

Effect of different planting frames on weed plants on the development of maize (*Zea mays*)

Efecto de diferentes marcos de siembra sobre las arvenses en el desarrollo del cultivo de maíz (*Zea mays*)

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ABSTRACT

The present work was carried out in the farm "Las Papas" belonging to the National Institute of Agricultural Sciences (INCA) located in San José de las Lajas, Mayabeque province, Cuba. The experimental area soil is dominated by Ferralitic Red Leached soil, typical eutrophic, characterized by a medium to high fertility. The aim of this work was to evaluate the influence of different sowing frames on levels of weeds in the commercial corn variety P-7928. For this purpose, the maize variety P-7928 was planted using four planting frames 0.90 × 0.30 m; 0.90 × 0.25 m; 0.75 × 0.30 m; 0.75 × 0.25 m combined each with one and two seeds per nest, except the first frame which was taken as a control treatment. During the stages of crop development, morphoagronomic characters were evaluated and statistically analyzed: stem diameter (SD), upper cob height (UCH), plant length (PL), number of grains per row (NGR), cob length (CL), mean stem diameter (MSD), mean cob diameter (MCD), number of grains per cob (NGC), mass of 100 seeds (M100S) and total seed mass per cob (TSMC). An economic analysis was also performed with the data obtained. The treatment with the best result in the evaluated parameters was the 0.75 × 0.25 m with two seeds per nest regardless of the number of seeds per nest. In addition, there was a marked tendency towards better results at higher population densities.

Keywords: competition, morphoagronomic characters, plant density, yield.

RESUMEN

El presente trabajo se realizó en la finca "Las Papas" perteneciente al Instituto Nacional de Ciencias Agrícolas (INCA) ubicada en San José de las Lajas, provincia Mayabeque, Cuba. El suelo predominante en el área fue Ferralítico Rojo Lixiviado, típicamente eutrófico, caracterizado por una fertilidad de media a alta. El objetivo de este trabajo fue evaluar la influencia de diferentes marcos de siembra en la variedad comercial de maíz P-7928 sobre el desarrollo de plantas arvenses. Para ello, se sembró la variedad de cultivo seleccionada a cuatro marcos de siembra (0,90 × 0,30 m; 0,90 × 0,25 m; 0,75 × 0,30 m; 0,75 × 0,25 m) combinados cada uno con una y dos semillas por nido, excepto el primer marco que se tomó como tratamiento testigo. Durante las etapas de desarrollo del cultivo se evaluaron los caracteres morfoagronómicos: diámetro del tallo (DT), altura superior de la mazorca (ALM), longitud de la planta (LP), número de granos por hilera (NGR), longitud de la mazorca (LC), diámetro medio del tallo (DMP), diámetro medio de la mazorca (DMP), número de granos por mazorca (NGC), masa de 100 semillas (M100S) y masa total de semillas por mazorca (MSTM). Se utilizó un análisis de varianza (ANOVA) de clasificación simple para el análisis estadístico; también se realizó un análisis económico con los datos obtenidos. El tratamiento con mejor resultado en los parámetros evaluados fue el de 0,75 × 0,25 m con dos semillas por nido independientemente del número de semillas por nido. Además, se observó una tendencia a obtener mejores resultados a mayores densidades de población.

Palabras clave: competencia, caracteres morfoagronómicos, densidad de plantas, rendimiento.

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INTRODUCTION

Maize (*Zea mays* L.) is a crop native in the Americas, probably in southern Mexico (Vera & al. 2020). It is of special importance, since it constitutes the basis of food in many countries and ranks third in world production after wheat (*Triticum aestivum* L.) and rice (*Oriza sativa* L.) (Sánchez & Pérez-Urria 2014).

In Cuba, this crop constitutes a staple food in human and animal feed, it also has a positive and direct influence on import substitution, therefore it constitutes the second cereal of importance in the country and its yield until 2016 was 1,92 t ha⁻¹ (MINAG 2017a). It is cultivated throughout the

island over an area that is between 77,000 and 100,000 ha, of which the eastern and central region stand out (Chirino-González & al. 2019).

Despite the high acceptance of this cereal by inhabitants and the importance it has for food security and the economy of Cuba, there are deficiencies in terms of its cultivation. It is evidenced by the current low yields mentioned above. According to an analysis of the crop carried out by MINAG (2017b) these are due to a group of technological violations in the crop that are making its productive growth impossible and therefore the state order committed to this grain is not fulfilled.

Corn has a high yield potential, but it is sensitive to stress, which means that agronomic management must be correctly adjusted. Its growth is directly related to the canopy's ability to capture incident sunlight. This capture is a function of the crop structure and depends on the type of plant, the quantity and its distribution on the ground (Blanco & al. 2015).

