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RESEARCH ARTICLE

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Development of an electronic profilometer to measure mobilization variables in soil harrowing

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Abstract

Aim of study: This experiment's objective is to develop an automatic data acquisition system for profilometry, evaluating four harrowing speeds.

Area of study: Federal University of Parana, Curitiba, Brazil.

Material and methods: We experimented at the laboratory using a completely randomized design, comparing the data of modified roughness, raised and mobilized area, blistering, and thickness. These were acquired with traditional and electronic profilometers in seven replications. We executed the field test in lines, using a completely randomized design. The profilometers were in the plots and the targeted speeds in the subplots. We submitted the data for analysis of variance and when significant, to Tukey's test and regression analysis.

Main results: Laboratory testing showed no significant difference in the parameters of modified roughness, elevated and mobilized area, blistering, and thickness, denoting the phase validation that indicates applicability in the field. The field testing presented superior results for the electronic profilometer in elevated and mobilized areas and soil layer thickness. That is due to the absence of interference in the measurements that occur in the conventional profilometer caused by the insertion of the rods in the soil.

Research highlights: The increase in the mechanized set speed provided the reduction of the elevated area and soil blistering caused by the rise in disc rotation and consequent deviation of the soil particles.

Additional key words: soil mobilization; blistering; profilometry; soil roughness.

Abbreviation used: DAS (data acquisition system); P (profilometry); TS (target speed).

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Introduction

Due to physical, chemical, and biological impediments in the soil, many producers have adopted deep soil preparation as an alternative to correct agronomic adversities, including soil compaction in deeper layers (Feng et al., 2020), replacing subsoiling and plowing with heavy harrowing (Kogut et al., 2016).

Profilometry monitors soil preparation quality, measuring the mobilized cross-sectional area, blistering, average layer thickness, index, and modification of soil roughness (Bögel et al., 2016). The evaluation of these parameters usually involves traditional equipment, such as a rod or slide bar profilometer (Borges et al., 2019). Other tools include contactless devices, such as drone images, optical lasers or digital cameras, ultrasonic sensors, or Lidar (light detection and ranging) sensors (Vasil'ev et al., 2021).

Contactless devices, such as drone images, were reported in the work of Fanigliulo et al. (2020), who compared traditional methods of evaluating soil roughness (laser profilometer) with drone RGB 3D imaging techniques for the evaluation of different soil preparation methods. The use of light drones allowed the replication of the results obtained by traditional methods, introducing advantages in terms of time, repeatability, and analyzed surface, reducing human error during data collection and creating a digital agriculture solution for laborious field monitoring. However, the limitation of flight operating time and data processing are still factors to be studied and solved in this method.

Laskoski et al. (2017) developed, built, and validated a laser profilometer to measure the soil mobilized and elevated areas, the average thickness of the mobilized layer, and blistering after soil preparation. The acquired variables did not present statistical significance compared to the parameters collected by the traditional rod and the developed profilometers. The developed profilometer showed superior performance in the collection, acquisition, and storage of data, in addition to not modifying the structure of the analyzed profile once it is a contactless method. However, this sensor has limitations regarding operation under incident solar radiation and sensitivity in the remittance of electrical signals.

Gilliot et al. (2017) developed a fully automatic photogrammetric approach to measure soil surface roughness from field photos taken with a digital camera sensor without geometric restrictions. These figures calculated 3D soil models with millimetric precision and generated 11 roughness indices implemented in a Python program. The results presented were that two roughness indices, the surface tortuosity index and the average height value, are more efficient in discerning levels of agricultural soil preparation. The authors reported noise problems during the electronic acquisition and the need to create shadows over the camera scanning area.

Ewetumo et al. (2019) developed an automated profilometer with a dual ultrasonic sensor in a tool holder plate equipped with an electronic horizontal displacement system and a central unit with a microcontroller. The results showed that the operating time was lower than 60 sec, with an accuracy and resolution of 1 cm besides the maximum deep range of 200 cm. This sensor's advantages include the possibility of detecting any material that does not absorb sound and does not influence color in the reading process, but it has the disadvantage that encrusted or accumulated solids can affect the measurement.

