La granjA:
Revista de
Ciencias de la Vida
pISSN:1390-3799; eISSN:1390-8596
https://doi.org/10.17163/lgr.n41.2025.10

Scientific paper/ Artículo científico

Agricultural Sciences

Planting Distance in *Zea mays* L. during the dry and rainy seasons on the central Coast of Ecuador

Distanciamiento de siembra en *Zea mays* L. durante la época seca y lluviosa en la Costa central del Ecuador

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Received on January 12th, 2022. Accepted, after revision on July 04th, 2022. Published on March 1st, 2025.

Abstract

The research was carried out in Mocache, province of Los Ríos, where three experimental corn trials were established, one on the property of Mr. Fortunato Cedeño Diaz, located in the John F. Kennedy sector, and two located on the "La María" Campus of the Quevedo State Technical University (UTEQ), with the purpose of evaluating the effect of different planting distances of a commercial hybrid (hybrid ADV-9139) and a creole variety (Creole variety S/N) of corn during the dry and rainy seasons, in order to define optimal planting distances to achieve better yields. A completely randomized design (CRD) with a unifactorial arrangement was applied, with six treatments composed of a combination of two variables: varieties and planting distances. The first consisted of two genotypes: hybrid ADV-9139 and a creole variety S/N, and the second consisted of distances of 0.6 *times* 0.2 m; 0.7 × 0.2 m and 0.8 × 0.2 m. Each of these treatments had four replications. The results showed little influence of distances on plant height, stem diameter and ear insertion height. Regarding productive parameters such as yield, T4 (Hybrid ADV - 9139 + 0.6 X 0.2) and T5 (Hybrid ADV - 9139 + 0.7 X 0.2) stood out in trials 1 and 3, while only T4 stood out in trial 2.

Keywords: Maize, density, genotypes, agronomic response, yield parameters.

Resumen

La investigación se desarrolló en el cantón Mocache provincia de Los Ríos, donde se establecieron tres ensayos experimentales de maíz, uno en la propiedad del Sr. Fortunato Cedeño Diaz, ubicado en el sector John F. Kennedy, y dos ubicados en el Campus "La María" de la Universidad Técnica Estatal de Quevedo (UTEQ), con el fin de evaluar el efecto de distintos distanciamientos de siembra sobre el comportamiento agronómico de un híbrido comercial (híbrido ADV-9139) y una variedad criolla (Variedad criolla S/N) de maíz durante la época seca y lluviosa para definir distancias de siembra óptimas que permitan alcanzar mejores rendimientos. Se aplicó un Diseño completamente al azar (DCA) con arreglo unifactorial, con seis tratamientos compuestos por la combinación de dos variables: variedades y distanciamientos de siembra. La primera conformada por dos genotipos: híbrido ADV-9139 y una variedad criolla S/N, y la segunda por distancias de 0,6 × 0,2 m; 0,7 × 0,2 m y 0,8 × 0,2 m. Cada uno de estos tratamientos tuvo cuatro repeticiones. Los resultados registrados demostraron una escaza influencia de las distancias sobre la altura de planta, diámetro del tallo y altura de inserción de mazorca. Respecto a los parámetros productivos como el rendimiento se logró destacar T4 (Híbrido ADV – 9139 + 0,6 X 0,2) y T5 (Híbrido ADV – 9139 + 0,7 X 0,2) en los ensayos 1 y 3, mientras que únicamente destacó T4 en el ensayo 2.

Palabras clave: Maíz, densidad, genotipos, respuesta agronómica, parámetros productivos.

Suggested citation:	Mestanza Uquillas, C., Cedeño Cárcamo, P., Véliz Zamora, D., Vásquez Matute, S. and Pinargote Alava, J. (2025). Planting Distance in *Zea mays* L. during the dry and rainy seasons on the central Coast of Ecuador. *La Granja: Revista de Ciencias de la Vida.* Vol. 41(1):144-154. https://doi.org/10.17163/lgr.n41.2025.10.

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1 Introduction

Maize (*Zea mays* L.) is one of the crops most susceptible to nutrient deficiency stress, particularly during the pre- and post-flowering period, known as the critical period. The extent to which the crop is affected during this stage is directly related to the agronomic practices employed and the availability of resources essential for plant growth (Videla et al., 2014).