Plant density is an effective tool to improve light capture, as well as the capture of plant-available nutrients found in the soil (Vallone & al. 2013). By their nature, weeds compete with economic crops for space, light, nutrients and water; in addition, due to the effects of root interference or exudates, they host harmful insects, reduce the efficiency of inputs and interfere with crop yields and cause their decline (Labrada & al. 1996).

In the tropical zone, weed populations are generally high in crops and if a set of measures for their timely management is not established, yield losses can be irreversible. Such adversities occur if the weeds grow next to economic crops and although the damage is framed only in a short period considered critical, in crops such as maize they cause losses exceeding 25 % of the yields (Vaz 2015).

In Cuba there are few studies carried out in order to determine what is the best plant density for the cultivation of corn that contributes to the reduction of weed plants. An adequate plant density allows achieving a crop with higher quality and at the same time a better yield. The traditional sowing frame generally used by farmers is not appropriate because it wastes space, which affects yields and can cause the appearance of weeds. Based on the above, the aim of this study was to evaluate the influence of different sowing frames on the levels of weeds in the agroproductive behavior of corn in the conditions of San José de las Lajas, Mayabeque.

MATERIALS AND METHODS

Geographical and edaphoclimatic characteristics of the experimental area

A maize production system was established for three years (2017-2019), at the National Institute of Agricultural Sciences,

San José de las Lajas, Cuba, km 3½ of the road to Jamaica and have its center at 22°59'40.79" N and 82°8'21.88" W. The corn was planted in December of each year on a Ferralitic Red Lixiviated eutrophic soil (Hernández & al. 2019) and Typic Rhodustalf, according to Soil Taxonomy (Soil Survey Staff 2010).

According to the climatic characteristics of the agroecosystem where the experiments were developed, they belong to the old Havana climate-region, which extends to the northeast of the province of Havana and is characterized by a short period of low rainfall from November to March, without producing a typical ecological drought (Gil-Reyes & al. 2020).

Experimental program

A field experiment was developed and repeated three times during 2019, 2020, and 2021 according to the following treatments (Table I). The experiment was conducted under a randomized block design with four replicates and six treatments. The data obtained were processed by means of the double classification analysis of variance and, when necessary, the Duncan's multiple range test was applied at 5 % probability.

The improved corn variety P-7928 with a 90-day cycle was used, although it was harvested as "tender" corn. Annual plantings were made in December. Soil preparation and other cultural practices were carried out according to the technical norms for the crop (MINAG 2000). The experimental unit (plot) had an area of 27 m² (6 × 4.5 m), separated by a 1 m wide aisle for densities of 0.75 m and 32.4 m² (6 × 5.4 m), separated by a 1 m wide aisle for 0.90 m densities. The results presented are the averages of their replications.

Evaluations carried out on the corn crop

For the maize crop, the following indicators were evaluated at harvest time: plant height (m), leaf area index, yield of tender cobs per ha (t ha⁻¹), stem diameter (SD) (cm), top cob height (TCH) (m), number of grains per row (NGR), number of rows (NR), number of grains per cob (NGC), cob length (CL) (cm), mean cob diameter (MCD) (mm), mass of 100 grains (M100G) and total mass of grain per cob (TMGC) (g).

TABLE I

Different treatments studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba

TABLA I

Diferentes tratamientos estudiados en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba

Treatment	Spatial arrangements used	Plant density (plants ha ⁻¹)
1	Control (0.90 × 0.30 m with two grains per nest)	73,926
2	0.90 × 0.25 m with one grain per nest	44,400
3	0.90 × 0.25 m with two grains per nest	88,800
4	0.75 × 0.30 m with two grains per nest.	88,578
5	0.75 × 0.25 m with one grain per nest	53,200
6	0.75 × 0.25 m with two grains per nest.	106,400

The Excel tool of the Microsoft Office 2010 package was used to tabulate and graph the data of the experiments. The analysis of variance (ANOVA) in its simple classification and the Duncan 95 % multiple comparison test of the statistical package *Stratigraphic Plus v.5.1* (<https://www.statgraphics.com>) were used.

Evaluations carried out on weeds

Number of weed species

The total number of species and individuals (by species and families) found per treatment was recorded with the aid of a 1 × 1 m frame that was repeated six times per replicate according to Braun-Blanquet (1979). Counts were made 15 days after the plantation emerged with 8-day intervals throughout the crop cycle.

Total cover (%)

This was carried out using the visual evaluation, estimating the total area covered by weeds within a square meter frame. To evaluate the level of incidence of weeds “weediness” (Table II), the Maltsev four-grade scale recommended by Alemán-Zeledón (2004) was used.

