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APPLICATION OF STATISTICAL PROCESS CONTROL IN MECHANIZED CORN SEEDING

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Abstract

Several factors alter the quality of the mechanized sowing process of corn, and the use of the statistical process control (SPC) technique not only allows the identification of process limitation points but also ensures the correct functioning and conduction of the mechanized process, determining critical factors. that may decrease their performance. In view of the above, the present study aims to qualitatively evaluate, through this technique, the longitudinal distribution of corn seeds as a function of different stands and operational speeds during the sowing process. The experiment was carried out in a randomized block design (CBD) with three replications and in a split-plot design. Data were submitted to analysis of variance and when significant, analyzed using Tukey's test, with 5% significance. To carry out the statistical process control, mean and amplitude control charts were used to evaluate the effect of operational speed, seed distribution, deposition depth and plant germination. The results indicate that the use of statistical process control is an efficient tool to identify the behavior of the corn sowing process. Based on the results, speeds close to 4.5 km/h allowed an efficient sowing process, as it presented a higher percentage of normal spaces in the distribution of maize seeds.

Keywords: control charts; germination; control charts; precision index; depth of deposition; operating speed.

APLICAÇÃO DO CONTROLE ESTATÍSTICO DE PROCESSO NA SEMEADURA MECANIZADA DO MILHO

Resumo

Vários fatores alteram a qualidade do processo de semeadura mecanizada do milho, e o uso da técnica do controle estatístico de processos (CEP) não só permite a identificação de pontos de limitação do processo como asseguram o correto funcionamento e condução do processo mecanizado determinando fatores críticos que possam diminuir seu desempenho. Diante do exposto, o presente estudo visa avaliar qualitativamente por meio desta técnica a distribuição longitudinal das sementes de milho em função de diferentes estandes e velocidades operacionais durante o processo de semeadura. O experimento foi realizado em delineamento de blocos casualizados (DBC) com três repetições e em esquema de parcela subdividida. Os dados foram submetidos a análise de variância e quando significativos analisados por meio do teste de Tukey, com 5% de significância. Para a realização do controle estatístico de processo, foram utilizadas cartas de controle de média e amplitude para avaliar o efeito da velocidade operacional, distribuição das sementes, a profundidade de deposição e a germinação das plantas. Os resultados indicam que o uso do controle estatístico de processo é uma ferramenta eficiente na identificação do comportamento do processo de semeadura do milho. Com base nos resultados, velocidades próximas a 4.5 km/h permitiram um processo de semeadura eficiente por apresentar maior percentual de espaços normais na distribuição de sementes de milho.

Palavras -Chave: germinação; gráfico de controle; índice de precisão; profundidade de deposição; velocidade operacional.

Introduction

Corn (*Zea mays* L.) is a crop of great economic importance due to its high nutritional value and intensive use in human and animal nutrition, and its yield is the result of several factors, such as the genetics of the seeds, soil and climate conditions, sowing operation, crop management, and spatial arrangement of plants (GALVÃO *et al.*, 2014; BATISTA *et al.*, 2018).

According to Sangoi *et al.* (2012), adequate population density and correct longitudinal distribution of corn plants in the sowing row are important factors when aiming to achieve high productivity since corn is highly sensitive to plant population variations, row spacing, distribution of plants in the row and uniformity of seedling emergence. In this sense, knowledge and quantification of spatial variability and the development of gaps and duplicated plants in the sowing furrow are also essential (STORCK *et al.*, 2015).

In the qualitative aspect of the sowing process, the proper adjustment of the seeder, including the machine's displacement speed, and dosing mechanisms, which deposit seeds at pre-established sowing densities, allow improvements in the results of the longitudinal distribution of seeds (DIAS *et al.*, 2014; BERTELLI *et al.*, 2016).

Albiero *et al.* (2012) mention that due to the high variability of agricultural processes, this result rarely occurs since the process varies depending on the raw material, mechanized systems, quality indices of agricultural operations, and operator qualification, among others. Therefore, the search for factors that optimize operational effectiveness and efficiency in agricultural operations allows for reducing the variability of controlled variables, allowing operational conditions with greater quality control.

The use of process quality control instruments is necessary to ensure the correct functioning of the process based on critical factors and, specifically in agriculture, aims to identify factors related to the efficiency and effectiveness of agricultural operations (MELO *et al.,* 2013). Therefore, with the application of this instrument, it is possible to verify the stability of agricultural operations, indicating whether the instability or variability of the agricultural process is generated by random causes (intrinsic) or by special causes (extrinsic), which helps in decision-making (VOLTARELLI *et al.*, 2015).

