Soil disturbance index as an indicator of seed drill efficiency in no-tillage agrosystems

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1. Introduction

No tillage consists of sowing without soil preparation. This system was created to improve soil management because, in the absence of tilling and with the presence of crop residue on the soil surface, substantial erosive processes were reduced and numerous soil attributes improved, especially an increase in the level of soil organic carbon (Bayer et al., 2002; Dieckow et al., 2009). In Brazil, this technique has been used for about 30 years, and it is considerably applied in the south central region. Currently, more than 27 million ha are cultivated under this system (Boddey et al., 2010), which has placed Brazil as the country with the second highest no-tillage cultivated area, only behind the United States of America (Higgins and Reganold, 2008). However, only around 6% of the arable lands are cultivated without tilling worldwide (Lal, 2007).

To sow in no-tilled soils, certain techniques and tools are necessary to slightly remove the residues present in the soil (residue clearance). Special planting equipment is able to pass through the previous crop residue without clustering it. Shanks are shaped to prevent the dragging and subsequent accumulation of residue. Similarly, they are designed to open seeding rows that provide the seed with adequate conditions for germination and subsequent plant development (ASABE, 2010). Any no-till seeding machinery that works in soils without primary tilling has distinct structural characteristics compared with the ones used in tilled soils, specifically regarding the active components. The seed drill components responsible for the soil disruption of the seed rows are shanks and cutting discs. Most of the soil mobilization is done by different types of shanks; but the most common arrangement consists of shanks and double offset discs. Comparing these two groove opening mechanisms, shanks had a higher soil mobilizing capacity than the double discs because of their capacity to work at greater depths (Silva, 2003; Bordignon, 2005). The power requirement of shanks is higher than the demand by discs, which results in higher fuel consumption, a slower tractor velocity seeding and, consequently, a lower field effective capacity (Silva, 2003). In general, the necessary power to tow a soil tilling tool is the sum of the forces from the shank drilling through soil, including cutting, breaking, and disturbing the soil, as well as the soil-shank friction (Hemmat and Adamachuk, 2008).

Despite of the smaller operational capacity, the greater draught and the energy consumption, shanks have replaced the double
disks because they constitute a suitable alternative for the localized rupture of soil compacted layers. Interestingly, Reis et al. (2006), working in a clayey Oxisol, concluded that the soil density in rows planted using a planter equipped with shank openers was lower compared with the soil density in rows where double disc openers were used; moreover, this lower soil density resulted in a higher percentage of corn emergence. Furthermore, Veiga et al. (2007) observed that row disturbance by shanks reduced the soil resistance to penetration for the 0–0.12 depth range, eliminating the differences observed in this variable among conventional tillage, scarification and no-tillage.

The possibility to rupture compacted surface soils, even in a localized manner, has induced famers to utilize shanks at greater depths, reaching, in some cases, depth as great as 20 cm. However, shanks with narrow points, as the ones used in the majority of the seed drill-fertilizers suitable for no-tillage, present a limited capacity to act efficiently when increasing the operation depth due to soil–shank interactions and soil structure rupturing behavior (Godwin and O’Dogherty, 2007; Hemmat and Adamachuk, 2008). When forcing narrow shank to operate at deeper layers, it is possible to operate at depths deeper than the critical depth (O’Callaghan and McCullen, 1965; Godwin, 2007); once this critical depth is overcome, a substantial increase in the draught force (DF) is obtained without a proportional increase in soil disturbance. When shanks operate at depths shallower than the critical depth, the soil disturbance occurs in three directions: forward, upward and sideways (Godwin and O’Dogherty, 2007). According to these authors, when the working depth is greater than the critical depth, the soil is predominantly dislocated forward and sideways. Therefore, the cross-sectional area, the fractured area and, consequently, the disturbed soil volume are reduced. This fact becomes relevant when applying shanks aiming to improve the physical structure of soils in no-tillage systems because it determines the shank working efficiency, both regarding the soil groove mobilization, the energy demand and the tractor-seed drill operational capacity. The reference values of shank critical depths can be obtained from the working depth and shank pointer width. The critical depth equals 5–7 times the pointer width (Godwin and O’Dogherty, 2007) and this is dependent of soil type and moisture content, becoming progressively smaller as friction angle becomes smaller and cohesion is significant only when presenting values below 1. The shank rake angle (Godwin and O’Dogherty, 2007) and certain soil characteristics, such as water content, soil compaction degree and angle of internal friction (Sánchez-Girón, 1996), also interfere with the way that the soil is ruptured and disturbed and, consequently, affect the critical depth.

