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Operational uniformity for a sugarcane planter

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Sugarcane planters must simultaneously perform furrowing, fertiliser application, seedling metering and furrow covering operations. Thus, the objective of this study was to evaluate the planting operational stages (including furrow opening, size and shape; the uniformity of seedling metering; and furrow closing) as a function of the planting speed and furrow depth. A completely randomised, 2x2 factorial design was adopted, with two planting speeds (5.0 and 6.5 km h\(^{-1}\)) and two furrow depths (0.35 and 0.45 m), with 20 replicates. The variables analysed were number of billets m\(^{-1}\), number of total and viable buds m\(^{-1}\), percent of inviable buds, furrow depth, furrow width, disturbed area and seedling cover height. The results were subjected to descriptive analysis, analysis of variance and statistical process control. Increased planting speed caused an increase in disturbed area and a decrease in cover height. The increase in furrow depth caused increases in disturbed area, furrow width, furrow depth and cover height. Furrow opening, seedling metering, cover height, planting depths and operation speed were all uniform within the planting operation.

Key words: Planting speed, furrow depth, statistical process control, Saccharum officinarum.

INTRODUCTION

All operations involved in the agricultural production system of sugarcane can currently be mechanised. However, the option of total mechanisation of planting operations only became available a few years ago because those operations were previously mostly performed in a semi-mechanised manner, with manual seedling distribution (Janini, 2008).

To meet the increased demand for ethanol and sugar in the domestic and foreign markets, several areas of the sugarcane industry have been moving towards mechanised field planting to address a labour shortage and higher production costs due to significant increases in cultivated areas (Cebim et al., 2012).

According to Serafim et al. (2013), three basic stages of mechanised planting exist: 1– Mechanised seedling and harvesting; 2– seedling transport and transfer (conducted with tractors or trucks with a trailer, known as transhipment); and 3– planting with a planter. In these mechanised stages, the seedling buds are subjected to further damage. Therefore, many producers use 18 to 22 buds per metre of furrow at planting to ensure that the final quality of the seedlings allows the ratio of 12 buds

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per metre of furrow; the remaining buds are rendered inviable during the process (Raveli, 2013).

Sugar cane planting traditionally uses deep furrows, 0.25 to 0.40 m in depth (Marques and Pinto, 2013). The seedling cover height ranges from 0.05 to 0.10 m and can vary depending on the sugarcane variety and planting season. During summer planting, seedlings should receive a thinner cover (0.05 to 0.07 m) to prevent undesirable sitting. For late planting (fall and later), seedlings are better protected from drought with a thicker cover (0.08 to 0.10 m) (Coleti and Stupiello, 2006).

Barros and Milan (2010) reported that a non-standardised farming operation may influence the process quality, compromising its continuity. The authors studied the continuous improvement process in sugarcane planting to identify its critical factors. With the improvements, they observed an increase in numbers within the desired limits. Similar studies using statistical process control in sugarcane have been conducted by Campos et al. (2008), Silva et al. (2008), Noronha et al. (2011), Cassia et al. (2014) and Ramos et al. (2014).

Planting speed can interfere with seedling metering. In addition, when the speed is changed, the machine must maintain planter uniformity and close the furrow. This fact was found by Taghinezhad et al. (2014) and Namjoo et al. (2015), on development of sugarcane prototypes in Iran. Such behaviours also vary when the desired depth is changed because they hinder the joint action of the furrow opener with the depth regulators as well as the efficiency of the furrow covering mechanism.

Thus, this study aimed to evaluate the mechanised planting operational stages (including the opening, size and shape of furrows; quality and uniformity of billetmetering; and furrow closing) while varying the planting speed and furrow depth for a sugarcane planting prototype.

