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# ARRANGEMENTS POPULATION AND ROW SPACING IN THE DEVELOPMENT OF CORN

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**ABSTRACT –** Different arrangements between plants make it possible to optimize the use of natural resources available in corn production, achieving better yield. Thus, this work aimed to evaluate some productive traits of the crop in different spatial arrangements. The leading production indicators of the corn were evaluated at the Experimental Farm of the São Paulo State University (FCAV – UNESP), campus in Jaboticabal – SP, Brazil—the statistical design in randomized blocks, with four replications. The treatments corresponded to 2-row spacings (single-row with 0.90m and twin-rows, interspersing spacing of 0.45m and 0.90m) and three plant populations (55,000, 60,000 and 65,000 plants ha$^{-1}$), composing a 2 x 3 factorial. Confirmatory and descriptive statistical analyses were carried out, and the statistical process control constructed control charts. Twin-row spacing showed the best results for yield and height of the first ear. The 65,000 ha$^{-1}$ population stood out for its lower data variability (smaller amplitude), providing more excellent quality in corn grain yield through spatial optimization of available resources.

**Keywords:** Statistical process control, Control charts, Corn Yield

# ARRANJOS DE SEMEADURA NO DESENVOLVIMENTO DA CULTURA DO MILHO

**RESUMO** - Por meio de diferentes arranjos entre as plantas é possível otimizar a utilização dos recursos naturais disponíveis na produção do milho, alcançado melhores produtividades. Dessa forma, objetivou-se com este trabalho avaliar alguns caracteres produtivos da cultura em diferentes arranjos espaciais. Foram avaliados os principais parâmetros indicadores de produtividade da cultura em uma área experimental da Fazenda de Ensino, Pesquisa e Extensão da Unesp/Jaboticabal-SP. O delineamento estatístico em blocos casualizados (DBC), com quatro repetições. Os tratamentos corresponderam a 2 espaçamentos de entrelinhas (linhas simples com 0,90m e linhas gêmeas intercalando espaçamento de 0,45m e 0,90m) e 3 populações de plantas (55.000, 60.000 e 65.000 plantas ha$^{-1}$), compondo um fatorial 2 x 3. Foram realizadas as análises estatísticas confirmatória, descritiva e construídas as cartas de controle de acordo com as premissas do controle estatístico do processo. Os espaçamentos em linhas gêmeas apresentaram os melhores resultados para produtividade e altura da primeira espiga. A população 65.000 ha$^{-1}$ destacou pela menor variabilidade dos dados (menor amplitude), conferindo maior qualidade nos valores de produtividade de grãos de milho por meio da otimização espacial dos recursos disponíveis.

**Palavras-chave:** Controle estatístico de processo, Cartas de controle, Produtividade

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Corn is a globally significant crop, with world production in 2022 reaching 1.21 billion tons (FAO, 2023). In Brazil, the 2022/2023 harvest yielded 131.87 million tons with an average yield of 5.9 tons per hectare (CONAB, 2023). However, low yield remains a challenge, often attributed to factors such as soil fertility, spatial arrangement of plants, choice of cultivars, water and nutrient deficiency stress, sowing time, poor control of practices and organic plants.

Corn cultivation is very demanding regarding spatial arrangement, as the corn plant has little or no compensatory effect when there is a failure and a double plant. Different arrangements from the usual for crops are an important factor in enhancing grain yield due to better efficiency in the incidence of solar radiation, photosynthetic rate, and canopy respiration (FERREIRA et al., 2021). That is why significant investments are already in narrow-row seeders and harvesters, leading corn producers to adopt twin-row plant arrangements (HAEGELE et al., 2014).

Twin-row corn can be an alternative for optimizing the spatial distribution of seeds, avoiding competition between plants in the sowing line for better use of available crop resources in a sustainable way (BALEM et al., 2014). The quality of the sowing process can provide adequate answers regarding the best spatial arrangement. Since the culture is monitored during its development, it indicates possible failures for possible process improvements to increase the quality of these operations (ORMOND et al., 2019). Therefore, based on the assumption that different spatial arrangements can interfere with the yield and quality of the corn production process, this experiment aimed to evaluate productive traits in different spatial arrangements.