In order to evaluate the accumulated biomass by weed species, a random sampling of three samples per m² per plot was performed. After the weeds were collected, the fresh mass of each one was recorded, equivalent to the percentage it represented within the m². To determine the dry mass, the total number of individuals of each one present in the sample was taken, which was then subjected to a temperature of 70 °C in an oven for three days, until constant mass values were reached.

Economic analysis of results

A specific economic analysis was carried out to evaluate the profitability of the planting frames. The cost of management labor, crop production and sales prices were used as a basis. The methodology used was the one proposed by FAO (1980); the economic evaluation of the results was made in Cuban

TABLE II

Scale used to evaluate the level of “weediness” in La Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba

TABLA II

Escala utilizada para evaluar el nivel de “maleza” en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba

Criteria for weeding according to Alemán-Zeledón (2004)	
Levels	Percentage of cover
Weak weeding	5 %
Medium weeding	6-25 %
Strong weeding	26-50 %
Very strong weeding	> 50 %

pesos (CUP). The following indicators were considered: (i) production value (\$/ha): result of the yield by the price in t of the product. (ii) Production cost (\$/ha): according to the expenses incurred in the production of 1 ha. (iii) Profit (\$/ha): result of the difference between the production value and the cost value; and (iv) profit/cost ratio: quotient obtained by dividing the profit by the production cost.

To calculate these indicators, the cost sheet, the agricultural technology chart of the maize crop (MINAG 2017a) and current prices (MFP 2021) were used as basic information. For the calculations, tender corn cobs were converted to dry corn based on Permuy-Arbelarde & al. (2000) criterion that every four tons of baby corn cobs is equivalent to one ton of dry corn.

RESULTS

Analysis of the composition of weeds present during the growth and development of the corn crop

During the growth and development of the crop, there were 15 species of weeds represented in eight botanical families (Table III). Out of all of them, *Sorghum halepense* (L.) Pers. and *Cyperus rotundus* L. were the most dominant, while *Rottboellia cochinchinensis* (Lour.) Clayton presented a medium dominance.

Although *Cyperus rotundus*, *Rottboellia cochinchinensis* and *Sorghum halepense* represented only 20 % of the total number of weeds recorded, they accounted for 73 % of the total diversity in the experimental area, which indicates their propagation capacity and dominance during the growth and development of the maize crop. The remaining families were represented with eight species, including *Chamaesyce hyssopifolia* and *Euphorbia heterophylla* of the *Euphorbiaceae* family. Some of them (*E. heterophylla*, *Parthenium hysterophorus*, *Portulaca oleracea*, *Kallstroemia maxima* and *Amaranthus dubius*) did not play a significant visible role in the system, both because of their scarce coverage within the agricultural space of the crop and because of their gradual disappearance during the growth and development of the economic crop. The monocotyledons were the dominant species with the greatest influence on the interspecific relationship. The grass *Eleusine indica* had a medium population and a low competitive capacity.

Some of the dicotyledonous weeds showed a high coverage and reached a grade five, that is, a very strong level of “weeding”, those were *Amaranthus dubius* and *Parthenium hysterophorus*. The weed species that did not survive at the end of the crop cycle, such as *Echinochloa colona*, *Urochloa platyphylla*, *Ischaemum rugosum*, *Portulaca oleracea* and *Parthenium hysterophorus*, could be related to the intraspecific relationship of the species and the density of plants used.

The dominance of the weeds was not modified significantly by plant density, there being only positional variability in dominance among them, because of the conditions in the

system. In order for the dominance to change completely, it seems to require greater repeatability over time and to be known through studies of seed accumulation in the soil.

Species such as *Euphorbia heterophylla*, *Parthenium hysterophorus*, *Portulaca oleracea*, *Kallstroemia maxima* that were shown to have no apparent influence on the weed community, seem to play a role of temporary protection of the space from the most aggressive weeds. The presence of weeds in interspecific relationship with the crop and related to plant density is yet to be studied in depth, but their tendencies should be assumed, given the monitoring of survival, where the strongest, due to their greater adaptability, dominate over the less adapted species.

Influence on biomass production of weeds in interspecific association with maize cultivation at different plant densities

Table IV shows the direct relationship between abundance and dry biomass production of weeds (g m^{-2}) in the maize crop by plant density. Dry biomass yields reached total values higher than 2.5 t ha^{-1} (266.2 g m^{-2}) (treatment 2), of which 63.4 % corresponded to broadleaf weeds (dicotyledons), which implies a greater extraction of water and nutrients from the soil. However, for corn production it constitutes an obstacle due to the competition established between them and

the crop, which is why the analysis by treatments can better express the advantages or disadvantages of their presence in the system, prior to the onset of economic damage to the crop.