Given the above, statistical methods for process control allow to evaluate the quality of corn planting to continuously improve the mechanized operation. Thus, this study aimed to apply statistical process control (SPC) to qualitatively evaluate the longitudinal distribution of seeds in a precision seeder as a function of different population densities and operating speeds in the corn crop.

Material and Methods

The experiment was carried out at the Federal Rural University of Rio de Janeiro - UFRRJ/ Seropédica-RJ, located at geographic coordinates 22° 46' 24" South Latitude and 43° 42' 08" West Longitude, and 33 m average altitude, on soil classified as Planossolo (EMBRAPA, 2006).

For the implementation of the experiment, in an area previously used for grazing, chemical control of weeds was carried out in the area, where after ten days the AL Avaré S2 corn cultivar (*Z. mays* L.) was planted, with 98% purity and 85% minimum germination, defined by the manufacturer on its packaging.

As a source of traction for moving the seeder-fertilizer, a John Deere tractor, model 5403, 4x2 TDA, rated engine power of 65 hp (47.8 kW) was used, equipped with rear diagonal tires measuring 16.9 -30 and front tires measuring 12.4-24, with 75% net ballasting in each, and a mass of 2,323 kg. The average slip during the operation was 9%, within acceptable limits for diagonal tires.

The precision seeder-fertilizer used was a Tatu Marchesan, model STP2, equipped with four seeding units spaced at 0.8 m, lagged double disc furrow opener for fertilizer and seeds, and a horizontal plate disc seed dosing mechanism with 28 holes, set to apply 400 kg/ha granulated mineral fertilizer NPK 04-14-08, according to recommendations obtained through soil analysis.

As a source of variation in the study, three populations of plants for the crop and four sowing speeds were tested. Thus, the experiment was carried out in a randomized block experimental design, with three replications and treatments arranged in a split plot. The plots were the plant populations (48,000; 65,000 and 72,000 plants/ha), and the subplots were the sowing speeds (2.2; 4.5; 5.8; and 8.3 km/h), totaling thirty-six experimental plots of 96 m^2 useful area.

Uniformity in seed longitudinal distribution in the sowing row was determined by measuring the distance between the emerged corn plants in the rows at two different points located in the middle and at the end of the row so that a sufficient distance was ensured for the full development of the desired operating speed for the evaluation.

During the sowing process, the deposition depth and the incidence of double seeds, seeds broken by damage, and mechanical failures were also determined. A second evaluation was carried out after a period of six days after sowing, which allowed checking the number of viable plants, that is, those with complete development during this period.

Spacings were evaluated and classified according to the methodology adapted by Kurachi *et al.* (1989). Thus, the percentage of spacing corresponding to the classes was determined: normal (0.5Xref <Xi< 1.5 XRef), multiple (Xi<0.5 XRef), and failed (Xi>1.5 XRef), based on the reference spacing (XRef), according to the seeder-fertilizer setting for the populations evaluated in the study, according to Table 1.

Table 1. Corresponding classes to spacing as a function of the desired population.

Population (plants ha^{-1})	**XRef**	**Normal**	**Multiple**	**Failed**
48000	26 cm	26< xi<39 cm	xi<13 cm	xi>39 cm
65000	19 cm	19< xi< 28,5 cm	xi<9,5 cm	xi>28,5 cm
72000	17,3 cm	17,3<xi<25,9 cm	xi< 8,6 cm	xi>25,9 cm

To express the uniformity of spacing between plants, the coefficient of variation of all spacing between plants in the sample (normal, multiple, and failed) was determined using equation 1:

$$CV = \left(\frac{S2}{x}\right).100 \quad (1)$$

where,

CV- Coefficient of variation, %;

S_2 - standard deviation of all spacing between plants, cm; and X- Mean of all spacing between plants, cm.

The plant distribution precision index corresponded to the ratio of the standard deviation of the normal spacing to the reference spacing of the seeder-fertilizer used for each population, calculated by equation 2:

$$IP = \left(\frac{S2}{Xref}\right).100 \qquad (2)$$

where,

IP - precision index;

S_2 - Standard deviation of normal spacing between plants, cm; and

Xref- reference spacing for the studied populations.

Data obtained for the spatial distribution, sowing depth, spacing uniformity, and precision index were tested by analysis of variance, F-test at 5% significance, and when significant, analyzed by Tukey's test for means comparison at 5% significance.

To assess the quality of sowing, a descriptive analysis of the data was performed, thus calculating the arithmetic mean, median, maximum and minimum values, standard deviation and coefficients of variation (CV), asymmetry (Cs), and kurtosis (Ck). Data normality was checked by the Shapiro-Wilk test, using control charts for individual values as statistical methods. Thus, the control and range graphs showed, as a central line, the overall mean, the mean range, the upper (UCL) and lower control limits (LCL), calculated based on the standard deviation of the variables (for UCL = 3σ, and for LCL = -3σ), when greater than zero.