Foldager et al. (2019) compared two soil profiling methods, Lidar and conventional metal rods sensor, in measuring the cross-sectional area and groove geometry after soil preparation. Using Lidar, a system generated 3D scans of the soil surface and an average groove geometry allowed comparing the geometric variations along the grooves. The measurements of cross-sectional area and geometries by the rod profilometer and Lidar showed up to 41% difference between the two methods. This Lidar sensor benefits from a low light operation and shows high precision under different rough and textural soil surfaces and low energy consumption, facilitating its use in field conditions. Its limitations are the requirement for more complex electronic circuits, developer experience, and being more susceptible to particulate interference in its optical assembly.

Sampling process automation is often used in agriculture to assist decision-making, minimize the occurrence of process failures, and promote positive decisions (Tian et al., 2020). This tool has numerous benefits in soil profilometry, especially the execution in continuous cycles. Currently, the traditional method used in profilometry is costly and time-consuming. It also generates an inordinate amount of data to post-process, suggesting the need to modernize this system through electronics and automation.

Among the automated models, Polyakov & Nearing (2019) developed a laser profilometer as an alternative for expensive and complex systems. It had a good performance under various conditions compared to the Lidar system which presented overestimated roughness results.

Operational speed and the implement's operation depth affect soil preparation results. It can contribute to the elevation of the work layer, generating the so-called floating effect. However, this implication on heavy harrows is little studied, considering that their constructive characteristics can minimize the minus effects of increasing operational speed in harrowing operations.

Thus, the objective was to develop an automatic data acquisition system (DAS) for profilometry processes in conference to the traditional method, comparing the effect of four speeds on soil preparation as a verification test.

Material and methods

Field experiment

The experiment happened at Cangüiri Farm, Pinhais-PR, Brazil (25°23′40″ S, 49°07′22″ W; altitude 910 m asl). The climate is Cfb, and the soil is a clayey-textured humic dystrophic Ferralsol. In the 0.0-0.10, 0.10-0.20, and 0.20-0.30 m layers, the soil resistance to penetration values were 0.90, 2.87, and 3.51 MPa; soil density values were 1.25, 1.34, and 1.29 g cm^{-3}; and water content was 30.09, 30.26, and 30.48 g g^{-1}, respectively. The liquidity limit is 37.50 g g^{-1}, while the plasticity limit is 29.17 g g^{-1}, resulting in 8.40 g g^{-1} of the plasticity index.

The heavy harrow model SGAC14C (Civemasa™) prepared the strips of mobilized soil. It had 14 cut-out discs 30 inches in diameter, spaced at 0.36 m, totalizing a working width of 2.34 m and a total mass of 3,150 kg. The imple-

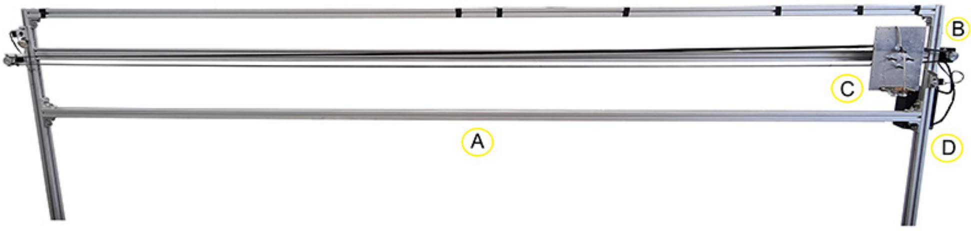

Figure 1. Electronic profilometer.

ment connects to the drawbar of the New Holland™ tractor, model T7 260, with power (DIN 70020; Deutsches Institut für Normung, 1986) of 160.92 kW, Full-Powershift transmission, sized by ASABE D496.3 (2011).

Development and construction of the electronic profilometer

The experiment was under controlled environment conditions. The developed electronic profilometer (Figs. 1 and 2) has the following components: structure (A), electric drive (B), reading sensor (C), and data acquisition system (D).