To measure the soil disturbance efficiency achieved with shanks, it is necessary to quantify the soil disturbance in the seedling grooves and to measure the cross-sectional area. The soil disturbed area is the soil portion that is ruptured and mixed by the shanks. Shanks move part of the soil from one or both sides of the groove. The removed soil is deposited on the non-disturbed area and cannot be considered mobilized area because soil and roots of this fraction were not disturbed (Fohlke et al., 2000). Considering the mobilized area, the groove depth and the distance between rows, it is possible to calculate the soil disturbed volume for a given groove length or area (m² or ha). Measuring the shank DF allows the determination of other soil disturbance efficiency indicators, such as the specific draught (SD). This variable corresponds to the average DF divided by the cross-sectional area. When the shank depth becomes higher than the critical depth, SD drastically increases. Therefore, SD is less accurate because of the exponential increase in DF with a greater depth (Godwin, 2007) and due to the great variability of the cross-sectional area.

Thus, we suggest a new soil disturbance efficiency indicator, named “disturbance index” (DI). The DI is obtained by dividing the groove disturbed area (cm²) by the maximum shank working depth (cm). It is recommended to use centimeters as the basic unit because it facilitates the visualization due to sub metric scale in which this process occurs. In other words, DI shows how many square centimeters of groove section are disturbed for each deeper centimeter of the shank working depth. As the DI increases, the shank efficiency of soil disturbance becomes higher. Similarly, constant DI values in response to increases in shank depth performance indicate that the critical depth has not yet been reached. When the working depth becomes higher than the critical depth, DI values become smaller and soil disturbance is compromised. Another advantage of DI is that electronic instruments, which are not always available, are unnecessary to measure it. In contrast, they are necessary for obtaining DF. The determination of shank working depth as a function of the cross-sectional area does not demand costly instruments, only a sample stick profilometer (Debiasi, 2008; Conte et al., 2009).

Thus, this research is based in the hypothesis that DI can be an indicator of soil shank disturbance efficiency. Differences in DI values are expected in different soil types. For the each soil type and under different tilling conditions, the determination of DI will detect the critical depth as a function of geometrical differences of soil properties and characteristics. Here, we aimed to obtain and validate the DI as an index to evaluate the shank performance and to compare this index with other soil disturbance parameters in no-tillage systems (such as SD).

2. Materials and methods

To obtain the necessary parameters for this experiment, numerous trials in different soil conditions and different shank models were carried out throughout the last 4 years. Here we present the evaluations of two soil conditions, whose physical attributes are presented in Table 1.

2.1. Rhodic Hapludox (Oxisol)

The experiment was established in May of 2001 at the Espinilho farm, which belongs to Agropecuária Cerro Coraodo, located in São Miguel das Missões county. The geomorphological unit corresponds to the Planalto Médio region in Rio Grande do Sul state (Brazil; 29°03’S latitude and 53°50’W longitude).

Before our experiment was set, the area was cultivated under no-tillage for 10 years, with black oat (Avena strigosa Schreb) during the winter and soybean (Glycine max) during the summer. In the fall of 2001, after the harvest of soybean, the experiment was established by sowing black oat and Italian ryegrass (Lolium multflorum Lam.). Since 2001, an integrated system of crops and livestock was adopted, with soybean during summer and black oat
and ryegrass during winter. The soil evaluations were carried out during the soybean sowing from 2006 to 2009.

2.2. Rhodic Paleudult (Alfisol)

Another area was used to perform experiments with a different type of soil. This experiment was established in 1988 at the Agronomic Experimental Station (30°05′22″S latitude and 51°39′08″W longitude) of the Federal University of Rio Grande do Sul, in Eldorado do Sul county, Rio Grande do Sul state (Brazil). The soil is a Rhodic Paleudult (Alfisol), with a clay loam texture, gravel and of granitic origin. This layer had a mean slope of 3%. The mean local annual rainfall is 1,440 mm. The climate is subtropical with a warm humid summer, i.e., Cfa according to the Koeppen classification.