Periodic rainfall causes an increase in the biomass of weeds, because of a high light input in the final stage of the crop cycle, which for corn increases when the leaves begin to dry, but this is not an element to consider in this analysis. Since the harvest was carried out with the corn in its tender stage; therefore, it is assumed that the spatial arrangement used could favor such results.

Treatment 6 was the one that provided the lowest biomass production of broadleaf weeds with a plant density of $106,400 \text{ plants ha}^{-1}$, lower than the production found in treatment 2, which is the density generally used by producers with a density of $44,400 \text{ plants ha}^{-1}$. It was the treatment that most benefited the population of broadleaf weeds. In grassy weeds, treatment 6 also showed lower biomass production of weeds compared to treatment 1, which favored the population of these weeds. Weed biomass production was reduced from low to high density in both broadleaf and grassy weeds. This makes them potential weed inhibitors, as they offer a lower aerial density while capturing more resources, such as water and light.

TABLE III

Species and number of individuals recorded in interspecific relationship with the maize crop in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba

Species marked in bold indicate the most dominant species in the crop.

TABLA III

Especies y número de individuos recolectados en la relación interespecífica con el cultivo del maíz en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba

Las especies marcadas en negrita indican las más dominantes en el cultivo.

Families	Species	Number of individuals per m ²
Amaranthaceae	<i>Amaranthus dubius</i> Mart. ex Thell.	50
Asteraceae	<i>Parthenium hysterophorus</i> L.	21
Cyperaceae	<i>Cyperus rotundus</i> L.	200
Cucurbitaceae	<i>Melothria pendula</i> L.	3
Euphorbiaceae	<i>Chamaesyce hyssopifolia</i> (L.) Small	8
	<i>Euphorbia heterophylla</i> L.	9
	<i>Urochloa platyphylla</i> (C. Wright) R. D. Webster	8
	<i>Cynodon dactylon</i> (L.) Pers.	5
Poaceae	<i>Echinochloa colona</i> (L.) Link	43
	<i>Eleusine indica</i> (L.) Gaertn.	20
	<i>Ischaemum rugosum</i> Salisb.	3
	<i>Rottboellia cochinchinensis</i> (Lour.) Clayton	150
	<i>Sorghum halepense</i> (L) Pers.	186
Portulacaceae	<i>Portulaca oleracea</i> L.	13
Zygophyllaceae	<i>Kallstroemia maxima</i> (L.) Hook. & Arn.	15
Total of individuals (N)		734
Total of species (S)		15

TABLE IV

Dry biomass production of weeds during the maize crop cycle in Las papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba

T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with un grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with un grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹). SEX: mean standard error. Means followed by different letters, in the column, for each variable in joint analysis, differ from each other at the 0.05 probability level of significance, according to Duncan's test (1955).

TABLE IV

Producción de biomasa seca de las arvenses durante el ciclo del cultivo de maíz en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba

T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹). SEX: error estándar de la media. Las medias seguidas de letras diferentes, en la columna, para cada variable del análisis conjunto, difieren entre sí al nivel de significación de probabilidad de 0,05, según la prueba de Duncan (1955).

Treatments	Monocotyledons (g m ⁻²)	Dicotyledons (g m ⁻²)	Total (g m ⁻²)
1	26.55 d	76.73 c	103.28 c
2	84.10 a	182.12 a	266.22 a
3	11.57 e	29.46 d	41.03 e
4	37.95 c	15.38 e	53.33 d
5	61.20 b	106.40 b	167.60 b
6	8.04 f	10.10 f	18.14 f
SEX	0.92	1.23	0.98

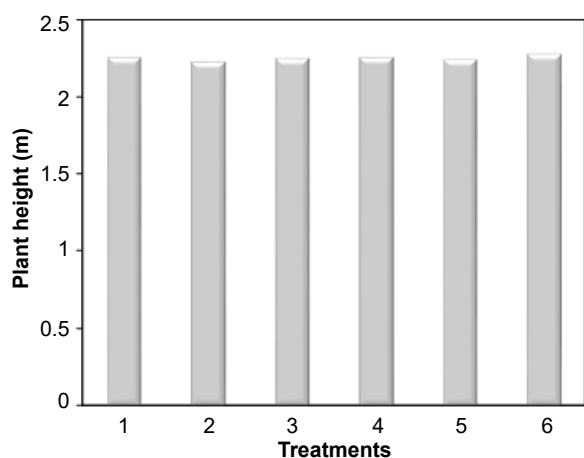


Fig. 1. Plant height of the different planting densities studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with un grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with un grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹).