The rectangular structure of dimensions 3×1 m in anodized aluminum profiles supports the reading transverse linear displacement system. The electronic control is a driver model NEO-DM322E (Leadshine™) that allows the precise current adjustment for the hybrid type stepper motor (Nema 17) with an accuracy of 0.09º and torque of 8.0 kgf·cm. It drives the symmetrical transmission shaft of the pulley and toothed belt (Fig. 3), providing constant traction to the tool holder plate. It uses a three-dimensional laser triangulation scanning sensor, model ODS 96M/V-5010-600-421 (Leuze Electronic Germany™), with an accuracy of ± 2% and a resolution of 0.5 mm. It allows detecting the location of the emitted beam with the aid of an internal camera through the method of light emission on a given surface.

The DAS implemented in a microcomputer model ATmega 328 (Atmel™) contains eight analog inputs and 14 digital inputs/outputs programmed by software, the clock speed of 16 MHz, and an analog to digital converter of 10 bits. The acquisition frequency of one hertz relates to the soil profile reading from the laser sensor connected to the DAS. It stores the data on a hard disk for later tabulation and analysis.

Development and construction of the conventional profilometer

The conventional profilometer (Fig. 4) developed has the following components: structure (A) and mechanical reading system (B). The rectangular structure (3×1.5 m) consists of tubular aluminum, and the vertical ends have conductive rails for the displacement of the marking material. The profile elevation mechanism consists of aluminum rods with plugs to minimize the unwanted effect of deepening into the ground, spaced 0.05 m apart, and distributed along a line on the profilometer support.

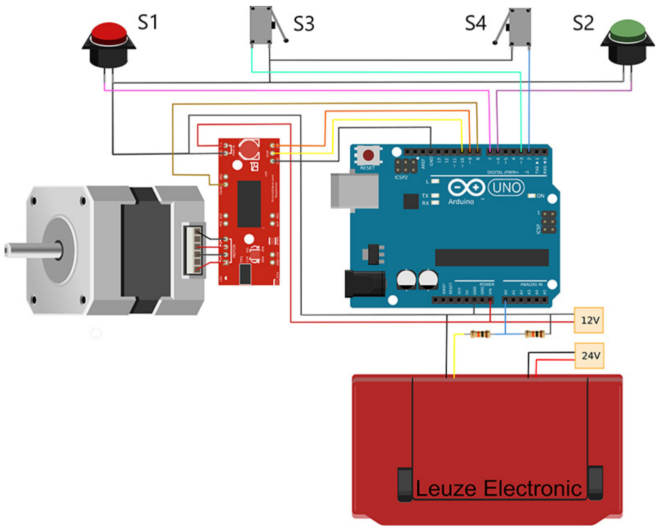

Figure 2. Electric diagram: S1, displacement from left to right; S2, displacement from right to left; S3 and S4, sensors that inform the initial and final position, respectively.

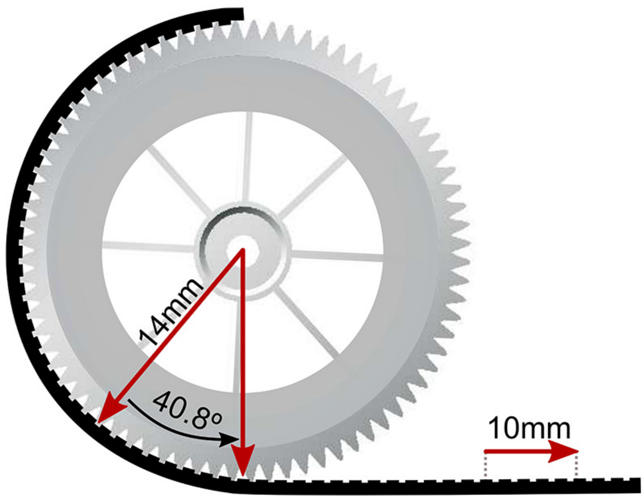

Figure 3. Angular displacement ratio.

Table 1. Statistical synthesis of analysis of variance and test of means for soil profilometry parameters in the laboratory.