## Material and Methods

The experiment was installed in the experimental area of Unesp/Jaboticabal-SP, close to the geographic coordinates 21°14’54” S and 48°16’51” W, with an average altitude of 568 meters, slope of 4% and gentle undulating relief. The soil was classified as RED LATOSOL typical eutrophic, with clayey texture (EMBRAPA, 2013). Aw climate (subtropical), according to the Köppen classification adapted by Alvares et al. (2013).

The corn crop was direct seeding system, from January to May 2015, using the simple hybrid P3456H from Pioneer. Mineral fertilization, in the sowing furrow, was with 350 kg ha$^{-1}$ of the 08-28-16 (NPK formula). Top dressing at stage V4, using 120 kg of KCl ha$^{-1}$ and 300 kg of Urea ha$^{-1}$. To control weeds, 1.2 L ha$^{-1}$ of Paraquat (200g L$^{-1}$) and 2.0 liters ha$^{-1}$ of Atrazine.

During the evaluated period, there was a total rainfall of 567.2 mm. The average maximum temperature was 28.84°C, oscillating between 25.92°C and 30.54°C, and the average minimum temperature was 19.02°C, oscillating between 15.54°C and 23. 06°C. The average relative humidity was 80.38%, ranging between 70.54 and 87.76%. Data were collected at the Unesp/


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Jaboticabal-SP meteorological station.

The Massey Ferguson tractor model MF 7370 with power of 125 kW (170 hp) in the engine, nominal rotation of 2000 rpm that gives 540 rpm in the power take-off, Tractor (4 × 2 TDA), working in the march L3, to realize the sowing of the crop. The seeder consisted of 7 rows spaced 0.45 m apart (working width 3.6 m), adjustable to different row spacings by removing the central seeding units.

The statistical design used was randomized blocks, with treatments of 2 spacing (single-row of 0.90m) and twin-row (interspersing spacings of 0.45m and 0.90m) and 3 plant populations (55,000, 60,000 and 65,000 plants $ha^{-1}$). This treatments composed a 2 x 3 factorial with 4 replications, making a total of 24 plots of $10m^2$.

The variables collected in each experimental plot were described and referenced as: a) ear height: they were obtained through measurement, with a millimeter ruler; from the base of the plant close to the ground until the ear insertion; b) Mass of 1000 grains: random counting of eight repetitions of 1000 grains was carried out (BRASIL, 2009); c) Number of rows per ear: count of the number of rows per ear; d) Number of grains per rows of ear: count of the average number of grains per rows of ear; and e) Grain yield (kg $ha^{-1}$): ears were collected from the useful area of each plot and threshed using a mechanical threshing machine. The grains were separated, weighed and the values corrected for the wet basis of 13%, and the values extrapolated to kg $ha^{-1}$.

Descriptive statistics were performed, with measures of central tendency (arithmetic mean and median), measures of dispersion (amplitude, standard deviation, and coefficient of variation) calculated, and the symmetry and kurtosis coefficients calculated.

Analysis of variance was performed, using Snedecor's F test, at 5% probability and when there was significance, the Tukey test was applied at 5% probability to compare means, using the SAS® statistical package.

To verify the quality of the sowing process, the results were evaluated through statistical control of the process, according to the statistical design from the quality control perspective. We collected 32 random samples, depending on the space for each variable, which were considered a quality indicator for the analysis of the process.

The lower (LCL) and upper control limits (UCL) resulted from statistical analysis and were determined according to the process variability. Control limits allow inferring whether there is variation in results due to uncontrolled causes in the process (special causes). They are calculated based on the standard deviation of the variables, as demonstrated in equations 1 and 2.

$$UCL = \bar{x} + 3\sigma \ (1)$$

$$LCL = \bar{x} - 3\sigma \ (2)$$

where,

UCL: upper control limit;

$\bar{x}$: mean of the variable;

σ: standard deviation.