Results and Discussion

The results of the analysis of variance in Table 2 evidenced that the regulation of planting density (DS) was significant for spacing, as well as for normal and multiple spacing. Regarding the operational speeds (V) evaluated, the effect was significant for normal spacing, multiple spacing, failed spacing, coefficient of variation, and precision index. According to Kopper *et al.* (2017), specifically in the corn crop, the increase in population density and the decrease in row spacing intensify competition for light, nutrients, and water, thus mainly limiting the production of grains per ear.

Table 2. Analysis of variance expressed by F-test and test of mean for planting depth (Prof), spacing (Esp), normal spacing (Eno), múltiple spacing (Emul), failed spacing (Ef), coefficient of variation (CV) e precision index (IP).

Density (plantas/ha)	**Prof (cm)**	**Esp (cm)**	**Eno (%)**	**Emul (%)**	**Ef (%)**	**CV (%)**	**IP (%)**
48000	6,3 a	33,1 a	66,7 a	16,7 a	16,a	26,1 a	10,6 a
65000	4,6 a	23,2 b	66,7 a	16,7 a	16,a	25,8 a	13,6 a
72000	5,6 a	20,1 b	58,3 b	25 b	16,a	24,9 a	12,9 a
Speeds (km/h)	**Prof (cm)**	**Esp (cm)**	**Eno (%)**	**Emul (%)**	**Ef (%)**	**CV (%)**	**IP (%)**
2,2	6,0 a	21,1 a	44,4 d	41,4 a	14,2 b	29,2 b	34,5 a
4,5	5,4 a	27,4 a	88,8 a	0,8 c	11,2 b	34,7 a	22,5 c
5,8	5,3 a	26,7 a	66,7 b	11,2 c	22,1 a	40,8 a	26,9 b
8,3	5,2 a	26,5 a	55,5 c	22,2 b	22,3 a	25,9 b	12,4 d
F-Test							
DP	6,6 ns	192,6*	184,4 *	143,2 *	4,94 ns	15,26 ns	1,14 ns
V	2,4 ns	36,6 ns	1162 *	1035,1 *	121,2*	137,2 *	225,7 *
POP x V	4,1 ns	19,8 ns	97,6 ns	38,4 ns	45,7 ns	20,8 ns	126,5 ns
CV (%)	30,7	21,8	27,3	22,1	18,5	25,8	12,6

Means followed by the same letter in the column do not differ statistically by the Tukey test at 5%. ns-not significant; *-significant to the F test at 5%.

The sowing depth showed no significant effect of any of the analyzed factors and their interaction, with results similar to those reported by Troguello *et al.* (2013), who evaluated different soil management and operating speeds. On the other hand, Garcia *et al.* (2011) studied the sowing quality in the corn crop, at two operating speeds, and observed that the increase in speed from 2.5 to 4.4 km/h provided a depth increase of 30.2%, at speeds similar to those evaluated in the present study.

As for the operational speeds evaluated, the speeds of 2.2 and 8.3 km/h presented lower percentages for normal spacing and higher percentages for multiple spacing, statistically differing from the other evaluated treatments. In general, in longitudinal seed distribution, the occurrence of double and failed spacing should be null or close to zero, however, the speed of displacement of the machine, the filling of the cells, and the speed of fall of the seeds directly affect the uniformity in seed distribution, thus decreasing the percentage of normal spacing.

Thus, according to the criterion reported by Tourino *et al.* (2009), the seeder performed well, considering that it distributed the seeds in the range of 75 to 90% normal spacing. In this way, in the present study, the speed of 4.5 km/h presented a value within the acceptable range, 88.8%, allowing to state that the ideal range for the best seed deposition is close to this operational speed.

As for failed spacing, there was an increase as operational speeds above 5.8 km/h were adopted. The results obtained corroborate Santos *et al.* (2011), in which the mechanized sowing process, the increase in speed interferes with the establishment of plants in the field, as it negatively influences the amount of adequate spacing and increases the number of failures during sowing.

The seeder precision index decreased as the operating speed increased and was statistically different for each speed. In general, our findings were similar to those obtained by other authors such as Bottega *et al.* (2018) and Alonço *et al.* (2015), varying between 10 and 35% of hits in the evaluated speeds for precision seeders.