One of the most significant factors in this regard is population density. Changes in population density can elicit different responses in productive parameters, which in turn depend on the genotype and environmental quality (Quevedo et al., 2015). This phenomenon is explained by the availability of resources per plant, which is influenced by crop processes such as light capture and utilization, as well as genotype-specific traits like reproductive plasticity and the stability of biomass partitioning during the critical period. It is well known that modern hybrids differ in the population density that maximizes their yield (Ogando et al., 2017).

However, given the modifications introduced in recent maize genotypes -such as reduced plant height, lower ear insertion height, decreased plant sterility, shorter anthesis-silking interval, plants with more upright leaves, and higher yield potential- it is necessary to reevaluate recommendations regarding spacing and planting density (Martínez et al., 2017).

A similar situation occurs with landrace varieties, which have been cultivated and selected by farmers over generations. These varieties retain unique identities and great adaptability but lack formal breeding programs (CIMMYT, 2014). Combined with the absence of appropriate practices, such as the implementation of optimal planting distances, this has hindered the full exploitation of the potential found in many of these materials.

Considering the above and the significant cultural, socioeconomic, and dynamic importance of this crop in municipalities like Mocache, as well as in the province of Los Ríos —which accounts for 43.81 % of the national maize production (1,479,770 tons) according to INEC (2020)— it is imperative to reconsider strategies to increase productivity. These strategies must aim to meet local demand, a critical factor in strengthening the productive chain in the region.

In this context, this paper aims to evaluate the effect of different planting distances on the agronomic performance of a commercial hybrid and a landrace maize variety under the agroclimatic conditions of Mocache during the dry and rainy seasons. The objective is to determine the optimal planting distance to achieve higher yields.

2 Material y Methods

2.1 Experiment location and crop management

The establishment of maize trials 1 and 2 cultivated during the rainy season took place in December 2020. Trial 1 was conducted on the property of Mr. Fortunato Cedeño Diaz, located in the John F. Kennedy sector of Mocache Canton, Los Ríos Province, with geographic coordinates: 1°15′57.3″ South Latitude and 79°29′43.8″ West Longitude, at an altitude of 71.4 meters above sea level. Trial 2 was carried out at the "La María" Campus of UTEQ, with geographic coordinates: 1°05′01″ South Latitude and 79°30′02″ West Longitude, at an altitude of 66 meters above sea level.

Trial 3 was established in the same location as Trial 2 but during the dry season in May 2021. Table 1 provides a description of the agroclimatic conditions present in Mocache Canton.

Table 1. Agroclimatic conditions of the Mocache canton, Los Ríos province

Agroclimatic data	Average values
Altitude	75 msnm
Temperature	24.9 °C
Relative Humidity (%)	84 %
Precipitation	2216.3 mm
Topography	Irregular

Regarding management, three experimental trials of 1,320 m^2 were established at the sites and during the seasons previously mentioned. Manual operations such as weeding, and plowing were carried out to prepare the fields. Experimental units were then randomly assigned.

Once the fields were prepared, sowing was performed manually using a planting stick (espeque). The following planting distances were employed: 0.6 × 0.2 m, 0.7 × 0.2 m and 0.8 × 0.2 m. Weed control was conducted conventionally, using selective pre-emergent and post-emergent herbicides to prevent collateral damage. Fertilization was performed using urea and diammonium phosphate (DAP). Similarly, pest control was carried out conventionally, applying systemic and contact insecticides. Fungicides were also used, proving essential given that the trials were conducted during the rainy season. Since the sowing for trials 1 and 2 was scheduled for December 2020, coinciding with the beginning of the rainy season, irrigation was not required, and the crop was grown under rainfed conditions. However, for trial 3, conducted during the dry season, sprinkler irrigation was applied to achieve field capacity. Finally, the harvest was performed manually once the plants had reached physiological maturity.

