-1600.

Mion RL, Benez SH, Viliotti CA, Moreira JB, Salvador N (2009) Tridimentional efforts analyses of furrow opening in no tillage seeder. Ciên Rural. 39:1414-1419.

Palma MAZ, Volpato, CES, Barbosa JA, Spagnolo RT, Barros MM, Boas LAV (2010) Effects of work operation depth of shanks in a seeder-fertilizer on slip, traction force and fuel consumption of a tractor. Ciên Agrotec. 34:1320-1326.

Reis EF, Vieira LB, Souza CM, Schaefer CEGR, Fernandes HC (2002) Performance of two no-tillage fertilizer-seeders under different water contents on sandy soil. Eng Agric. 10:61-68.

Reis EF, Moura JR, Delmond JG, Cunha JPAR (2007) Operational characteristics of one no-tillage fertilizer-seeders the culture of the soy (*Glycine max (*L.) Merril). J Agri Tech & Sci. 16(3):70-75.

Rosolem CA, Fernandez EM, Andreotti M, Crusciol CAC (1999) Root growth of corn seedlings as affected by soil resistance to penetration. Pesq Agropec Bras. 34(5):821-828.

Ruggiero MAG, Lopes VLR (1996) Cálculo numérico: aspectos teóricos computacionais. 2nd edn. São Paulo: Makron Books.

Sene M, Vepraskas MJ, Naderman GC, Denton HP (1985) Relationships of soil texture and structure to corn yield response to subsoiling. Soil Sci Soc Am J. 49(2):422-427.

Silva FAS, Azevedo CAV (2006) A New Version of the Assistat-Statistical Assistance Software. 4th World congress on computers in agriculture. Orlando, American Society of Agricultural and Biological Engineers, 393-396 .

Streck CA, Reinert DJ, Reichert JM, Kaiser DR (2004) Soil physical alterations with soil compaction induced by traffic of a tractor in no-tillage system. Ciên Rural. 34(3):755-760.

Tardieu F (1994) Growth and functioning of roots and of root systems subjected to soil compaction. Towards a system with multiple signaling? Soil Tillage Res. 30:217-243.

Troger HCH, Reis AV, Machado ALT, Machado RLT (2012) Analyzing the efforts in furrow openers used in low power planters. J Braz Assoc Agric Engineering. 32:1133-1143.

Vieira RD, Carvalho NM (1994) Testes de vigor em sementes. Funep, Jaboticabal.