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LCL: lower control limit (If the calculated value of the LIC was negative, it was considered null, LCL = 0).

If there is an outlier (failure due to special causes), the control chart highlights the out-of-control point with the respective error number. This occurrence may indicate non-random variation in the results due to a special cause and should be investigated. When no point is highlighted on the control chart, there is no fault observation in the process; consequently, the process is under statistical control.

The Minitab® software was used to create descriptive statistics and control charts. The normality of the data was also verified using the Ryan-Joiner test at 5%.

## Results and discussion

All the data analyzed were normal, confirmed by the Ryan-Joiner test (Table 1). According to descriptive analysis, the data already indicated this normal behavior due to the asymmetry and kurtosis coefficients being within the range between -2 and 2, the standard deviation values being close to zero, and the median values being very close to the averages.

In the descriptive analysis (Table 1), the amplitude, standard deviation and coefficient of variation values were considered low. This data represents the low variability of the values obtained and allows us to conduct a deeper analysis of the process (CUNHA et al., 2018).

The sowing arrangement (row spacing and plant population) can be adjusted to obtain greater yield. However, the spacing and population interaction had no significant effect. The mass of 1000 grains, ear height, and grain yield presented an isolated effect for spacing and population.

The twin rows compared to the single-row presented a greater mass of 1000 grains, greater ear height and grain yield of 5%, 8.96% and 7.31% respectively (Table 2). In this plant arrangement, it can have high penetration of light and agrochemicals in the canopy, improving the photosynthetic rate, health and longevity of leaves close to the ground, and can maximize corn yield (Balkcom & Bowen, 2020).

There was no difference between the spatial arrangements studied for the number of rows of grains per ear and the number of grains in the ear row, although low variability was found according to standard deviation (Tables 1 and 2). These results corroborate Novacek et al. (2013), who also found no differences for the same biometric variables using Twin-row compared to single-row.

The mass of 1000 grains in the populations (Table 2) shows an increase of 3.72% and 5.86% respectively for the populations of 60,000 and 65,000 plants per hectare compared to the population of 55,000 plants per hectare ($\hat{Y}_{M1000}$= 247,13 + 0,00213$X_{POPULAÇÃO}$; $R^2$ = 0,9767). Fumagalli et al. (2017) differed from the results found, as the authors observed that the increase in plant density caused a linear reduction in the mass of one thousand grains

There was an increase of 8.64% and 17.28% in the yield means (Table 2) for the respective populations of 60,000 and 65,000 plants per


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**Table 1**. Descriptive statistics of corn production variables in spatial arrangements (SA): single rows 55,000 plants ha$^{-1}$ (SR55), 60,000 plants ha$^{-1}$ (SR60), 65,000 plants ha$^{-1}$ (SR65) and Twin-rows with 55,000 ha$^{-1}$ (TR55), 60,000 ha$^{-1}$ (TR60), 65,000 ha$^{-1}$ (TR65). Ear Height (EARH), Number of rows per ear (NRPE), Number of Grains in the Ear Row (NGRE), Mass of 1000 grains (M1000), Yield (YIELD).