Fig.1. Peso de la planta(m) en las diferentes densidades de siembra estudiadas en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹).

Influence of planting frames on morphoagronomic traits evaluated in maize cultivation

Plant height of the maize crop

No significant differences in the plant height parameter were found (Figure 1). This is because at low planting densities, the maize plants had less competition for water and nutrients, and at high planting densities, plants had more competition and thus grew in search of sunlight, thus equaling the height of the plants planted at low densities. Although if we perform the analysis numerically, we can observe that treatment 6 was the one that reached the greatest height (106,400 plants ha⁻¹).

Diameter of stem base of the maize crop

Stem diameter influences the support of the plant; the smaller the diameter, the greater the probability that the plant will fall under the weight of the cob. For the variable stem diameter, a significant statistical difference was found among the treatments; there was an increase in stem diameter in T2 and T5, which showed an average of 3.204 cm and 3.201 cm, respectively, compared to the rest of the treatments, as shown in Figure 2.

Cob diameter

For the diameter of the cob in measurements made, no significant differences were found among the treatments. There was a small increase with the decrease in the density of corn planting, in T2 and T5 with 6.79 cm and 6.78 cm of diameter respectively were greater in relation to T1 with 6.74 cm of diameter, T3 with 6.76 cm and T6 with 6.63 cm of diameter of the cob, as shown in Figure 3.

Although there was no significant difference, it increased linearly with the decrease in planting density, because competition between plants for space, water and nutrients is minimal at low densities, which allows a greater size of the ears in relation to higher planting densities. The cob diameter parameter has a marked influence on maize yield since a larger diameter of the cob, because it depends on the average diameter of the cob and can mean a larger grain size and therefore a higher grain weight.

Leaf area index

For the variable of leaf area index, a statistically significant difference was found among the treatments, there was an increase when the planting densities in the corn crop increased, so T6 had a greater difference than the rest of the treatments, and it yielded lower results, (treatments 2 and 5, Figure 4).

When analyzing the results of the yield components (Table V), it is observed that for the traits number of grains per row (NGR) and number of grains per cob (NGC) there are statistically significant differences between treatments, which suggests that the planting frame shapes influenced the evaluated parameters. As observed in the previous analysis where the variables of crop growth and development were analyzed, the treatments that showed the best results in both traits

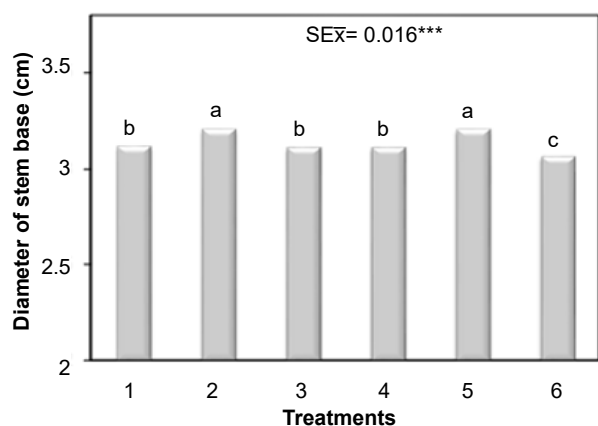


Fig. 2. Stem base diameter (cm) of the different planting densities studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with un grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with un grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106 400 plants ha⁻¹). $SE\bar{x}$: mean standard error, *** significant for $p \leq 0,001$

Fig. 2. Diámetro de la base del tallo (cm) en las diferentes densidades de siembra estudiadas en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹). $SE\bar{x}$: error estándar de la media, *** significativo para $p \leq 0,001$

were 6, followed by treatments 3 and 4. In the case of the character mass of one hundred grains (M100S), treatment 6 was the one that obtained the best result, it was statistically superior to the rest; however, in the total mass of grains (MTSM), the best treatments were 4 and 6.

In the character diameter of the cob (CD), it was observed that there were statistical differences among the treatments, more specifically T6, which is the treatment with the largest diameter, grouping again among the treatments with the smallest planting frames. For cob length, there was a similar behavior to the previous parameters. In general, there was a tendency in the growth and development parameters as well as in the yield components, with the best results being found in those treatments where there was a higher plant density, which corresponded to the treatment with the highest yield.

Yield (t ha⁻¹)

Figure 5 shows the calculation of corn yield in tender cobs. For the yield variable, a significant statistical difference was found among all the treatments studied, by increasing the planting density and reducing the distance between rows in the corn crop.