2.2 Experimental Design

The three trials were conducted using a Completely Randomized Design (CRD) with a unifactorial arrangement, consisting of six treatments formed by the combination of two variables: varieties and planting distances. The first variable included two genotypes: the ADV-9139 hybrid and a landrace variety (S/N), while the second variable comprised planting distances of 0.6 × 0.2 m, 0.7 × 0.2 m and 0.8 × 0.2 m. Each treatment had four replications. The effective area of each trial was 1320 m^2, consisting of 24 plots of 25 m^2 each.

2.3 Measurements and statistical analysis

Plant height was recorded 60 days after sowing (DAS) by randomly selecting 10 plants per plot (replication) and measuring the distance from the soil surface to the base of the plant's ear using a measuring tape. To determine the number of rows, ear diameter, and ear length, 10 ears were randomly selected, and measurements were taken and recorded for each parameter. Additionally, the 100-seed weight and grain yield were determined. This required threshing the ears harvested from the effective area of each experimental plot, followed by moisture standardization to 13 % using the following formula:

$$PU(13\,\%) = \frac{Pa(100 - Ha)}{100 - Hd}$$

Where:
PU represents the weight adjusted to 13 % moisture,
Pa is the actual weight,
Ha is the current moisture content,
Hd is the desired moisture content.

The data obtained from the three trials were subjected to analysis of variance (ANOVA), and treatment means were compared using Tukey's test (5 %). The statistical analysis was performed using InfoStat software, version 2019.

3 Results and Discussion

3.1 Plant height (m)

Plant height exhibited two distinct scenarios. The first occurred in Trials 1 and 2, where analysis of variance demonstrated statistically significant differences between treatments ($P<0.05$). In Trial 1, the highest values were observed in T1, T3, and T2, with measurements of 2.86, 2.82, and 2.81 m, respectively. In Trial 2, the treatment that stood out was T1, with a value of 2.98 m. On the other hand, in Trial 3, no statistically significant differences between treatments were found ($P>0.05$) (Table 2).

3.2 Number of rows per ear

Regarding the number of rows per ear, according to the ANOVA with a variation coefficient of 3.87 %, there were no significant statistical differences among the treatments that constituted trials 1, 2 and 3 ($P>0.05$), obtaining averages that ranged between 14 and 16 rows per ear in each of the cases (Table 3).

3.3 Cob diameter (mm)

According to the analysis of variance for ear diameter in trial 1, there were no significant statistical differences between treatments ($P>0.05$) (Table 4). This scenario was replicated in trial 2, where there were no statistical differences between treatments or factors ($P>0.05$). On the other hand, trial 3 obtained statistical differences, with T3 being the different treatment with a record of 47.85 mm.

Table 2. Plant height at 60 dds (m) in trial 1, 2 and 3. Mocache, Los Ríos province, Ecuador.

Plant height[1]				
	Location of trials	**John F. Kennedy, 2020 rainy season (test 1)**	**Campus "La María", 2020 rainy season (test 2)**	**Campus "La María", dry season 2021 (test 3)**
		60 dds[2]	**60 dds[2]**	**60 dds[2]**
Trat[3]	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	2.86 a	2.98 a	2.34 a
T2	Creole variety S/N + 0.7 X 0.2	2.81 a	2.48 b	2.64 a
T3	Creole variety S/N + 0.8 X 0.2	2.82 a	2.40 b	2.52 a
T4	ADV Hybrid – 9139 + 0.6 X 0.2	2.40 b	2.31 b	2.30 a
T5	ADV Hybrid – 9139 + 0.7 X 0.2	2.37 b	2.38 b	2.50 a
T6	ADV Hybrid – 9139 + 0.8 X 0.2	2.35 b	2.29 b	2.26 a
C.V(%)		4.23	8.25	11.86
x̄		2.61	2.47	2.43

[1]equal letters are not significant according to Tukey's test (P>0.05).
[2]dds: Days after the sown,
[3]Trat: Treatment.

3.4 Cob length (cm)

According to the ANOVA results, statistically significant differences in cob length were observed among treatments in trials 1, 2, and 3 (P<0.05). Treatments T4, T5, and T6 exhibited distinct outcomes in each case, whereas treatments T1, T2, and T3 recorded lower values (Table 5).