MATERIALS AND METHODS

The study was conducted on February 23, 2013 in the municipality of Ibitinga, São Paulo (SP), Brazil, in an area belonging to the Santa Fé Plant, located near the coordinates 21°48’35.05” S latitude and 48°55’30.27” W longitude, with an average altitude of 475 m. The soil of the experimental area was classified as Alic Red-yellow Latosol (Oxisol in the USDA soil classification system), with a medium texture, according to the methodology described by Embrapa (2013). The RB 96-6928 sugarcane variety was used in this experiment.

The mechanised sugarcane planting was conducted with a tractor-planter set, consisting of a Valtra BT 210 4x2 TDA tractor, with a 2200-rpm engine with 154.4 kW horsepower (210 cv), and a two-row sugarcane billet planter, Santal PDM 2 (Figure 1), which performs the planting operation (furrow opening, fertiliser application, seedling metering, insecticide application, furrow closing and compaction) in two rows simultaneously.

A completely randomised design (CRD) was adopted in a 2 x 2 factorial arrangement, with the following treatments: two planting speeds (5.0 and 6.5 km h⁻¹) and two furrow depths (0.35 and 0.45 m), with 20 replicates per treatment and each replicate composed of samples from both planting rows (right and left), at a 20 m distance from each other along the rows.

The billets used in the planting were characterised, and 30 units were collected inside the transhipment truck and planter. The billets were 431 mm in length, 27 mm in diameter, and 243 g in weight, with 3.6 buds per billet and 79% viability. The bud damage caused by the harvesting operation was 14.7%, with 6.4% damage in the transport to the planter.

The number of billets was recorded after planting by direct counting of four metres of the evaluation furrows after the furrows were opened with a hoe. For a better experimental control, only one evaluator performed the count for each treatment (20 replicates).

The total number of buds was counted by direct counting using the same billets previously obtained in the four meters of both evaluation furrows (left and right). The number of viable buds was determined by direct counting of the same billets used to assess the number of total buds in the four meters of both evaluation furrows and performed after the mechanised sugarcane planting. A viable bud was one with no damage caused by pests and diseases and also no cuts from the seedling harvesting until the planting in the furrows.

The percent of inviable buds was obtained from the difference between the total buds and viable buds, thus providing the percentage of damaged buds in relation to total buds. For the variables furrow depth, furrow width, disturbed area and cover height, a profilometer was used, consisting of 30 rods 3-cm apart with a maximum height of 70 cm. A grid with horizontal lines 1-cm apart was placed at the bottom of the profilometer for easy reading, and the readings were analysed using photographic images. The position of the upper end of the rods followed the geometric shape of the furrow, thus enabling the readings.

After planting, with the furrows covered, the measurements were conducted with the profilometer, and the furrow width was defined as the distance from the first rod to the last rod, disregarding the lateral soil elevation caused by the furrowing mechanism of the planter. Then, the furrows were manually opened until the compacted layer was found; it was then possible to model the furrows and to then proceed again with the profilometer measurements.

The furrow depth was defined as the average of the three rods with the highest measurement at the furrow bottom. The cover height was defined as the difference between the furrow depth and the average of the three rods with the highest measurement in the initial furrow.

To calculate the total disturbed area, after the photographic readings, the results were processed in a spreadsheet, where the cross-sectional area of the soil disturbed by the furrowing mechanism was obtained, in cm², through the trapezoid rule methodology (Ruggiero and Lopes, 1996).

During the planter operation, the soil water content was measured using the gravimetric method (Embrapa, 1997), which resulted in 11.1% in the 0.00-0.15 m layer, 13.5% in the 0.15-0.30 m layer, and 13.1% in the 0.30-0.45 m layer.

The results were processed by the Minitab® 16 software, in which descriptive analysis was conducted to determine the measures of central tendency (mean and median) and the coefficients of variation, skewness and kurtosis to assess the behaviour of the studied variables. The results were subjected to the Anderson-Darling normality test, and the variables with “non-normal” distribution were transformed. The data-fitting models used were $Y=\sqrt[4]{Y}$ for the variable damaged buds and $Y=\ln(Y)$ for the variable furrow width.