Analysis	Evaluated parameters				
	Modified roughness (%)	**Raised area (cm^2)**	**Mobilized area (cm^2)**	**Blistering (%)**	**Thickness (cm)**
Normality SW [1]	0.868	0.807	0.856	0.835	0.785
Homogeneity LEV [2]	0.001	0.329	0.376	0.172	0.375
Test F [3]	0.269 NS	0.965 NS	0.515 NS	1.447 NS	0.123 NS
CV (%) [4]	32.83	27.90	28.22	27.41	28.94
Means test [5]					
Conventional	488.78	1970.14	3339.01	51.62	11.92
Electronic	533.99	2269.40	3707.04	61.19	12.56

[1] Shapiro-Wilk normality test: SW ≤ 0.05, data abnormality; SW > 0.05, normality in the data. [2] Levene's test of homogeneity of variances: LEV ≤ 0.05, heterogeneous variances; LEV > 0.05, homogeneous variances. [3] Analysis of variance F test (ANOVA): NS – not significant; * ($p < 0.05$) and ** ($p < 0.01$). [4] CV: coefficient of variation. [5] In each column, for each factor, means followed by the absence of letters do not differ from each other by the "Tukey test" ($p < 0.05$).

Evaluation and calibration of the electronic profilometer in the laboratory

Soil profilometry evaluations took place in a reservatory with the established profiles: mobilized, not mobilized, and cut. The gravimetric soil moisture is 0.22 kg kg^{-1}.

The electronic and conventional profilometers obtained the roughness index and the mobilized soil profile. Those allowed estimating soil blistering, mobilized, and elevated area. They had a width of 2.8 m with points reading every 0.05 m. Both profilometers were even to the transverse profile of the area. Thus, the soil profile reading performed before the modifications obtained the natural (not mobilized) soil conditions while after harrowing registered the elevation profile and cutting, according to Carvalho Filho et al. (2007).

Soil profilometry parameters

We calculated the elevated and mobilized area according to Simpson's Rule (Eq. 1), according to Uddin et al. (2019).

$$\int_{X_0}^{X_n} dx = \frac{h}{3}\left(f_0 + 4f_1 + 2f_2 + 4f_3 + 2f_4 + \ldots + 2f_{n-2} + 4f_{n-1} + fn\right) \quad (1)$$

in which,

$$h = \frac{X_n - X_0}{n}, X_n > X_0$$

being n = number of intervals; f = the height of the dimensions, mm; h = the distance between dimensions, cm; and X = number of shares.

The surface roughness index (Eq. 2) is the standard deviation between the natural logarithms of the elevated readings, multiplied by the average height of the elevations.

$$\sigma y = \sigma x \text{ ha} \quad (2)$$

in which σy = roughness index estimate represented by the standard deviation between heights, mm; σx = standard deviation between the natural logarithms of heights; and ha = average height, mm.

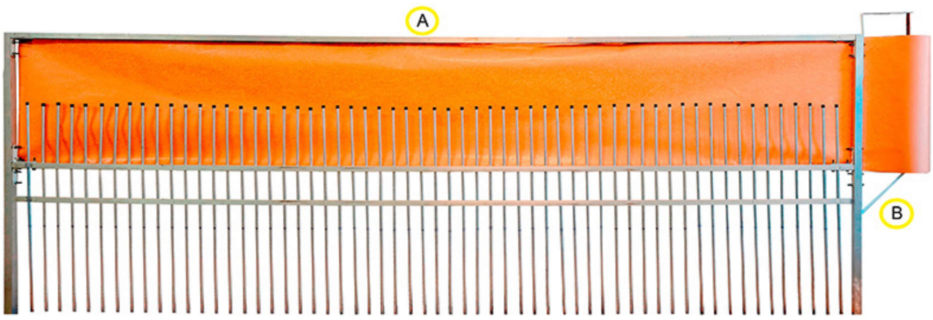

Figure 4. Conventional profilometer

The mobilized area consists of the portion between the unharrowed part and the cut-out profile, while the elevated area sits between the intact profile and the soil surface profile after the mobilization.

After obtaining the mobilized soil profile, we calculated the average thickness using Eq. 3:

$$Lt = \frac{A_m}{L_p} \qquad (3)$$

in which Lt = average thickness of the mobilized layer, m; Am = mobilized area of the soil, m²; and Lp = profilometer length m.

Soil blistering (Eq. 4) is the ratio between the elevated and the mobilized area of the analyzed profile:

$$Bt = \frac{A_e}{A_m} \qquad (4)$$

in which Bt = blistering, %; Ae = elevated area, m²; and Am = mobilized area, m².