3.5 Weight of 100 seeds (g)

Regarding the weight of 100 seeds, ANOVA revealed statistically significant differences among the treatments in trial 1 (P<0.05). Treatments T4, T5, and T6 showed distinct values, with averages of 43.75, 43.75, and 46.25 g, respectively, compared to T1, T2, and T3, which recorded lower values of 36.00, 37.25, and 36.50 g, respectively. In contrast, no statistically significant differences among treatments were observed in trials 2 and 3 (P>0.05) (Table 6).

Table 3. Number of rows per ear in trials 1, 2 and 3. Mocache, Los Ríos province, Ecuador.

Number of rows per ear[1]				
	Location of trials	**John F. Kennedy, winter of 2020 (test 1)**	**Campus "La María", winter of 2020 (test 2)**	**Campus "La María", summer of 2021 (test 3)**
Treatment	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	15.25 a	14.50 a	14.40 a
T2	Creole variety S/N + 0.7 X 0.2	15.55 a	15.50 a	14.75 a
T3	Creole variety S/N + 0.8 X 0.2	15.60 a	15.00 a	15.35 a
T4	ADV Hybrid – 9139 + 0.6 X 0.2	15.25 a	15.50 a	14.47 a
T5	ADV Hybrid – 9139 + 0.7 X 0.2	15.30 a	14.00 a	14.27 a
T6	ADV Hybrid – 9139 + 0.8 X 0.2	14.95 a	15.00 a	14.47 a
C.V (%)		3.87	6.52	4.00
x̄		15.32	14.92	14.62

[1]equal letters are not significant according to Tukey's test (P>0.05).

3.6 Grain yield (kg/ha)

For the grain yield variable, the analysis of variance revealed statistically significant differences among the treatments in the evaluated trials (P<0.05). Treatments T4 and T5 stood out in trials 1 and 3, while in trial 2, only T4 demonstrated superior performance (Table 7).

Table 4. Ear diameter (mm) in trials 1, 2 and 3. Mocache, Los Ríos province, Ecuador.

Cob diameter (mm)[1]				
	Location of trials	**John F. Kennedy, 2020 rainy season (test 1)**	**Campus "La María", 2020 rainy season (test 2)**	**Campus "La María", dry season 2021 (test 3)**
Treatment	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	48.75 a	44.50 a	43.43 cd
T2	Creole variety S/N + 0.7 X 0.2	49.44 a	46.13 a	45.00 bc
T3	Creole variety S/N + 0.8 X 0.2	49.49 a	46.20 a	47.85 a
T4	ADV Hybrid – 9139 + 0.6 X 0.2	48.27 a	45.40 a	43.43 cd
T5	ADV Hybrid – 9139 + 0.7 X 0.2	48.63 a	44.18 a	42.57 d
T6	ADV Hybrid – 9139 + 0.8 X 0.2	49.57 a	45.03 a	46.17 ab
C.V (%)		1.81	2.02	2.07
x̄		49.11	45.24	45.00

[1]equal letters are not significant according to Tukey's test (P>0.05).

Table 5. Ear length (cm) in trials 1, 2 and 3. Mocache, Los Ríos province, Ecuador.

Cob length (cm)[1]				
	Location of trials	**John F. Kennedy, winter of 2020 (test 1)**	**Campus "La María", winter of 2020 (test 2)**	**Campus "La María", summer of 2021 (test 3)**
Treatment	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	17.28 b	16.00 b	13.50 c
T2	Creole variety S/N + 0.7 X 0.2	17.16 b	15.93 b	14.50 bc
T3	Creole variety S/N + 0.8 X 0.2	17.63 b	15.96 b	15.00 b
T4	ADV Hybrid – 9139 + 0.6 X 0.2	20.51 a	18.08 a	17.44 a
T5	ADV Hybrid – 9139 + 0.7 X 0.2	20.25 a	19.01 a	17.42 a
T6	ADV Hybrid – 9139 + 0.8 X 0.2	20.25 a	19.01 a	18.79 a
C.V (%)		3.84	3.90	3.87
x̄		18.85	17.33	16.11

[1]equal letters are not significant according to Tukey's test (P>0.05).