The transformed results were subjected to analysis of variance by the F-test, at 5% probability. When the F-test was significant, the means were compared by Tukey’s test, at 5% probability, using Sisvar 4.3.

The variability analysis was conducted using statistical process control in Minitab® 16 with variable control charts, using as indicators the previously described variables with non-normal data.
To obtain the charts, the mean values and upper (UCL) and lower (LCL) control limits for each treatment were plotted; the latter was defined as the overall mean of the variable ± three times the standard deviation. When the LCL calculation resulted in negative values, the LCL was considered to be null because negative values have no physical significance for the studied variables.

RESULTS AND DISCUSSION

As shown in Table 1, the variables billets m⁻¹, total and viable buds m⁻¹, furrow depth, disturbed area and cover height were normally distributed based on the Anderson-Darling test. The mean and median values are similar, which indicates little data dispersion, except for the variable damaged buds, whose median value is less than the mean.

The data dispersion parameter values reveal a high range and standard deviation for the variables billets m⁻¹, total and viable buds m⁻¹, and damaged buds, with coefficients of variation classified as high or very high (Pimentel-Gomes and Garcia, 2002), indicating high data variability. The cover height, despite having equal mean, median and range, also had a high standard deviation and consequently a high coefficient of variation.

Although, the data range was high for the variables furrow width and disturbed area, their standard deviations were low, and they therefore had low and medium coefficients of variation, respectively. For furrow depth, both the mean and standard deviation were low, with a medium coefficient of variation.

Filho and Storck (2007) and Freitas et al. (2009) stated that the coefficient of variation is the most used parameter to evaluate experimental quality, and the lower the coefficient of variation, the greater the experimental accuracy, and vice-versa. This parameter allows the comparison between experiments without the need for equal units.

When analysing the coefficients of skewness (Table 1), which quantify the deviation of a distribution relative to a symmetrical distribution, a small skewness is observed for the disturbed area and moderate skewness for billets m⁻¹, total viable buds m⁻¹, furrow width, furrow depth and cover height, where the two latter were negative, meaning that the frequency curve of the data distribution has a longer “tail” to the left. Only the percent of damaged buds had a high coefficient of skewness. The coefficients of kurtosis, or degree of “flattening” of a frequency distribution, reveal that the variables billets m⁻¹, total buds m⁻¹, damaged buds and furrow width exhibited (or more flattened at the top), with data weakly concentrated around its centre. For the variables viable buds m⁻¹, furrow depth, disturbed area and cover height,

Figure 1. Sugarcane billet planter (a and b); billet metering system (c and d).
Table 1. Descriptive statistical parameters for the analysed variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>R</th>
<th>CV</th>
<th>Cs</th>
<th>Ck</th>
<th>AD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billets m⁻¹</td>
<td>9.9</td>
<td>9.5</td>
<td>15.5</td>
<td>2.91</td>
<td>29.6</td>
<td>0.40</td>
<td>0.60</td>
</tr>
<tr>
<td>Total buds m⁻¹</td>
<td>31.5</td>
<td>30.3</td>
<td>50.0</td>
<td>9.68</td>
<td>30.8</td>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>Viable buds m⁻¹</td>
<td>27.7</td>
<td>27.0</td>
<td>45.5</td>
<td>8.81</td>
<td>31.8</td>
<td>0.34</td>
<td>0.18</td>
</tr>
<tr>
<td>Damaged buds (%)</td>
<td>11.9</td>
<td>10.1</td>
<td>35.7</td>
<td>6.87</td>
<td>58.0</td>
<td>1.12</td>
<td>1.28</td>
</tr>
<tr>
<td>Furrow depth (m)</td>
<td>0.37</td>
<td>0.37</td>
<td>0.20</td>
<td>0.04</td>
<td>11.5</td>
<td>-0.30</td>
<td>-0.31</td>
</tr>
<tr>
<td>Furrow width (m)</td>
<td>0.69</td>
<td>0.69</td>
<td>0.21</td>
<td>0.04</td>
<td>5.7</td>
<td>0.33</td>
<td>0.40</td>
</tr>
<tr>
<td>Disturbed area (cm²)</td>
<td>1444.3</td>
<td>1426.5</td>
<td>1179.0</td>
<td>251.2</td>
<td>17.4</td>
<td>0.07</td>
<td>-0.19</td>
</tr>
<tr>
<td>Cover height (m)</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.02</td>
<td>20.1</td>
<td>-0.16</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

