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Original article

Seeding density, morpho-physiological, and productive behavior of INIAP H-603 hybrid corn

Densidad de siembra y comportamiento morfo-fisiológico y productivo del maíz híbrido INIAP H-603

Rolando León-Aguilar[1], **Benny Avellán-Cedeño**[2], **Antonio Torres-García**[1], **Eduardo Héctor-Ardisana**[1*], **Osvaldo Fosado-Téllez**[1]

[1]Facultad de Ingeniería Agronómica, Universidad Técnica de Manabí, Ecuador

[2]Instituto Nacional de Investigaciones Agropecuarias, Estación Portoviejo, Ecuador

ABSTRACT: Corn (*Zea mays* L.) is one of the most important food crops, both for human and animal consumption. The objective of this research was to evaluate the effect of planting density on the morpho-physiological and productive behavior of INIAP H-603 hybrid maize, in summer with localized irrigation. A bifactorial design (distances between rows and plants) was used, in completely randomized blocks, with three levels per factor, nine treatments and three replications. The densities studied ranged from 33 000 to 71 000 plants ha^{-1}. The morpho-physiological variables determined were plant height, stem diameter, number of leaves, leaf length, female inflorescence height and total chlorophyll content. The productive variables measured were length, diameter, number of rows, number of grains and average mass of grains per cob and estimated yield per hectare. Analysis of variance and comparison with Fisher's LSD test showed significant differences in the interaction for relative chlorophyll content and number of rows per cob. Yield showed significant differences for the effect of the factors distance between rows and between plants, but not for their interaction. The highest yield (10.72 t ha^{-1}) was obtained at the density of 71 000 plants ha-1; the treatment with 33 000 plants ha-1 had the highest grain mass (209.54 g cob $^{-1}$) and the lowest yield (5.69 t ha^{-1}).

Key words: chlorophylls, maize, yield.

RESUMEN: El maíz (*Zea mays* L.) es uno de los cultivos más importantes para la alimentación, tanto humana como animal. El objetivo de esta investigación fue evaluar el efecto de la densidad de siembra sobre el comportamiento morfofisiológico y productivo del maíz híbrido INIAP H-603, en época de verano con riego localizado. Se utilizó un diseño bifactorial (distancias entre hileras y plantas), en bloques completamente al azar, con tres niveles por factor, nueve tratamientos y tres réplicas. Las densidades estudiadas oscilaron entre 33 000 y 71 000 plantas ha^{-1}. Las variables morfofisiológicas determinadas fueron: altura de la planta, diámetro del tallo, cantidad de hojas, longitud de las hojas, altura de la inflorescencia femenina y contenido de clorofilas totales. Las variables productivas medidas fueron: longitud, diámetro, número de hileras, cantidad de granos y masa promedio de los granos por mazorca y rendimiento estimado por hectárea. El análisis de varianza y la comparación con la prueba de LSD de Fisher evidenció diferencias significativas en la interacción para el contenido relativo de clorofilas y el número de hileras por mazorca. El rendimiento mostró diferencias significativas por efecto de los factores distancia entre hileras y entre plantas, pero no para su interacción. El mayor rendimiento (10,72 t ha^{-1}) se obtuvo en la densidad de 71 000 plantas ha^{-1}; el tratamiento con 33 000 plantas ha^{-1} registró la mayor masa de los granos (209,54 g mazorca $^{-1}$) y el menor rendimiento (5,69 t ha^{-1}).

Palabras clave: clorofilas, maíz, rendimiento.

*Author for correspondence: eduardo.hector@utm.edu.ec

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INTRODUCTION

Corn (*Zea mays* L.) is one of the most important crops for both human and animal food, in addition to providing raw material for agribusiness (1,2). In 2014, corn production reached 1 037.8 million tons, surpassed only by sugarcane and vegetable production (3). The area planted to hard dry corn in Ecuador amounted to 334 767 ha, with a production of 1 479 770 t and an average yield of 4.4 t ha^{-1} (4).

In recent years, in Ecuador, there has been an increase in hard dry corn yields, motivated by several factors, among them, the use of hybrid seeds with high yield potential and the introduction of improvements in the production system; the search for an optimal planting density has been among the alternatives that allow increasing yields (5). In spite of these results, there is a need for further research to precisely define the main factors that determine the obtaining of potential yields of the crop (6,7); in addition, it is necessary to look for models that are sustainable (8). There are multiple factors that affect crop yield, mainly the type of hybrid, sowing density, irrigation supply or rainfall incidence, sowing time, soil type, pest incidence and fertilization (9). For example, when evaluating the response of maize, variety INIAP 180, to nitrogen fertilization in Ambuela, Pichincha, Ecuador, it was recommended to consider its genetic potential and behavior in different plant densities per unit area; also, the importance of carrying out site-specific studies to determine the influence of climate, soil type and management on crop response was pointed out (10). On the other hand, it was suggested that an increase in planting density reduces the length and diameter of the stem and cob, but the final yield depends more on the density than on the behavior of these variables (11).