T6 (106,400 plants ha⁻¹) obtained the highest yield compared to the other treatments with a difference of 6.15 t ha⁻¹ with

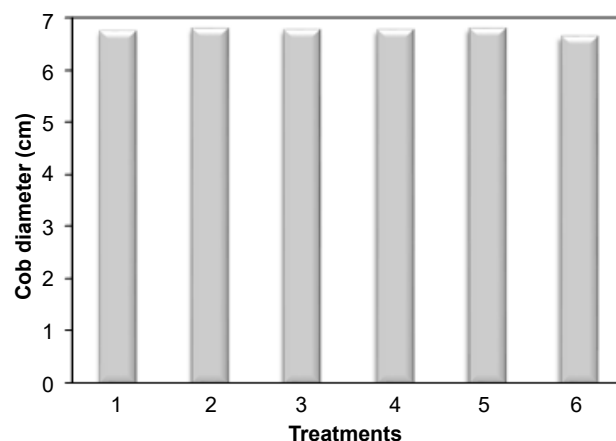


Fig. 3. Cob diameter of the different planting densities studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with un grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with un grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹).

Fig. 3. Diámetro de la mazorca en las diferentes densidades de siembra estudiadas en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹).

respect to the lowest yielding treatment T2 (44,400 plants ha⁻¹). There were no significant differences between treatments 3 and 5 with yields of 7.5 and 7.85 t ha⁻¹, respectively.

Economic analysis

For the economic analysis, the expenses incurred during the crop cycle in each treatment were taken into account. The indicator used was the number of tillage operations carried out and their costs per treatment, compared to the reference control (T1); the remaining phytotechnical operations were the same for all treatments.

Table VI shows the results of the economic analysis based on the costs, according to the method applied, where the best treatment was treatment 6. Here, the greatest gains were achieved and the lowest cost with respect to the control treatment (T1) and the rest of the treatments, which demonstrates the positive effect of the density used.

DISCUSSION

When the composition of weeds present during the growth and development of the corn crop was analyzed, the dominant species that appeared in the system was *Cyperus rotundus*

(Table 3). According to Boutin & al. (2014), the dominance of *C. rotundus* is due to its characteristic of being an aggressive and invasive perennial species that is difficult to control. In addition, it has high resistance to pre-emergent herbicides, such as atrazine (Bezic & al. 2007, Vaz 2015) one of the herbicides that were used for many years in the experimental area, before the beginning of the present work.

The coverage of the other monocotyledonous species except for those that became dominant in the treatment with the largest foliage and the longest time (with weeds throughout the cycle) was between 8 and 10 %, a value considered low according to Cerna-Bazán (2013) and according to Alemán-Zeledón (2004) corresponds to a medium level of “weeding”. In the taxonomic group of dicotyledonous vines, some of them showed a high coverage reaching a grade five, that is, a very strong level of “weeding”, which has been corroborated by Cerna-Bazán (2013).

Related to weeds that did not excel in the agroecosystem, it is inferred from an agronomic view that due to the complexity

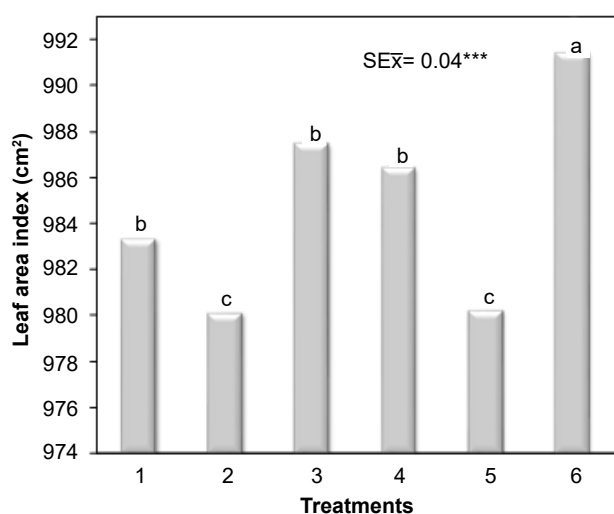


Fig. 4. Leaf area index of the different planting densities studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with a grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with a grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹). SE_x: mean standard error, *** significant for p ≤ 0,001

Fig. 4. Índice del área foliar en las diferentes densidades de siembra estudiadas en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹). SE_x: error estándar de la media, *** significativo para p ≤ 0,001