R: range; σ: standard deviation; CV: coefficient of variation (%); Cs: coefficient of skewness; Ck: coefficient of kurtosis; AD: Anderson-Darling normality test value; N: skewed distribution; and N: Normal distribution.

Table 2. Analysis of variance and means test for the variables billets per metre and total, viable and damaged buds.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Billets per metre</th>
<th>Buds per metre</th>
<th>Damaged buds (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Viable</td>
</tr>
<tr>
<td>Planting speed (km h⁻¹) (S)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>9.8ᵃ</td>
<td>31.0ᵃ</td>
<td>27.5ᵃ</td>
</tr>
<tr>
<td>6.5</td>
<td>10.0ᵃ</td>
<td>31.9ᵃ</td>
<td>27.9ᵃ</td>
</tr>
<tr>
<td>Furrow depth (D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.35 m</td>
<td>9.7ᵃ</td>
<td>31.5ᵃ</td>
<td>27.5ᵃ</td>
</tr>
<tr>
<td>0.45 m</td>
<td>10.0ᵃ</td>
<td>31.5ᵃ</td>
<td>27.9ᵃ</td>
</tr>
<tr>
<td>F-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.08⁰ns</td>
<td>0.17⁰ns</td>
<td>0.03³ns</td>
</tr>
<tr>
<td>D</td>
<td>0.18⁰ns</td>
<td>0.00¹ns</td>
<td>0.03³ns</td>
</tr>
<tr>
<td>S x D</td>
<td>0.43⁰ns</td>
<td>0.00¹ns</td>
<td>0.06⁰ns</td>
</tr>
<tr>
<td>CV (%)</td>
<td>30.00</td>
<td>31.33</td>
<td>32.38</td>
</tr>
</tbody>
</table>

In each column, for each factor, means followed by the same letters do not differ by Tukey’s test at 5% probability. * indicates significant at 5% probability by the F-test. CV (%): coefficient of variation.

The distribution was leptokurtic, that is, the frequency curve was more narrow than a normal distribution (or more tapered at the top), with the data strongly concentrated around its centre. Although, the skewness and kurtosis data were not normally distributed, only the percent of damaged buds and furrow width had a non-normal distribution by the Anderson-Darling probability test. Voltarelli et al. (2013) characterised quality indicators in mechanised agricultural operations and found similar results, with high data variation.

The analysis of variance data (Table 2) demonstrate that the variables billets m⁻¹, total and viable buds m⁻¹, and damaged buds did not significantly differ with increasing planting speed or furrow depth, which can be explained by the very high coefficient of variation (Pimentel-Gomes and Garcia, 2002).

The planting density was 9.8 billets m⁻¹, greater than that found by Garcia (2008), who found 6 billets m⁻¹ in sugarcane mechanised planting with a planter. The bud density was high (31.4 m⁻¹), this variable is related to the...
number of billets, and of those, 27.7 m⁻¹ were viable buds. Raveli (2013) mentioned that the density of viable buds is the most important feature in the planting process, as it is crucial to ensure good operational results.

The damaged buds totalled 11.9%, which is not a high damage rate for mechanised planting. Raveli (2013) reported that when the billets pass through the seedling metering mechanisms of the planter, the buds become damaged due to the abrasiveness of the mechanism. Buds are sensitive plant structures and easily damaged under such conditions, which results in a reduced quantity of viable buds, hindering the sugarcane sprouting, the plant stand, and consequently the final crop yield.