We calculated the modification in soil roughness (Eq. 5) considering the difference between the roughness index measured after and before tillage, divided by the roughness index before tillage, expressed as a percentage:

$$MR = \frac{RI_A - RI_B}{RI_B} \times 100 \qquad (5)$$

in which MR = modification of roughness, %; RIA = roughness index after soil preparation; and RIB = roughness index before soil preparation.

Evaluation of profilometry and soil preparation

The experimental area divides into four strips (seven repetitions), corresponding to the operating speeds of soil preparation.

The profilometers worked on the previously leveled piles, mounted in the transverse direction to the tractor orientation, according to Carvalho Filho et al. (2007). After obtaining the readings, the profilometer moved in the longitudinal direction. The natural soil profile was registered before harrowing the area.

The regulated heavy harrow coupled to the tractor mobilized the soil to obtain the strips. Afterward, the profilometers measured the mobilized surface and intern profile, called mobilized and cut-out profile, according to Fig. 5.

Experimental design and statistical analysis

We used a completely randomized design in the laboratory to evaluate, with seven replications, the two profilometers (conventional and electronic). Each had five parameters: modified roughness, raised area, mobilized area, blistering, and thickness.

Table 2. Statistical synthesis of analysis of variance and test of means for soil profilometry parameters in the field.

Analysis	Evaluated parameters				
	Modified roughness (%)	**Raised area (cm²)**	**Mobilized area (cm²)**	**Blistering (%)**	**Thickness (cm)**
Normality SW [1]	0.008	0.593	0.594	0.994	0.647
Homogeneity LEV [2]	0.855	0.381	0.044	0.874	0.029
Test F [3]					
P	3.912 NS	10.026 *	33.553 **	1.093 NS	84.019 **
TS	0.851 NS	7.070 **	0.159 NS	5.175 **	0.197 NS
P × TS	0.939 NS	0.220 NS	0.247 NS	0.250 NS	0.206 NS
CV (%) [4]					
P	23.53	30.37	8.94	33.72	7.35
TS	59.68	37.34	19.31	41.78	20.03
P × TS	66.14	65.28	21.36	61.34	20.89
Means test [5]					
Conventional	207.99	1011.99 B	3677.94 B	28.71	12.46 B
Electronic	177.88	1394.91 A	4370.30 A	32.28	15.60 A

[1] Shapiro-Wilk normality test: SW ≤ 0.05, data abnormality; SW > 0.05, normality in the data. [2] Levene's test of homogeneity of variances: LEV ≤ 0.05, heterogeneous variances; LEV > 0.05, homogeneous variances. [3] Analysis of variance F test (ANOVA): NS – not significant; * ($p < 0.05$) and ** ($p < 0.01$). [4] CV: coefficient of variation. [5] In each column, for each factor, means followed by the absence of letters do not differ from each other by the "Tukey test" ($p < 0.05$).