The lowest operational speed tested in the present study (2.2 km/h) presented a precision of 34.5%. According to Bertelli *et al.* (2016), even at lower speeds, practices have to be adopted to allow the proper use of the furrow opening mechanism and the regulation of the seed dosing mechanism, resulting in a quality operation and thus allowing greater crop production.

To verify the quality of the sowing process, Table 3 lists the results of descriptive statistics of the parameters of central tendency (mean, median, and amplitude) and dispersion (standard deviation and coefficient of variation) for seed spacing, sowing depth, and germination. According to Pimentel-Gomes (2009), if the coefficient of variation (CV) is less than 10%, it is considered low, that is, the experiment has greater precision; between 10 and 20% is considered medium, and high between 20 and 30%.

Table 3. Descriptive statistical analysis for spacing, depth, and germination of the sowing process.

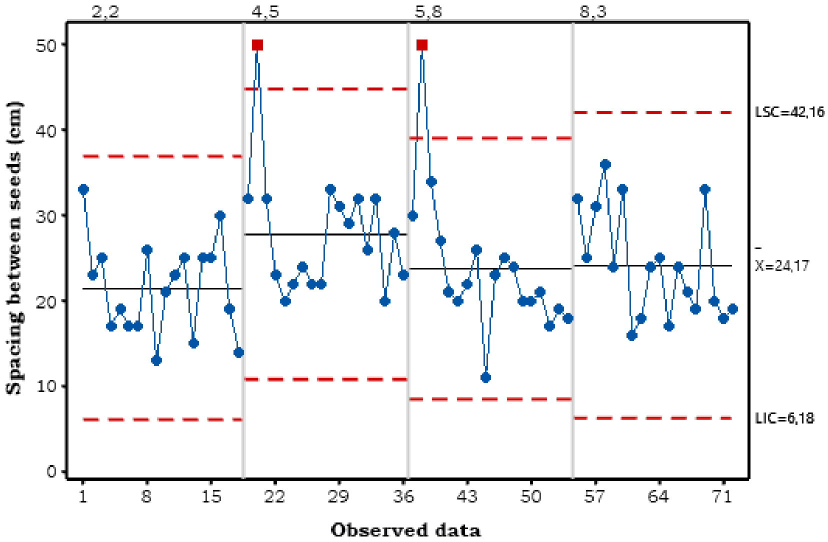
			Value			Coeficientes			
Variable	**Mean**	**Median**	**Max.**	**Min.**	**Standard deviation**	**CV**	**Ck**	**Cs**	
Seed spacing (cm)	24,3	23,0	50,0	11,0	7,16	29,4	2,95	1,26	A
Sowing depth (cm)	5,4	5,5	9,0	2,0	1,71	31,9	-0,59	-0,19	N
Germination (%)	65,3	64,6	100	20	22,8	34,9	-0,93	0,03	N

(N) normal distribution (A) asymmetric distribution by Shapiro Wilk's test at 5% probability

From this analysis, the values of the coefficients of variation found indicate a high dispersion for all the evaluated variables. Melo *et al.* (2013) qualitatively evaluated, using statistical process control, the longitudinal distribution of seeds based on two speeds (4 and 7 km/h) and two types of seeders (precision and pneumatic), and observed values similar to those obtained here.

Based on the data obtained, control charts were made, as illustrated in Figure 1. The individual control chart indicated that, during the sowing process, the spacing between plants remained under control for the speeds of 2.2 and 8.3 km/h, and the opposite pattern was observed for the other speeds evaluated. Most of the data were below the mean value for each evaluated speed class, such behavior is explained by the kurtosis and the asymmetry coefficients that present positive values, as well as indicate the degree of dispersion to the right and above the values of the distribution around the mean.

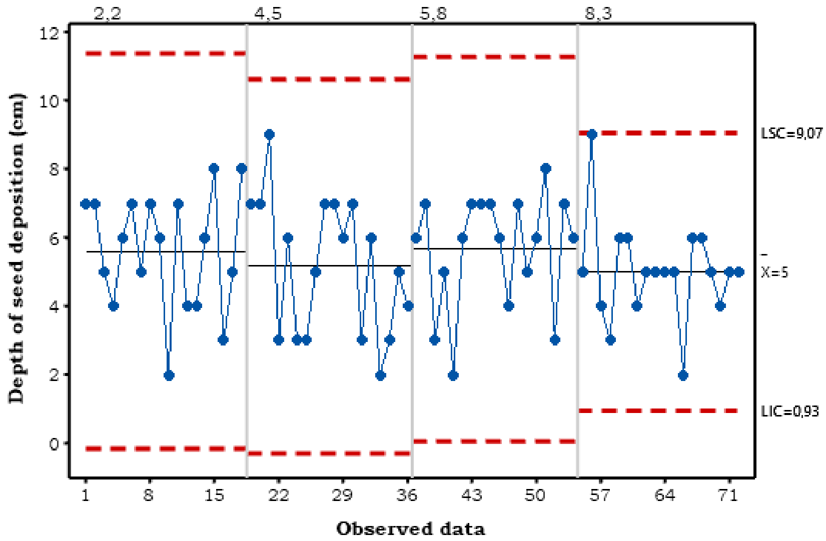
Figure 1. Control chart for seed spacing as a function of operating speed.