Raveli (2013) found that 9.48% of the buds were rendered inviable by the mechanised planting operation. Garcia (2008) found 35% inviable buds after planting but did not state the percentage of buds that were rendered inviable by the planting operation.

The furrow depth (Table 3) was not affected by the planting speed, reaching a mean of 0.37 m. For the 0.35 m depth treatment, the furrow depth was similar to the pre-established depth (0.34 m), confirming that the planter has the ability to meet this setting, regardless of planting speed. Furrowing failed to meet the 0.45 m setting, digging 0.05 m lower than desired; however, uniformity was maintained, as indicated by the low coefficient of variation (8.59%), which justifies a new calibration of the depth-limiting wheel.

Anjos and Figueiredo (2008) stated that, in general, the depth should be between 0.25 and 0.30 m and not exceed the depth reached by the tillage system so that the root system reaches the aerated, uncompacted soil in conditions that favour root development. However, with the use of subsoilers in soil tillage, the furrow depth can be increased because the equipment decompacts the soil at greater depths.

In general, if the soil moisture conditions are favourable, good sprouting rates will occur, regardless of depth. However, in unfavourable climate conditions, a deeper furrow provides better moisture conditions for the billet. In addition, the deep furrow contributes to less erosion by decreasing surface runoff (Cebim, 2008).

For the furrow width, the results showed the same means for the higher planting speed (Table 3). Furrow width increased with greater furrow depth, but very little difference (0.03 m) was observed, which was expected due to the furrow opener shape, as the furrow opener reached higher soil depths under these conditions (0.45 cm).

Because it was directly correlated with the depth and width analyses, the area disturbed by the furrow openers exhibited a similar pattern of results as the furrow depth treatment (Table 3). The disturbed area increased by 6% when the planting speed increased, which was also observed by Silveira et al. (2011, 2013), and a larger disturbed area was observed with increasing furrow depth.

For the cover height of the furrows, although a difference was observed with treatment planting speed, it was small (0.01 m), and the remaining results were similar, averaging 0.10 m. These results indicate that this is an efficient covering mechanism, regardless of the planting conditions. The results can be considered adequate for crop sprouting; according to Coleti and Stupiello (2006), the billet cover height ranges from 0.05 to 0.10 m and can vary depending on the sugarcane variety and planting season.

Regarding the billet metering mechanism (Figure 2a), the right and left furrows were uniform for all treatments (speed x depth). Low variability was observed in the billet metering operation, which indicates operational uniformity.

Table 3. Analysis of variance and means test for furrow depth, furrow width, disturbed area and cover height.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Furrow depth (m)</th>
<th>Furrow width (m)</th>
<th>Disturbed area (cm²)</th>
<th>Cover height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting speed (km h⁻¹) (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>0.37ᵃ</td>
<td>0.68ᵃ</td>
<td>1401.9ᵇ</td>
<td>0.11ᵃ</td>
</tr>
<tr>
<td>6.5</td>
<td>0.37ᵃ</td>
<td>0.70ᵇ</td>
<td>1486.7ᵃ</td>
<td>0.10ᵇ</td>
</tr>
<tr>
<td>Furrow depth (D)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.35 m</td>
<td>0.34ᵇ</td>
<td>0.67ᵇ</td>
<td>1271.8ᵇ</td>
<td>0.10ᵃ</td>
</tr>
<tr>
<td>0.45 m</td>
<td>0.40ᵇ</td>
<td>0.70ᵃ</td>
<td>1616.8ᵃ</td>
<td>0.10ᵃ</td>
</tr>
<tr>
<td>F-test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.216ᵃ</td>
<td>1.815ᵇ</td>
<td>4.437*</td>
<td>4.884*</td>
</tr>
<tr>
<td>D</td>
<td>60.552ᵃ</td>
<td>10.704*</td>
<td>73.529*</td>
<td>1.106ᵇ</td>
</tr>
<tr>
<td>S x D</td>
<td>3.436ᵃ</td>
<td>0.037ᵇ</td>
<td>0.037ᵇ</td>
<td>1.278ᵇ</td>
</tr>
<tr>
<td>CV (%)</td>
<td>8.59</td>
<td>1.37</td>
<td>12.46</td>
<td>19.54</td>
</tr>
</tbody>
</table>