| Variables | SA | Mean | Media | Moving Range | SD | CV (%) | Coefficients Ck | Coefficients Cs | RJ |
|---|---|---|---|---|---|---|---|---|---|
| EARH | SR55 | 0.67 | 0.71 | 0.5 | 0.13 | 19.07 | -0.75 | -0.28 | 0.98 $^{N}$ |
| | SR60 | 0.62 | 0.65 | 0.41 | 0.11 | 17.95 | -0.98 | -0.27 | 0.97 $^{N}$ |
| | SR65 | 0.71 | 0.73 | 0.3 | 0.08 | 12.18 | -0.22 | -0.89 | 0.95 $^{N}$ |
| | TR55 | 0.67 | 0.7 | 0.72 | 0.14 | 20.86 | 7.86 | -2.4 | 0.87 $^{N}$ |
| | TR60 | 0.71 | 0.74 | 0.36 | 0.09 | 13.23 | -0.59 | -0.45 | 0.98 $^{N}$ |
| | TR65 | 0.79 | 0.78 | 0.22 | 0.06 | 7.83 | -0.72 | 0.39 | 0.98 $^{N}$ |
| NRPE | SR55 | 19.13 | 19 | 17 | 3 | 15.70 | 2.81 | 0.02 | 0.96 $^{N}$ |
| | SR60 | 18.36 | 18 | 7 | 1.68 | 9.14 | 1.76 | -1.07 | 0.98 $^{N}$ |
| | SR65 | 19.41 | 19.5 | 7 | 2.06 | 10.62 | -1.01 | 0.12 | 0.99 $^{N}$ |
| | TR55 | 18.94 | 19 | 9 | 1.93 | 10.21 | 2.69 | -1.11 | 0.96 $^{N}$ |
| | TR60 | 19.61 | 20 | 4 | 1.41 | 7.18 | -1.12 | 0.24 | 0.99 $^{N}$ |
| | TR65 | 19.47 | 20 | 6 | 1.39 | 7.14 | 0.03 | -0.39 | 0.99 $^{N}$ |
| NGRE | SR55 | 33.72 | 35 | 18 | 4.44 | 13.16 | 0.21 | -0.86 | 0.97 $^{N}$ |
| | SR60 | 34.75 | 35 | 13 | 4.12 | 11.85 | -1.18 | 0.13 | 0.98 $^{N}$ |
| | SR65 | 35.06 | 35 | 10 | 2.87 | 8.19 | -0.79 | 0.19 | 0.99 $^{N}$ |
| | TR55 | 33.31 | 34 | 24 | 4.17 | 12.52 | 3.96 | -0.94 | 0.95 $^{N}$ |
| | TR60 | 33.97 | 34 | 13 | 3.21 | 9.44 | 0.11 | -0.21 | 0.99 $^{N}$ |
| | TR65 | 33.94 | 34 | 11 | 2.83 | 8.33 | -0.59 | 0.29 | 0.99 $^{N}$ |
| M1000 | SR55 | 376.66 | 375.00 | 110 | 2.76 | 7.32 | -0.55 | 0.13 | 0.99$^{N}$ |
| | SR60 | 385.00 | 380.00 | 100 | 2.19 | 5.68 | 0.51 | -0.4 | 0.99 $^{N}$ |
| | SR65 | 391.36 | 390.30 | 51.56 | 1.42 | 3.63 | -0.2 | 0.27 | 0.98 $^{N}$ |
| | TR55 | 350.31 | 340.00 | 120 | 3.59 | 10.24 | -1.35 | 0.17 | 0.97 $^{N}$ |
| | TR60 | 368.91 | 370.00 | 60 | 1.18 | 3.19 | 1.32 | -0.28 | 0.98 $^{N}$ |
| | TR65 | 378.16 | 375.00 | 40.54 | 1.04 | 2.76 | -0.49 | -0.12 | 1.00 $^{N}$ |
| YIELD | SR55 | 8235 | 8254 | 5364 | 1639 | 19.91 | -1.06 | -0.26 | 0.97 $^{N}$ |
| | SR60 | 9917 | 10068 | 4065 | 1057 | 10.65 | -0.49 | -0.09 | 0.98 $^{N}$ |
| | SR65 | 9858 | 9830 | 2532 | 635 | 6.44 | -0.27 | -0.02 | 0.99 $^{N}$ |
| | TR55 | 9075 | 9654 | 6036 | 1787 | 19.69 | -0.78 | -0.64 | 0.96 $^{N}$ |
| | TR60 | 10451 | 10344 | 4862 | 1254 | 12.00 | -0.12 | 0.46 | 0.98 $^{N}$ |
| | TR65 | 10531 | 10612 | 3275 | 891 | 8.46 | -0.85 | 0.04 | 0.99 $^{N}$ |

SD: Standart deviation; Coefficient of variation; Ck: kurtosis coefficient; Cs: symmetry coefficient; RJ: Ryan-Joyner normality test.