In the specific case of speeds 4.5 and 5.8 km/h, the process presented instability and, in both cases, the process was out of control, due to the presence of points outside the control limits (points 20 and 38). Such behavior can be explained by the presence of special reasons inherent to the sowing process. Weirich Neto *et al*. (2015) studied the distribution of corn seeds and highlighted the main reasons for the reduction in the quality of the operation factors such as disc and/or ring inappropriate for the hybrid sieve, lack or excess of graphite, treatment of seeds with high abrasiveness, seed positioning inside the furrow, soil-seed contact made difficult by the amount of straw in the furrow opening system, inadequate soil moisture for sowing.

When evaluating the depth of seed deposition, the distribution of values according to all the studied velocities allows to state that the process remained controlled, as shown in Figure 2. The general mean depth of seed deposition was 5.4 cm deep, which according to Weirich Neto *et al*. (2007) is within the ideal range for corn cultivation, which is approximately 50 mm, as possible variations depend on other factors, such as soil conditions and management.

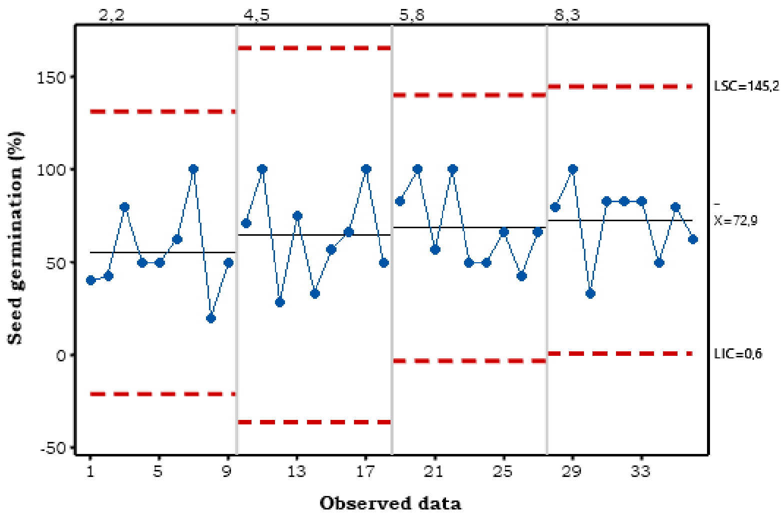
Figura 2. Control chart of seed deposition depth as a function of operational speed.



In general, sowing depths must be adequate to guarantee seed germination and seedling emergence, as greater depths make emergence difficult due to greater energy expenditure of seeds, while very shallow depths, or bare seeds, are subjected to difficulties due to low soil moisture due to less contact of the seeds with the soil.

Regarding seed germination, according to Figure 3, for all evaluated speeds, data were within the limits of statistical control. Importantly, in soils that are not conventionally managed, higher operating speeds promote greater soil stirring, reduced straw-cutting efficiency, lower planting depth, and furrow compaction, which can directly interfere with the germination process.

Figure 3. Control plot of corn seed germination as a function of displacement speed.



Therefore, according to the data obtained, and under the experimental conditions, germination presented values between 55 and 72.9%, values well below the germination given by the seed manufacturer. According to Copetti (2014), in the specific case of germination, the results may be directly related to possible mechanical damage and seed quality.

In view of the results, the statistical control of the processes allowed to identify the factors that made possible the instability in the longitudinal distribution of the seeds as a function of the operational speed. Similar results were obtained by Arcoverde *et al*. (2016), highlighting the need to establish an improvement plan that includes training and monitoring actions in the sowing operation.

Conclusion

The use of statistical process control (SPC) was efficient in identifying the behavior of the sowing process, indicating instability in the longitudinal distribution of seeds and stability in seed deposition depth and germination for the evaluated speeds. According to the results and the qualitative analysis of the sowing process, the ideal speed for corn sowing is close to 4.5 km/h, thus presenting an acceptable distribution of seeds based on the highest percentage of normal spacing. Higher operating speeds present lower planting precision due to the significant increase in the percentage of missed and multiple spacing during the corn-sowing process.

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