In each column, for each factor, means followed by the same letters do not differ by Tukey’s test at 5% probability. "ns" indicates not significant; "*" indicates significant at 5% probability by the F-test. CV (%): coefficient of variation.
as the results did not go outside the statistical control limits at any points. Thus, even if the planting speed and the furrow depth are increased, the planter performs the billet metering operation within the uniformity standards.

For total buds m\(^{-1}\) (Figure 2b), a pattern similar to that obtained for billet metering was observed, with only one point outside the control limits for the left planting furrow, at a 0.45 m depth, for both planting speeds, 5.0 and 6.5 km h\(^{-1}\); this pattern may be attributed to factors such as tractor sliding and lack of pressure in the hydraulic system. However, in general, uniformity is again observed between the right and left furrows, and variability was only increased by the high number of buds per billet (measured in the billet characterization stage).

The number of viable buds m\(^{-1}\) (Figure 3a) exhibits similar results to the number of billets m\(^{-1}\) (Figure 2a) and
Figure 3. Variable control charts: viable buds m⁻¹ (a) and damaged buds (%) (b). LF: Left furrow; RF: right furrow; UCL: upper control limit; LCL: lower control limit; X: mean of individual values; and MR: mobile range.

includes bud damage caused by the planter, given that the damage caused during the harvest and transport stages has already been accounted for. The results stayed within the control limits, with no change as a function of the treatment. The metering operation remains uniform during seedling loading in the planter and is not affected as the planter seedling load decreases.

For damaged buds (Figure 3b), some points were outside the normal process variation at the 0.45 m depth and planting speed of 6.5 km⁻¹. However, this was an isolated occurrence within the sample, suggesting vulnerability of the operation only in these conditions and thus not hindering the operational quality.

The furrow depth results (Figure 4a) are uniform, with
Figure 4. Variable control charts: furrow depth (m) (a) and furrow width (m) (b). LF: Left furrow; RF: right furrow; UCL: upper control limit; LCL: lower control limit; X: mean of individual values; and MR: mobile range.

Low values for range and variation and the absence of any abnormal events during the operation. Moreover, depth did not decrease along the seedling metering operation, demonstrating that the prototype furrowing system, which follows the ground surface, is able to compensate for the weight loss of the billets inside the planter throughout the operation. When the planting speed increased, there was also no reduction in furrow depth; that is, the machine maintained uniformity with increasing operational capacity.
For furrow width (Figure 4b), the uniformity in samples is again observed, with reduced range and variation values, as well as the absence of any abnormal events throughout the operation. As with the furrow depth, the planter was able to maintain furrow uniformity regardless of planting speed or changes in the seedling load inside it, which changes its total weight.

Because it is directly correlated with the depth and width analyses, the results for the soil area disturbed by furrow openers were very similar (Figure 5a). The range between the left and right furrows increased, which does not compromise the operation because, as shown in
Figures 4a and 4b, despite the variability in the soil surface, the planter is able to maintain uniformity. The variability remained within the control limits, suggesting that it is an effect of the process, which is constantly subject to change.

The cover height results (Figure 5b) were homogeneous despite the occurrence of one point outside the control limits, which may be linked to the lack of uniformity of the aggregates, thus forming lumps, especially at higher depths and speeds.

Conclusions

The increase in planting speed caused an increase in disturbed area and a decrease in cover height. Increased furrow depth caused increased disturbed area, furrow width, furrow depth and cover height. The planting operation demonstrated operational uniformity in furrow opening, seedling metering and cover height at the different planting depths and speeds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

REFERENCES