3.7 Discussion

The height data recorded for the ADV-9139 hybrid in the three evaluated trials align with those reported by Moreira (2019) for the same hybrid, established in the Mocache canton during the 2019 rainy season, with a value of 2.01 m at 52 days. However, it was observed in this research that the native variety S/N, across all spacing treatments, achieved higher height values than the hybrid, likely due to its wild traits. This behavior is commonly seen in native or mestizo varieties, as noted by authors such as Quiroz et al. (2017), Molina and Isasi (2018) and Cabrera et al. (2019), who found that mestizo plants (native $\times$ improved) exhibit greater height than hybrids, a finding corroborated by Rodríguez et al. (2016). Regarding planting spacing, Quiroz et al. (2017) recorded a similar scenario, where increased population densities did not result in significant phenotypic variability in plant height across genotypes.

Thus, both previous findings and the observations from this study suggest that marked differences exist between genotypes in growth traits such as height, attributed to distinct development patterns and genetic heritage expressed differently, even under similar environmental conditions (Sánchez et al., 2011). This was not the case with spacing, where it is commonly observed that closer row spacing enables plants to capture a greater proportion of total radiation due to an increase in the leaf area index and light interception efficiency per unit surface area, thereby promoting greater height development (Soltero et al., 2010). This phenomenon has been documented in various studies, including those by Campos (2022), Gómez et al. (2021) and Satorre (2021).

Despite this, it is important to clarify that plants with reduced height are generally the result of the genetic improvement process these materials undergo. This is supported by authors such as Bastidas et al. (2015) and Gordón and Camargo (2021), who note that this characteristic can be seen as an advantage during harvest, as well as reducing lodging of both roots and stems.

On the other hand, Velez (2019) highlights the influence of planting distance. In his study, he analyzed the effects of three spacings (0.80 × 0.25m, 0.80 × 0.30m and 0.80 × 0.35m) on maize cultivation using the Somma, ATL 400, and Pioneer hybrids, observing better results in productive parameters with a spacing of 0.80 m × 0.25m. This finding aligns with the conclusions of Millán, cited by Pérez (2015).

Regarding cob diameter, similar results were observed in trials 1 and 2 of Quimi (2015) study, conducted in nearby cantons such as Quevedo and Balzar. This research evaluated experimental and commercial hybrids, with the former achieving diameters of 48.9 mm compared to 46.7 mm for the latter. Concerning spacing, Zamudio et al. (2015) cited by Sánchez (2017), reported larger cob diameters in double-row systems using a commercial hybrid (AS-722), attributing this to lower population density per hectare. This is consistent with results from trial 3, where the 0.8 × 0.2 m spacing outperformed other densities.

Table 6. Weight of 100 seeds (g) in trials 1, 2 and 3. Mocache, Los Ríos Province, Ecuador.

	Weight of 100 seeds (g)[1]			
	Location of trials	**John F. Kennedy, winter of 2020 (test 1)**	**Campus "La María", winter of 2020 (test 2)**	**Campus "La María", summer of 2021 (test 3)**
Treatment	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	36.00 b	30.00 a	39.15 a
T2	Creole variety S/N + 0.7 X 0.2	37.25 b	30.00 a	38.85 a
T3	Creole variety S/N + 0.8 X 0.2	36.50 b	30.00 a	39.28 a
T4	ADV Hybrid – 9139 + 0.6 X 0.2	43.75 a	37.50 a	39.27 a
T5	ADV Hybrid – 9139 + 0.7 X 0.2	43.75 a	37.50 a	38.97 a
T6	ADV Hybrid – 9139 + 0.8 X 0.2	46.25 a	37.50 a	42.77 a
C.V (%)		7.39	10.48	5.17
$\bar{x}$		40.58	34.50	39.83

[1]equal letters are not significant according to Tukey's test (P>0.05).

This is consistent with the results of Oyervides et al. (1990) cited by Cervantes et al. (2014), who determined negative effects on yield components such as cob diameter, by increasing population density; a pattern that is repeated in the research of Otahola and Rodríguez (2001).

Regarding cob length, the results obtained in this study are consistent with those of Martínez et al. (2017), who found no pronounced influence of spacing on cob length, despite observing a gradual reduction as maize plant population increased per hectare. This scenario was replicated in this study and is consistent with findings reported by Silva et al. (2009). Differences were attributed to genotypic variation among the evaluated lines, as the high heritability of these traits has been demonstrated in multiple studies, including those by Alonso et al. (2022) and Bueno and Tolentino (2022).