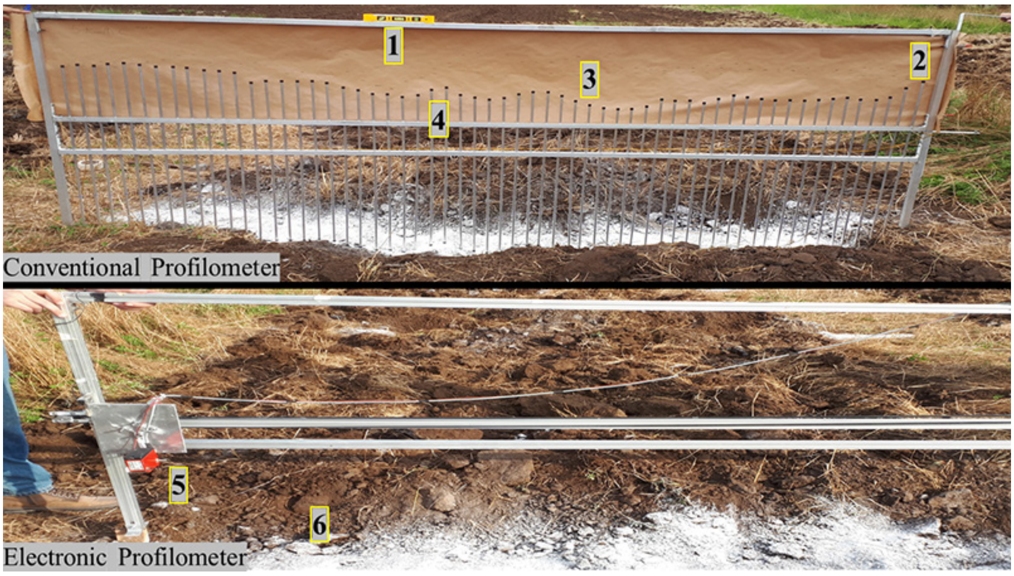

Figure 5. Field data collection with conventional and electronic profilometers: 1, level; 2, paper boards inserted at each experimental repetition; 3, evaluated profile data (pen marked); 4, manual vertical rods displacement; 5, laser sensor triggered by transverse displacement; and 6, white surface ($CaCO_3$) to increase laser sensor remission.

In the field, we experimented with a two-factor strip-plot design within randomized blocks (Miller, 1997). That led to the two profilometers (P) allocated in the plots and the target speeds (TS) of the soil preparation operation in the subplots (5.7; 6.8; 8.2 and 9.8 km h^{-1}). We obtained those in the F7, F8, F9, and F10 tractor gears. For each treatment, seven replications were performed, totaling 56 experimental units.

After checking the normality of the data using the Shapiro–Wilk test and homogeneity of variance (Levene), we submitted them to an analysis of variance (ANOVA, F value, $p < 0.05$). Then we compared the treatment means (P) using the Tukey test ($p < 0.05$) and the polynomial regression test to the quantitative factor (TS). We analyzed the data using Sigmaplot 12 (Systat Software Statistical Program™).

Results

Once the data showed normality and homogeneity, they underwent an analysis of variance (Table 1). The values of the T-test resulted in no significant difference in the means of the evaluated parameters for the two profilometers tested.

During the field test to evaluate the efficiency of the developed profilometer versus the conventional one, the acquired data classified as normal and homogeneous (Table 2). It was later evaluated by an analysis of variance, indicating that the means of modified roughness and blistering obtained by the two profilometers did not significantly differentiate between themselves. The mechanized set operational speed did not influence the modified roughness variable, as there was no interaction between the evaluated treatments.

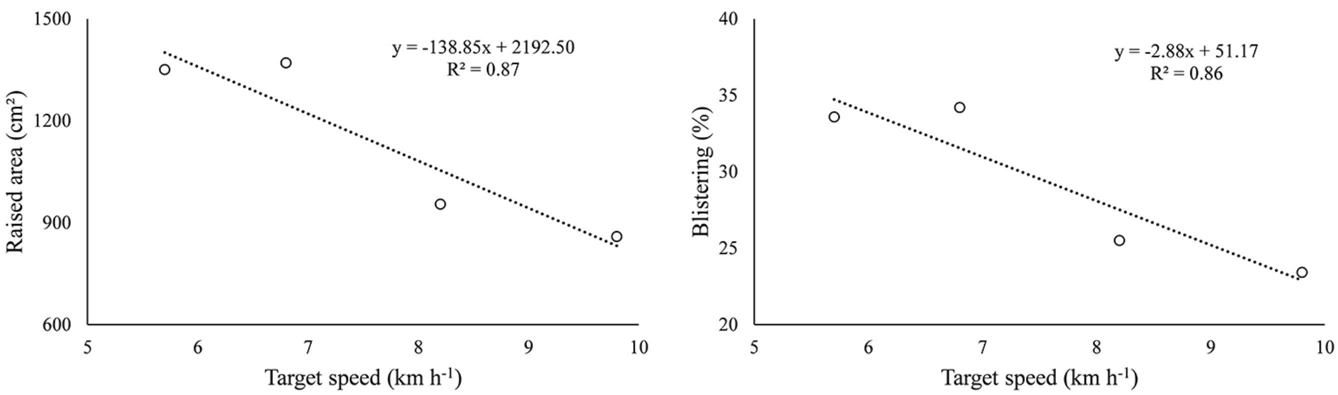

Figure 6. Target speed regression analysis

For the elevated area, the results of the F-test indicated that the mean values diverged by 38%, significantly to 5%, more for the electronic profilometer when compared to the conventional profilometer (Table 2). It showed a significant effect with the increase in the mechanized set operational speed (Fig. 6A), resulting in a decrease of 138.85 cm^2 of the elevated area with each one-kilometer per hour addition.