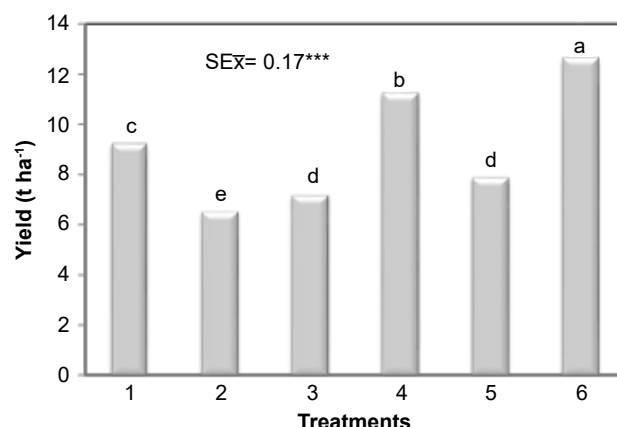


Fig. 5. Yield expressed in the amount of baby corn of the different planting densities studied in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with a grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with a grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹). Means followed by different letters, in the column, for each variable in joint analysis, differ from each other at the 0.05 probability level of significance, according to Duncan's test (1955), SE_x: mean standard error, *** significant for α ≤ 0,001.

Fig. 5. Rendimiento expresado en la cantidad de maíz tierno de las diferentes densidades de plantación estudiadas en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba. T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹), Las medias seguidas de letras diferentes, en la columna dindica diferencias significativas entre sí según la prueba de Duncan (1955) para α ≤ 0,05. SE_x: error estándar de la media, *** significativo para α < 0,001.

TABLE V

Yield component behavior in Las Papas farm, National Institute of Agricultural Sciences (INCA), San José de las Lajas, Mayabeque, Cuba.

NGR: number of grains per row, NGC: number of grains per cob, CD: cob diameter, CL: cob length, M100S: mass of 100 grains, TSMC: total mass of grains. T1: 0.90 × 0.30 m with two grains per nest (73,926 plants ha⁻¹), T2: 0.90 × 0.25 m with un grain per nest (44,400 plants ha⁻¹), T3: 0.90 × 0.25 m with two grains per nest (88,800 plants ha⁻¹), T4: 0.75 × 0.30 m with two grains per nest (88,578 plants ha⁻¹), T5: 0.75 × 0.25 m with un grain per nest (53,200 plants ha⁻¹), T6: 0.75 × 0.25 m with two grains per nest (106,400 plants ha⁻¹). SE \bar{x} : mean standard error. Means followed by different letters indicate differences between treatments for $p \leq 0,05$, according to Duncan's test (1955), *** significant for $p \leq 0,001$.

TABLA V

Comportamiento del componente de rendimiento en la finca Las Papas, Instituto Nacional de Ciencias Agrícolas (INCA), San José de las Lajas, Mayabeque, Cuba

NGR: número de granos por hilera, NGC: número de granos por mazorca, CD: diámetro de la mazorca, CL: longitud de la mazorca, M100S: masa de 100 granos, TSMC: masa total de los granos, T1: 0,90 × 0,30 m con dos granos por nido (73 926 plantas ha⁻¹), T2: 0,90 × 0,25 m con un grano por nido (44 400 plantas ha⁻¹), T3: 0,90 × 0,25 m con dos granos por nido (88 800 plantas ha⁻¹), T4: 0,75 × 0,30 m con dos granos por nido (88 578 plantas ha⁻¹), T5: 0,75 × 0,25 m con un grano por nido (53 200 plantas ha⁻¹), T6: 0,75 × 0,25 m con dos granos por nido (106 400 plantas ha⁻¹), SE \bar{x} : error estándar de la media. Las medias seguidas de letras diferentes difieren entre sí al nivel de significación de probabilidad de 0,05, según la prueba de Duncan (1955), *** significativo para $p \leq 0,001$.

Treatment	NGR	NGC	CD (cm)	CL (cm)	M100S (g)	TSMC (g)
T1	30.83c	419.07d	1.86b	15.32b	35c	99.67 e
T2	25.57e	353.21f	1.63d	14.56b	29.17e	107.51d
T3	31.97b	454.47b	1.87b	17.59a	36.52b	164.35 b
T4	31.21b	440.90c	1.86b	17.38a	35 c	177.44 a
T5	27.43d	379.20e	1.78c	17.16a	30.61d	132.60 c
T6	32.27a	455.33a	1.99a	17.53a	38.9a	178.46 a
SE \bar{x}	0,43***	0,78***	0,02***	0,82***	0,32***	0,95***

of factors involved in the process, including the allelopathic effects or radical exudates of some inhibitory or stimulatory species in the presence of other species. These did not excel in the system as occurs with *Setaria verticillata* Beauv., *Sorghum halepense*, *Digitaria bicornis* (Lam.) Roem. & Schult., *Rottboellia cochinchensis*, *Portulaca oleracea*, *Echinochloa crus-galli* (L.) P. Beauv. and *Cyperus rotundus* (Hernández-Escobar 2015).