According to authors such as Hidalgo et al. (2020), Sandal (2014), Quevedo et al. (2015) and Cifuentes (2014), grain yield is positively and significantly associated with the number and weight of kernels, which are highly influenced by increased plant density due to reduced planting distance. This suggests that narrower row spacing leads to higher 100-seed weight. However, this pattern was not observed in any of the trials evaluated in this study.

On the other hand, Shapiro and Wortmann (2006), cited by Soltero et al. (2010), found that reducing row spacing from 0.76 to 0.51 m resulted in a 4% increase in maize grain yield. A similar trend was observed in trial 1 of this study. Specifically for the ADV-9139 hybrid, comparing the spacing used in T6 (0.8 × 0.2 m) with that in T4 (0.6 × 0.2 m), corresponding to a 0.20 m row-spacing reduction, a 17% yield increase per hectare was recorded. However, this trend did not hold for the native variety S/N, where no consistent pattern was observed in trials 1 and 3.

Nonetheless, this does not imply that narrower spacings for native genotypes would necessarily result in higher yields. León et al. (2018) caution that an irrational increase in population density could lead to yield decline due to grain abortion and an increase in sterile plants. Conversely, low densities reduce vegetative and reproductive compensation.

Table 7. Grain yield (kg/ha) in trials 1, 2 and 3. Mocache, Los Ríos province, Ecuador.

	Grain yield (Kg/ha)[1]			
	Location of trials	**John F. Kennedy, winter of 2020 (test 1)**	**Campus "La María", winter of 2020 (test 2)**	**Campus "La María", summer of 2021 (test 3)**
Trat[2]	**Description**			
T1	Creole variety S/N + 0.6 X 0.2	7699.11 c	10300.00 bcd	6770.97 b
T2	Creole variety S/N + 0.7 X 0.2	8139.39 c	9731.75 cd	6893.00 b
T3	Creole variety S/N + 0.8 X 0.2	7384.27 c	8632.50 d	7562.50 b
T4	ADV Hybrid – 9139 + 0.6 X 0.2	12707.42 a	13724.00 a	11278.01 a
T5	ADV Hybrid – 9139 + 0.7 X 0.2	12002.87 a	12036.50 ab	10437.63 a
T6	ADV Hybrid – 9139 + 0.8 X 0.2	10599.01 b	10864.50 bc	8452.66 b
C.V (%)		4.33	7.53	8.76
$\bar{x}$		9755.345	10881.54	8565.80

[1]equal letters are not significant according to Tukey's test (P>0.05).
[2]Trat: Treatment.

4 Conclusions

Regarding the agronomic performance of the materials studied across the three trials, planting spacings showed minimal influence. Plant height (m), stem diameter (cm), and cob insertion height did not exhibit statistically significant differences. Yield components such as cob length, cob diameter, and 100-seed weight clearly contributed to the increase in yield per unit area. However, this increase was not driven by the weight or dimensions achieved but rather by the reduced planting distance, which allowed for a higher number of plants per unit area, resulting in more cobs and, consequently, a greater quantity of kernels.

Planting distance affected yield only in the ADV-9139 hybrid, which achieved higher yields with a row spacing of 0.60 m compared to spacings of 0.70 m and 0.80 m.

Acknowledgments

The authors extend their gratitude to the Faculty of Agricultural Sciences of the Technical State University of Quevedo for the support provided in carrying out this research, and to Engineers Jonathan Cedeño and William Sarabia for their assistance with data collection.

The activities conducted in this research are part of the FOCICYT 7th Call Project titled Aerospace Technology Applied to Spectral Responses of Tropical Crops as a Technical Element for Crop Improvement. Phase I: Maize (*Zea mays* L.).

Author's contribution

C.A.M.U.: Conceptualization, data curation, formal analysis. P.J.C.C.: Research, methodology, drafting -original draft. D.V.V.Z.: Project management, resources, and supervision. S.C.V.M.: Software, validation. J.J.P.A.: Visualization, writing - review and editing.

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