The adequate density of plants per unit area is important to obtain a high yield in corn production, so it is necessary to determine a planting frame that allows reaching an adequate planting density, which allows the plants to benefit to the maximum from the available water, soil nutrients and solar energy, looking for the reduction of production costs (12). There is a tendency to reduce the distance between rows in corn planting, arguing reasons such as machinery design, working comfort and land utilization (13).

The objective of this research was to evaluate the effect of planting density on the morpho-physiological and productive behavior of INIAP H-603 hybrid corn, cultivated in summer, with localized irrigation.

MATERIALS AND METHODS

The research was carried out at the Experimental Campus La Teodomira, belonging to the Faculty of Agricultural Engineering of the Technical University of Manabí, located in the parish of Lodana, Santa Ana canton, province of Manabí, Ecuador. The experimental site is located at the geographical coordinates 80°26'22'' west longitude and 01°04'15'' south latitude, in the Portoviejo river basin, at an altitude of 60 meters above sea level.

The single hybrid INIAP H-603 was used, from the cross between the parents POB.3F4.27-1-1-1 (female) and CML-451 (male), with an average plant height of 259 cm and cob insertion at 127 cm; the stem has approximately 12 to 14 nodes. The plants are resistant to lodging or tipping. Its life cycle, from sowing to harvest, is 120 days; male flowering is at 55 days and female flowering at 57 days; its cob is conical-cylindrical with a length and diameter of 20 and 5.3 cm, respectively (14).

Sowing was done manually, placing one seed per site, under the distances established in the experimental design. Soil fertilization was carried out applying the required dose, according to INIAP recommendations, for the INIAP H-603 hybrid, divided as follows: Yaramila Complex (12-11-18+S) and 8-20-20 formula fertilizer at 15 days after planting; urea and muriate of potassium in mixture at 25 days and urea at 35 days. It was complemented with applications of Evergreen foliar fertilizer (80 mL per 20 L pump), mixed with insecticides during spraying for pest control.

At 20 days after planting, the insecticide Engeo (Thiamethoxan+Lambda cyhalothrin) was applied (20 mL per 20 L pump) to control insect vectors of viruses and larvae of codling moth (*Spodoptera frugiperda*). After 32 days, toxic bait was applied to control the budworm, mixing Chlorpyrifos sprayed on dry sand (150 mL per 50 kg of sand), applied directly to the head of plants. Weed control was carried out manually and with the use of herbicides Terbutryn (100 mL), Pendimethalin (200 mL) and Amine (100 mL), per pump of 20 L of water.

For irrigation, a localized system with dripper tapes was used, separated at 0.15 m and with flow rates of 1.5 L h^{-1}. The Cropwat 8.0 program was used for scheduling, with crop, soil and agroclimatic data obtained from the La Teodomira Climatological Station, which was used to determine the crop's water requirements. On this basis, 21 irrigations were planned, with gross doses between 12 and 24 L m^{-2}. According to the gross doses and dripper flow rates, irrigation times were determined, which were between 33 and 35 minutes for the initial period of the crop, between 45 and 50 minutes in the intermediate stage and between 55 and 60 minutes in the final stage.

Experimental design

A bifactorial experiment was carried out with three levels per factor: distance between rows (1, 2 and 3) and distance between plants (A, B and C), with nine treatments, using a randomized complete block design, with three replications (Table 1), forming 27 experimental units. Each plot consisted of five rows and 10 randomly selected plants were evaluated in each experimental unit. The total area of the experiment was 441.64 m^2.

Variables and statistical analysis

At 60 days after sowing, the following morpho-physiological variables were determined: plant height (PH), stem diameter (SD), number of leaves (LH), leaf length (LH), height of female inflorescence (HFI) and relative chlorophyll content (CCR). The Minolta SPAD-502Plus chlorophyll meter was used to determine CCR.

At 120 days, when the grains had 12-14 % moisture content, the variables associated with yield were evaluated: cob length (CL), cob diameter (CD), number of rows (NRC), number of grains per cob (NGC) and average mass of grains per cob (MGC). Based on the mass of grains per cob and planting density, the total yield per hectare was estimated for each of the treatments evaluated.

The assumptions of normality and homoscedasticity of the variables were checked with the Shapiro-Wilk and Levene tests, respectively. The results were processed by analysis of variance with MINITAB v.18.1 statistical software and the means of the treatments were compared with Fisher's least significant difference (LSD) test.