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**Table 2**. Corn production variables in spatial arrangements: single rows 55,000 plants ha$^{-1}$ (SR55), 60,000 plants ha$^{-1}$ (SR60), 65,000 plants ha$^{-1}$ (SR65) and Twin-rows with 55,000 ha$^{-1}$ (TR55), 60,000 ha$^{-1}$ (TR60), 65,000 ha$^{-1}$ (TR65). Ear Height (EARH), Number of rows per ear (NRPE), Number of Grains in the Ear Row (NGRE), Mass of 1000 grains (M1000), Yield (YIELD).

| Arrangements | EARH (m) | NRPE (Un. ear$^{-1}$) | NGRE (Un. row$^{-1}$) | M1000 (grains) | YIELD (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| **SR** | 0.67 b | 19.00 a | 34.50 a | 384.31 a | 9336.33 b |
| **TR** | 0.73 a | 19.50 a | 33.75 a | 365.79 b | 10019.17 a |
| **F test(5%)** | 5.36* | 1.80 ns | 1.29 ns | 9.37** | 5.29* |
| **lsd** | 0.06 | 0.79 | 1.41 | 6.05 | 633.04 |
| **Populations** | | | | | |
| **55,000** | 0.67 b | 19.25 a | 33.50 a | 363.44 b | 8654.86 b |
| **60,000** | 0.67 b | 19.00 a | 34.37 a | 376.95 a | 10184.00 a |
| **65,000** | 0.75 a | 19.50 a | 34.50 a | 384.76 a | 10194.38 a |
| **F test (5%)** | 4.73* | 0.60 ns | 0.91 ns | 4.06* | 11.86** |
| **lsd** | 0.08 | 1.19 | 2.10 | 8.87 | 944.83 |
| **Int. AxP** | 1.05ns | 0.60 ns | 0.33 ns | 0.23 ns | 0.09 ns |
| **CV (%)** | 9.38 | 4.74 | 4.74 | 4.09 | 7.52 |

Means followed by the same letter in the column do not differ by the Tukey test ($p \leq 0.05$) and compare the treatments for each variable. lsd: least significant difference.

hectare compared to the populations of 55,000 plants per hectare ($\hat{Y}_{PRODUTIVIDADE} = 440,63 + 0,154X_{POPULAÇÃO}$; $R^2 = 0,7551$). The results differ from those found by Ruffo et al. (2015) who did not find a positive effect of plant population on grain yield, but corroborate Novacek et al. (2013) who justified their higher yield when choosing the largest populations, regardless of the conFiguretion of the sowing rows.

According to Haegele et al. (2014), plant population is important for corn yield, but yield gains associated with higher densities may depend on the genetic predisposition of corn hybrids to tolerate greater competition, environmental conditions and soil fertility levels. Williams et al. (2021) twin-row corn sowing showed increased grain yield and optimal agronomic plant populations ranged from 104 to 119 thousand plants ha$^{-1}$.

The control charts for ear height (Figure 1) at TR 65,000 showed the highest averages, facilitating mechanized harvesting and avoiding possible losses. This causes a stable process without the presence of points outside the control limits; that is, they present better process quality.