It has been observed that a group of species whose characteristics are probably similar or possess some common protective nexus that unites them accompanies each crop. Species such as *Cyperus rotundus* and *Rottboellia cochinchensis* persist in most Cuban agroecosystems (Leyva & al. 2015).

Equidistant distribution (weed biomass), on the other hand, significantly reduced the population of monocotyledonous weeds (Table 4), and to the extent that these were the dominant ones, the total number of weeds of both types was similarly affected. However, there was no difference with the normal distribution in the grass control. This confirms the observations of Yao & Shaw (1964) and that maize with equidistant distributions makes better use of light and water, thus limiting the availability of these factors for weed growth.

In relation to the stem diameter indicator in this research, it matches with Pérez-Somarriba & Hernández-Fernández (2022) who also found statistically significant differences in stem diameter due to the effect of population and distance between rows. This behavior could be seen by the lower competition between plants planted at low densities, according to Blanco & al. (2015), the stem diameter increases as plant population is reduced.

Roca-Mendoza (2019) found that there was no significant difference for ear diameter by spacing effect in corn crop whose results matches with that of this research where no significant differences were found. On the other hand, Tinoco-Alfaro & al. (2008) stated that low density allows the appearance of larger ears, possibly two per plant, but high densities are always the result of many medium-sized ears, which favors a decrease in production, due to the presence of small ears, which is directly proportional to the diameter of the stem.

The results obtained in the leaf area index is in accordance with that mentioned by Blanco-Valdés (2019) who affirms that the increase in plant density strongly increases the leaf area index in the vegetative stage of the plants. Tinoco-Alfaro & al. (2008), who used an empirical equation in the Sorkan model, predicted a greater interception of light as the distance between rows decreased.

The results obtained on yield components do not match with those found by Andrino (2014) who found no significant statistical differences when evaluating LM in five planting frames. Like Quevedo-Amaya & al. (2015), when evaluating the same traits in maize found that population density had no influence on them that does not coincide with the results of the present work. The maize crop yield also matches with other studies, where significant statistical differences were found as the population density increased.

On the other hand, this result is also related to the greater number of plants and therefore of ears per square meter at high densities. According to Loza-Espinosa (2017), with low densities, the individual production per plant is maximum but the yield per area is low. Also, by increasing the density, the individual production is low, but the productivity per area increases until it reaches a maximum.

Related to this, Quevedo-Amaya & al. (2015) in their research, propose that there is an increasing trend in yield as the number of plants per unit area increases. It is similar to that concluded by Pedroso (2019) who found that for their varieties and hybrids the same phenomenon occurs, however they say that yields are very low with low populations, while Ramírez-Iguarán (1980) reports that production increases as the population is higher until reaching the maximum density where yields decline.

After performing the economic analysis, the data of the same agree with those of Quevedo-Amaya & al. (2015). These authors found that the population density treatment for the maize hybrid that impacted with the highest profitability (59.65 %) was the highest density (106 400 plants ha⁻¹) which coincides with the results of this work.

The analysis of the economic valuation in this study shows that there is an economic feasibility in the productive management, which indicates the possibility of using a strategy with the management of stocking densities in order to increase yields in the corn crop. The economic analysis conceived allowed an integral valuation of the results obtained from the productive point of view, since those treatments that presented the best performance in terms of yield and quality, also showed superior economic efficiency indicators.

CONCLUSIONS

Treatment 6 with a plant density of 106.400 plants ha⁻¹ was the one that presented the lowest production of weed biomass compared to the rest of the treatments studied. During the growth and development of the crop, there was an abundance of 734 and a diversity of 15 species of weeds, of which monocotyledons dominated over dicotyledons and *Sorghum halepense* and *Cyperus rotundus* were the most dominant, while *Rottboellia cochinchinensis* had an average dominance. The treatment with the lowest plant density (44,400 plants ha⁻¹) was the one with the greatest number of weeds. The best performance was obtained in the 0.75 × 0.25 m planting frame with two grains per nest, being the treatment where the greatest gains were achieved.

AUTHOR'S CONTRIBUTION

Y. Blanco designed and set up the experiments and defined the study methodology. O. Cartaya performed the data analysis. A. Lamz wrote and prepared the first version of the manuscript. All authors participated in the evaluations and data collection.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest: The authors declare that they have no conflict of interest.

Ethics approval: All authors have carried out fieldwork and data generation ethically, including obtaining appropriate permitting.

Consent for publication: All authors have consented to publishing this work.

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