RESULTS AND DISCUSSION

Table 2 shows the results of the individual and combined effect of the factors under study, distance between rows and distance between plants (RS x PS) on morpho-physiological variables. No significant differences were found in the variables of plant height, stem diameter, number of leaves, leaf length and female inflorescence height; on the other hand, significant differences were observed in relative chlorophyll content (CCR).

Other authors have observed that the increase in planting density did not affect plant height and the number of leaves, but reduced stem diameter (15). Regarding the relative chlorophyll content (CCR), the distance between rows has not been a factor associated with changes in this variable, but planting density has; with densities between 87 500 and 128 700 plants ha^{-1} significant effects on the relative chlorophyll content have been found (16). This result may be a response of the plant to achieve greater light uptake.

In the present investigation, the relative chlorophyll content ranged from 47.83 to 53.67 SPAD units. It is considered that values around 51 SPAD units in maize can generate a yield according to its potential (17). Optimal

Table 1. Experimental treatments, according to the distance between rows (1, 2 and 3) and between plants (A, B and C)

Treatment	Interaction	Row spacing (RS)	Plant spacing (PS)	Sowing density (plants ha^{-1})
T1	1 x A	0.70 m	0.20 m	71 000
T2	1 x B	0.70 m	0.25 m	56 000
T3	1 x C	0.70 m	0.30 m	47 000
T4	2 x A	0.85 m	0.20 m	59 000
T5	2 x B	0.85 m	0.25 m	47 200
T6	2 x C	0.85 m	0.30 m	39 294
T7	3 x A	1.00 m	0.20 m	50 000
T8	3 x B	1.00 m	0.25 m	40 000
T9	3 x C	1.00 m	0.30 m	33 333

Table 2. Average values of morpho-physiological variables in INIAP H-603 hybrid corn at 60 days, with different planting densities, in the summer season, with localized irrigation

	PH (cm)	SD (cm)	NL	LL (cm)	HFI (m)	CCR (SPAD)
RS	NS	NS	NS	NS	NS	**
1	255.33 ± 4.36	2.53 ± 0.05	13.28 ± 0.17	110.81 ± 0.79	1.16 ± 0.04	52.69 ± 0.63 a
2	253.11 ± 4.34	2.50 ± 0.02	13.07 ± 0.11	111.18 ± 0.76	1.13 ± 0.03	50.12 ± 0.76 b
3	240.73 ± 3.66	2.62 ± 0.06	13.08 ± 0.11	109.46 ± 0.62	1.07 ± 0.03	50.49 ± 0.68 b
PS	NS	NS	NS	NS	NS	NS
A	252.81 ± 4.11	2.50 ± 0.04	13.16 ± 0.16	110.62 ± 0.82	1.15 ± 0.03	51.13 ± 0.64
B	250.99 ± 4.93	2.54 ± 0.04	13.16 ± 0.14	110.21 ± 0.81	1.14 ± 0.04	50.73 ± 0.64
C	245.37 ± 4.67	2.61 ± 0.05	13.12 ± 0.10	110.61 ± 0.67	1.07 ± 0.02	51.43 ± 1.03
RS x PS	NS	NS	NS	NS	NS	**
1A	258.63 ± 4.33	2.48 ± 0.10	13.33 ± 0.43	110.47 ± 1.80	1.21 ± 0.02	51.78 ± 1.76 ab
1B	261.57 ± 5.37	2.48 ± 0.05	13.33 ± 0.32	110.73 ± 1.22	1.23 ± 0.05	52.62 ± 0.63 ab
1C	245.80 ± 10.50	2.63 ± 0.09	13.18 ± 0.17	111.23 ± 1.62	1.05 ± 0.05	53.67 ± 0.64 a
2A	255.67 ± 7.46	2.52 ± 0.07	13.23 ± 0.22	111.97 ± 1.50	1.13 ± 0.11	51.47 ± 0.70 ab
2B	250.90 ± 11.40	2.50 ± 0.03	13.03 ± 0.29	110.97 ± 1.67	1.12 ± 0.07	51.06 ± 0.31 abc
2C	252.75 ± 5.92	2.49 ± 0.01	12.95 ± 0.03	110.60 ± 1.15	1.14 ± 0.02	47.83 ± 1.52 c
3A	244.13 ± 8.36	2.50 ± 0.07	12.90 ± 0.17	109.43 ± 0.99	1.10 ± 0.09	50.15 ± 0.74 bcd
3B	240.50 ± 4.70	2.65 ± 0.09	13.10 ± 0.15	108.93 ± 1.52	1.09 ± 0.12	48.52 ± 0.44 cd
3C	237.57 ± 7.63	2.72 ± 0.12	13.23 ± 0.26	110.00 ± 1.04	1.02 ± 0.01	52.81 ± 0.38 ab