All other arrangements presented points


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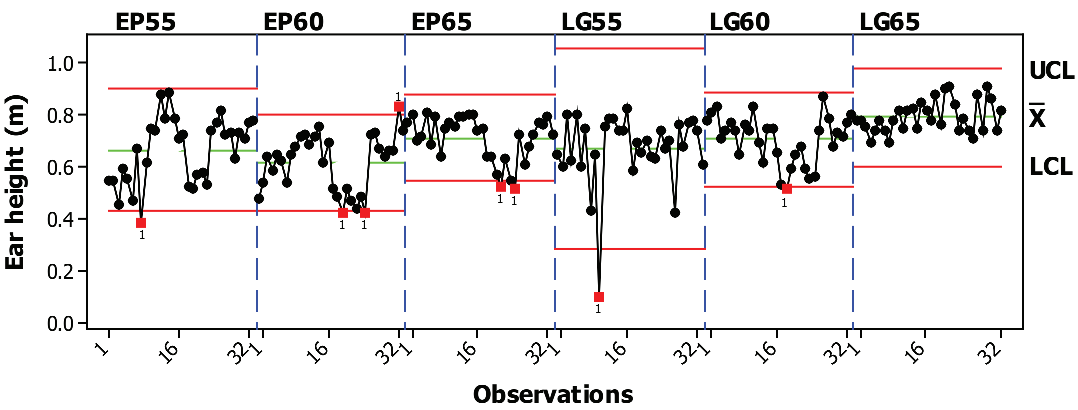


**Figure 1**. Control charts to ear height (m) corn for spatial arrangements: single-row (SR) e twin-row (TR) at populations 55,000, 60,000 e 65,000, plants ha$^{-1}$.

outside the upper and lower control limits, making the process unstable and of low quality. This fact can be proven by the moving amplitude charts, which help identify whether there are extrinsic factors to the process. These factors may be related to the 6 M's (machines, manpower, material, method, measurement and milieu), in which this tool can inform us whether a certain process is predictable or not predictable (Ormond et al., 2019).

The outliers' points found for ear height can be characterized by failures during the sowing process, which delay seed germination and thus harm seed development. The results are similar to those found by Silva et al. (2014), who reported that the ear insertion height was influenced by spacing and plant population. With the smallest population analyzed (40,000 plants ha$^{-1}$), there was a reduction in the ear insertion height. cob about the largest populations.

In Figure 2, the averages for the spacings and populations studied are similar, showing little influence of plant arrangement on the number of rows of grains per ear. The SR65, TR60, and TR65 arrays show lower data variability and process stability on both individual value charts and moving amplitude charts.

The data for the population of 55,000 plants ha$^{-1}$ in the single row (Figure 2) show greater variability. In the same population, for the spacing in twin rows, there were two outliers due to imperfections in the terrain and the presence of weeds. This fact corroborates HELVIG et al. (2020), who obtained poor ear formation in points where there was poor ear formation due to competition from weeds.

The number of grains per row shows that in the twin-row spacing of 55,000 plants per hectare, there were outliers in the control chart (Figure 3). Such process instability was justified by the occurrence of a special cause related to the environmental factor (milieu), specifically


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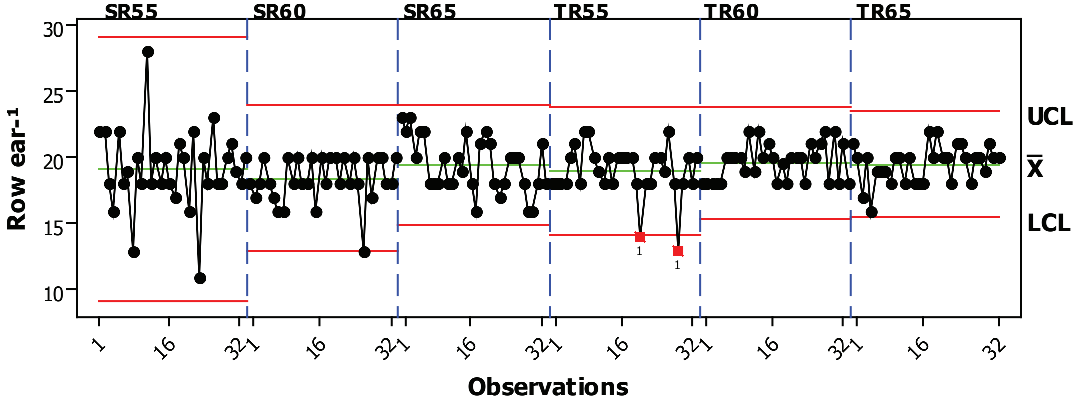