The tested profilometers' means also diverged statistically in the mobilized area, resulting in a 19% higher reading for the electronic profilometer. The operational set speed did not significantly influence the measurement of the mobilized area, as there were no reports of an interaction between the evaluated treatments (Table 2).

With soil blistering (Fig. 6B), which represents the percentage between the raised area and the mobilized area resulting from the action of the soil preparation implement, we observed that the lowest blistering index occurs at a speed of 9.8 km h^{-1}. That is due to the tendency of high area reduction with the increasing speed of the discs.

Additionally, a trend of lower values for the soil layer thickness was observed in this experiment, around 25% lower than the electronic profilometer, as shown in Table 2.

Discussion

The results presented in Table 1 support the validation of the development equipment, indicating its use for the field, corroborating with Laskoski et al. (2017). The developed profilometer did not statistically differ when compared to the traditional ones.

The conventional profilometer presented lower values for the elevated area due to the immersion of the rods on the surface of the mobilized soil (Table 2). The deepening of the stems underestimates the soil surface altimetric values, as described by Laskoski et al. (2017). Considering that this effect does not occur when using the electronic profilometer, the analyzed profile data is more accurate since its reading occurs through laser scanning of the soil surface (Ferenčík et al., 2019).

Speed selection affects the final groove quality, depending on the soil projection (Francetto et al., 2021), and influences the soil blistering index (Fig. 6B). The disk blade deflects the soil particles as a fluid, especially at high operating speeds, corroborating with Ahmadi (2018) when describing grid movements over the ground.

This fact shown in soil thickness (Table 2) is due to the sensitivity of the parameters to the characteristics of the used instrument, including its measurement scale (Martinez-Agirre et al., 2020). The conventional profilometer presents a biased reading for the elevated area resulting in the decrease of this parameter. The divergences related to soil thickness are due to the insertion of rods of the conventional profilometer into the soil at the time of installation of the equipment. That can also be correlated to lower soil density after the grading operation (Kool et al., 2019), promoting the occurrence of rod insertion into the soil.

With the verified similarity between the traditional and electronic equipment, there is the possibility of optimizing soil preparation monitoring. The monitoring can act as a data source for management plan elaborations and decision-making. It can also help the farmer acknowledge the real soil preparation quality, considering that conventional equipment can underestimate soil surface altimetric values because of the deepening of the reading rods. That does not occur with the developed equipment because its reading is performed indirectly through the laser sensor.

As conclusions, the obtained results demonstrate the efficiency of the developed profilometer in measuring the proposed parameters. It also provides greater data collection agility and operational mobility. The laboratory testing showed no significant difference in the parameters of modified roughness, elevated and mobilized area, blistering, and thickness, denoting the phase validation that indicates applicability in the field. During the field tests, the electronic profilometer presented superior results for the elevated and mobilized area and soil layer thickness. That is due to the absence of interference in the measurements that occur in the conventional profilometer due to the insertion of the rods in the soil. The increase in the mechanized set speed reduced the elevated area and soil blistering. That is due to the rise in the disc rotation and consequent soil particle deviation.

Authors' contributions

Conceptualization: G. G. Zimmermann, S. P. Jasper.
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Formal analysis: G. G. Zimmermann, S. P. Jasper, R. S. Ferraz.
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Supervision: S. P. Jasper.
Validation: G. G. Zimmermann, S. P. Jasper, D. Savi, R. S. Ferraz, E. A. Gracietti.
Visualization: G. G. Zimmermann, S. P. Jasper, D. Savi, R. S. Ferraz, E. A. Gracietti.
Writing – original draft: G. G. Zimmermann.
Writing – review & editing: G. G. Zimmermann.

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