The soil of this area was subjected to field trials with different cultivation rotation systems, including corn, soybean and beans during summer, and fallow or cover crops (black oat and ryegrass, black oat and vetch, vetch and oilseed radish) during winter. The soil data for this experiment were obtained during the soybean sowing from 2005 to 2009 and represent an average of several evaluations of the shank operation depths. Here, we present this information to confront it with the information obtained from the Oxisol.

In the year of 2006 for the Oxisol and for all of the years in the Rhodic Paleudult, the evaluations referred to shanks-equipped seed drill-fertilizers with 5 rows, with 40 cm between rows, pulled by a tractor with mechanical front wheel drive (MFWD), maximum engine power of 53 kW, and operated at an average speed of 5.6 km h\(^{-1}\). Shanks presented a width of 0.0257 m, a rake angle of 18° and lengths of 0.415, 0.440 and 0.475 m. In 2007, 2008 and 2009, in the Oxisol, shanks were used in a seed drill-fertilizer with 8 rows, with 45 cm between rows, pulled by a tractor with maximum engine power of 77 kW, and operated at a speed of 4.5 km h\(^{-1}\). This shank model is characterized by shank and width of 0.010 m and 0.02275 m, respectively, a rake angle of 20° and lengths of 0.390, 0.410 and 0.440 m. The variation in the depth performance of different tests was obtained not only with shanks of different lengths, but also by position adjustments in relation to the shank support.

To measure the shank DF, strain gages, able to measure the deflection occurred during operation, were installed. The deflection is proportional to the horizontal force necessary to drag the shank. The data were obtained with a frequency of five readings per minute and were stored by dataloggers CAMPBEL SCIENTIFIC, CR23X model (for further details about instrumentation see Cepik, 2006; Hemmat and Adamachuk, 2008).

Measurements to assess the soil groove disturbance were made immediately after seed drilling by carefully removing the disturbed soil both manually and with the aid of scoops. To obtain the exposed groove shape, we used a profilometer of 35 cm wide, which is composed of sticks separated at 1 cm that can be vertically dislocated up to 30 cm (Fig. 1a). For each evaluated site, the soil was removed from grooves of approximately one meter, and three profilometer measurements were done. These three measurements constituted one sample, and subsamples are necessary due to the high variability presented by this variable. To obtain readings after the groove exposure, the profilometer was positioned in a transverse way. Subsequently, the profilometer sticks were released. The positioning of the sticks copied the soil groove geometry, which allows the transcription to paper sheets. The highest vertical distance between groove bottom and soil surface correspond to its greatest depth. The vertical distances for each point copied from the groove bottom to the soil surface were measured in the laboratory and using an spread sheet (Microsoft Excel\textsuperscript{\textregistered}). The cross-sectional area is the result of depth values integration with groove width (in cm, Fig. 1b). The ratio between the mobilized soil area and the maximum depth of the groove constituted the disturbance index.

For the regression analysis of DI and SPD, the data were tested at a 5% level of significance.

3. Results and discussion

A shank DF or any other equipment pulled through the soil with a horizontal force demands energy to rupture and disturb

![Fig. 1. (a) Profilometer of sticks and (b) graphical representation of the obtained profile and average readings.](image)

![Fig. 2. Draught force for the shank of a seed drill (N) as a function of the depth of operation in an Oxisol.](image)
the soil structure and mass in the groove (Hemmat and Adamachuk, 2008). Smaller change in the work depth causes large changes in DF, which became noticeable when three depths were observed in the Oxisol (Fig. 2). This result is in agreement with Godwin (2007). Fig. 2 shows three geometrically identical shanks operating at 6, 9 and 12 cm deep in an Oxisol, with a black oat and ryegrass pasture immediately after grazing. Before the seed drill shanks were used, a cutting disc segmented the residues and disturbed the soil and, therefore, the required DF diminished up to 40%, according to Bordignon (2005). Our data regarding DF refer only to the shank demand. To obtain the total DF necessary for each seed drill unit (row), the cutting disc DF and the friction power, which considers the whole ensemble resistance, must be summed. The DF demanded by shanks have been used to map the soil compaction spatial variability in different agricultural systems, as proposed by Bergeijk et al. (2001) and experimentally presented by Herzog et al. (2004), Cepík et al. (2005) and Conte et al. (2007). The DF correlates with the physical attributes of soils, such as mechanical resistance to penetration (Hanquet et al., 2004; Conte et al., 2008).