**Figure 2**. Control charts to number of rows per corn ear for spatial arrangements: single-row (SR) e twin-row (TR) to populations 55,000, 60,000 e 65,000, plants ha$^{-1}$.

the presence of an abnormal ear.

Populations of 65,000 plants per hectare showed the lowest process variability in the two spacings analyzed, demonstrating better quality of the grain number process, with a greater number of points close to the average (Figure 3).

According to the Control charts of individual values for the mass of 1000 grains (Figure 4), the twin lines at populations of 60,000 and 65,000 plants ha$^{-1}$ showed a stable process and less data variability. This result indicates better process quality concerning single-row for the three populations evaluated. However, through the analysis of the mobile amplitude charts, only the TR65 treatment was highlighted, which presented a stable process and less variability.

M1000 grains greatly influence on corn yield and twin-rows show better process quality with larger populations. Regardless of the row spacing employed, previous studies highlight the possible need to optimize row

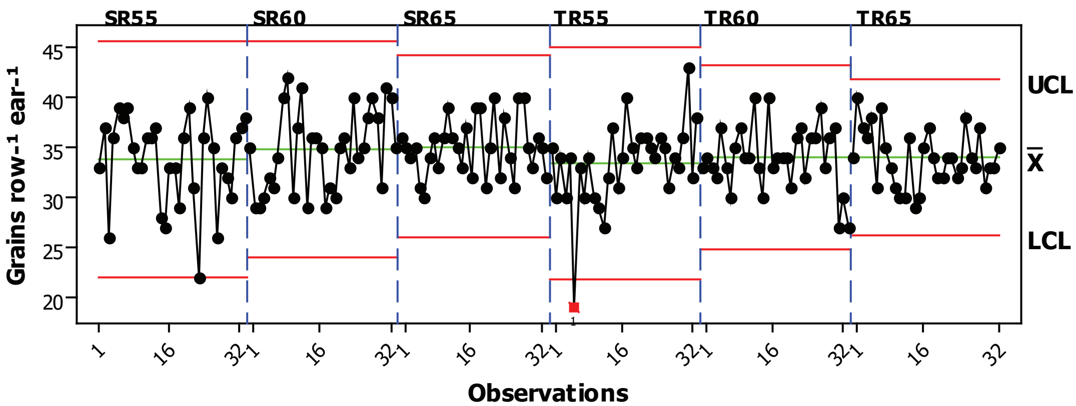


**Figure 3**. Control charts to number of grain in ear row of corn for spatial arrangements: single-row (SR) e twin-row (TR) at populations 55,000, 60,000 e 65,000, plants ha$^{-1}$.


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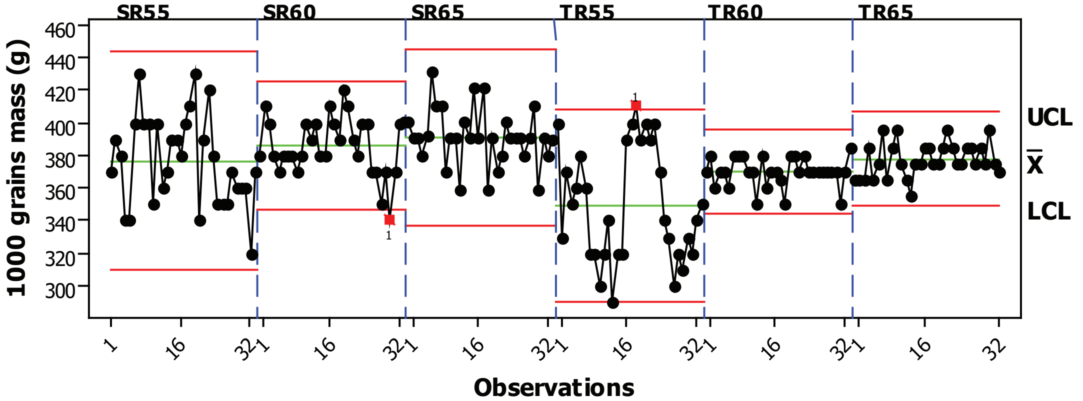