The DF variability results from the soil-shank interaction and the particular way in which the soil rupture is produced, which is associated with differences in water content, soil texture and compaction (Fig. 2; Hayhoe et al., 2002). Therefore, to analyze this variable it is necessary to have a good amount of data, so that the obtained results truly represent the field conditions. Similarly, using DF to obtain other variables, such as SD, that results from the ratio of the average DF to the groove disturbed area, it is important to have considerable DF values to reduce the variability.

The SD can be a good shank performance indicator, especially when the wasted energy and power of different shank models operating at same depth are compared. This index evaluates the shank constructive parameters and its implication when quantifying the disturbed soil and required DF. To evaluate the efficiency of soil disturbance of shank models operating at different depths, it must be considered that increases in DF are not proportional to the operating depth, as shown in Fig. 2. In general, SD increases when the working depth increases, as shown in Fig. 3. This figure compares SD values identified by the years. In each year, the evaluations were done with different water contents, which interfere with the soil–metal adhesion, cohesion and friction forces (Sánchez-Girón, 1996) and, thus, alter the demanded DF. Interestingly, in each sampling occasion, SD increased with higher shank operating depths. Thus, SD was not a good indicator of soil disturbance efficiency in relation with the shank working depth in no-till conditions.

Therefore, it was necessary to measure the disturbed soil in relation with shank working depth. Quantifying the soil disturbed area and dividing this value by a fixed factor (the shank working depth) resulted in the disturbance index (DI; Fig. 4). This index assessed the shanks’ efficiency of soil disturbance when regulated to operate at increasing depths. If DI values remained constant as shanks operated at greater depths, the soil disturbance is efficient. In contrast, drastic decreases in DI values indicated a loss of the soil disturbance efficiency. This evaluation was necessary because, depending on the pointer widths, the critical depth is achieved at around 15 cm.

The DI and SD variation with different shank working depths in the Rhodic Paleudult and Oxisol is presented in Figs. 5 and 6, respectively. In the Oxisol, as SD increased with shank working depth, the DI values remained constant (Fig. 5). This result demonstrates that, for the Oxisol, shanks were efficient in disturbing soil even when performing at 18 cm of depth. This trend, however, did not occur in the Alfisol because the DI increased until shanks reached 12 cm of depth (Fig. 5). The DI decreased at greater depths. Therefore, for this type of soil, 12 cm represented the working depth that resulted in the highest disturbance efficiency.
When comparing these soils, higher DI values occurred in the Oxisol (Fig. 7). This trend can be explained by considering the differences observed between these soils regarding the parameters of the Coulomb effect equation (cohesion and angle of internal friction), which determines the soil resistance to rupture with tillage tools. Oxisols are well structured soils, due to their mineralogy and texture, with high clay, iron and aluminum contents, which promote intense aggregation, thus, soil cohesion is higher (Sánchez-Girón, 1996). According to Godwin and O’Dogherty (2007), a soil with low cohesion tends to flow naturally with stresses smaller than 200 kPa, which were similar to the values of angle of internal friction obtained by the author for a sandy Alfisol. According to the same author, a normal stress of 200 kPa was less than the Oxisol microaggregate strength. Therefore, in this situation, friction occurs among microaggregates instead of primary soil particles, resulting in higher values of angle of internal friction.

4. Conclusions

The DI constitutes an efficient index for evaluating shank efficiency of disturbed soil grooves when more working depths are demanded. The disturbance index was able to detect alterations in soil disturbance of the evaluated soil classes, Rhodic Paleudult (Alfisol) and Rhodic Hapudox (Oxisol). The disturbance efficiency, measured by DI, was smaller in the Alfisol than in the Oxisol. In the Alfisol, the highest disturbance efficiency occurred when shanks worked at 12 cm of depth, while in the Oxisol, this value was not reached until a working depth of 18 cm.

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References