**Figure 4**. Control charts to mass of 1000 grains (g) of corn for spatial arrangements: single-row (SR) e twin-row (TR) at populations 55,000, 60,000 e 65,000, plants ha$^{-1}$.

spacing or arrangement along with plant density (HAEGELE et al., 2014).

For M1000, twin row spacing with a population of 55,000 plants showed the occurrence of points outside the upper and lower control limits, for these points' imperfections in the sown area. Also, weeds were detected, corroborating HELVIG et al. (2020) who recommended a critical interference period of 40 days for weeds to not compromise corn grain mass in direct and conventional planting systems.

Yield showed a stable process for all spatial arrangements analyzing the individual value charts, despite the high amplitude in single-row and twin lines in the population of 55,000 plants per hectare (Figure 5), a point related to special causes (6 M's) of environment.

Yield control chart (Figure 5) showed process stability in all treatments, corroborating HAEGELE et al. (2014) who also compared twin rows with single-row in high plant

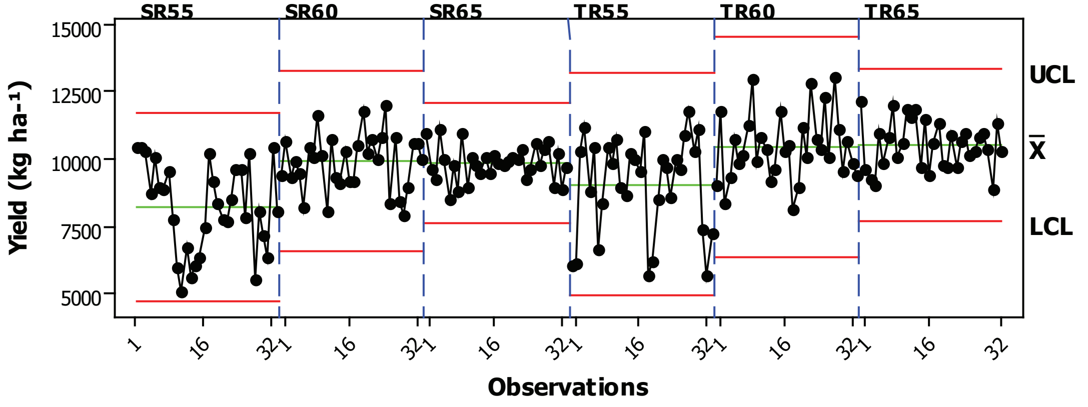


**Figure 5**. Control charts to grain yield (kg ha$^{-1}$) of corn for spatial arrangements: single-row (SR) and twin-row (TR) at populations 55,000, 60,000, and 65,000, plants ha$^{-1}$.


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populations for corn and did not obtain great data variability or difference between their spatial arrangements.

The finding that twin-rows produce less than single rows at high densities suggests that corn producers should not exceed plant densities employed for single rows (HAEGELE et al., 2014). The increase in plant population can be harmful in drought conditions, justified by greater sensitivity to drought and greater yield variability over the years (LOBELL et al., 2014).

## Conclusions

The spatial arrangements in twin lines are superior for the height of the first ear and yield, except for the mass of 1000 grains.

The population of 55,000 plants ha$^{-1}$ shows lower values for ear height, mass of 1,000 grains and yield.

Control charts are efficient quality control tools, detecting greater variability in the population of 55,000 plants ha$^{-1}$.

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