PH: plant height; SD: stem diameter; NL: number of leaves; LL: leaf length; HFI: height of female inflorescence; CCR: relative chlorophyll content. RS: distance between rows; PS: distance between plants; RS x PS: interaction. Different letters indicate significant differences for the LSD test

Table 3. Average values of yield variables in INIAP H-603 hybrid corn at 120 days with different planting densities in the summer season with localized irrigation

	CL (cm)	CD (cm)	NRC	NGC	MGC(g)	YIELD (t ha^{-1})
RS	NS	NS	NS	NS	NS	***
1	18.20 ± 0.23	5.14 ± 0.04	15.17 ± 0.21	478.67 ± 10.06	193.41 ± 3.35	9.13 ± 0.45 a
2	17.96 ± 0.14	5.13 ± 0.02	15.38 ± 0.11	484.19 ± 9.38	194.49 ± 3.13	7.65 ± 0.43 b
3	18.41 ± 0.36	5.13 ± 0.02	15.17 ± 0.12	495.24 ± 13.37	195.80 ± 4.46	6.57 ± 0.35 c
PS	**	*	NS	NS	**	***
A	18.07 ± 0.19 b	5.11 ± 0.02 b	15.47 ± 0.14	483.96 ± 6.92	187.96 ± 3.70 b	9.26 ± 0.46 a
B	17.70 ± 0.17 b	5.10 ± 0.03 b	14.99 ± 0.15	487.16 ± 7.85	191.38 ± 2.21 b	7.46 ± 0.41 b
C	18.81 ± 0.27 a	5.19 ± 0.02 a	15.29 ± 0.14	486.99 ± 8.79	204.37 ± 1.98 a	6.63 ± 0.30 c
RS x PS	NS	NS	*	NS	NS	NS
1A	18.03 ± 0.46	5.14 ± 0.06	15.87 ± 0.13 a	477.6 ± 11.80	184.57 ± 4.03	10.72 ± 0.26
1B	18.07 ± 0.14	5.06 ± 0.07	14.67 ± 0.33 b	496.0 ± 21.50	194.05 ± 6.06	8.94 ± 0.26
1C	18.50 ± 0.56	5.22 ± 0.04	14.97 ± 0.15 ab	462.4 ± 20.00	201.62 ± 3.00	7.74 ± 0.09
2A	18.00 ± 0.27	5.10 ± 0.03	15.17 ± 0.23 ab	468.3 ± 4.93	189.41 ± 8.48	9.20 ± 0.51
2B	17.62 ± 0.24	5.09 ± 0.02	15.37 ± 0.14 ab	483.4 ± 14.80	192.12 ± 1.02	7.30 ± 0.10
2C	18.28 ± 0.07	5.19 ± 0.04	15.60 ± 0.17 ab	500.9 ± 2.83	201.95 ± 0.96	6.45 ± 0.01
3A	18.18 ± 0.34	5.09 ± 0.02	15.27 ± 0.18 ab	506.0 ± 5.03	189.88 ± 8.23	7.86 ± 0.38
3B	17.42 ± 0.39	5.14 ± 0.02	14.93 ± 0.18 ab	482.1 ± 0.13	187.99 ± 3.34	6.16 ± 0.12
3C	19.65 ± 0.18	5.17 ± 0.04	15.30 ± 0.29 ab	497.7 ± 7.88	209.54 ± 4.13	5.69 ± 0.13

CL: cob length; CD: cob diameter; NRC: number of cob rows; NGC: number of grains per cob; MGC: mass of grains; YIELD: estimated yield. RS: distance between rows; PS: distance between plants; RS x PS: interaction. Different letters indicate significant differences for the LSD test

planting densities, with more uniform spatial arrangements, allow a greater interception of solar radiation and, thus, a greater amount of photosynthesis by the plant; with high planting densities, plantations are achieved that allow an earlier coverage of the inter-row, reaching a higher biomass production.

The inter-row distance factor (RS) significantly influenced the estimated yield and had no significant effect on the remaining variables. The interplant distance (PS) factor produced significant differences on cob length and diameter, kernel mass and estimated yield; the interaction of the two factors had a significant effect only on the number of rows in the cob (Table 3).

Significant planting density-dependent variations have been found in cob length and diameter, number of kernels and their mass, but not in the number of rows (18). High yields have been obtained in maize when high planting densities have been used in the hybrid Impacto with 112 500 plants ha^{-1} (16) and with 104161 plants ha^{-1}, in 10 hybrids of different degrees of genetic progress (18). In an experiment developed with two sowing densities, the highest yield was achieved with 62 500 plants ha^{-1} (19), so it has been suggested that sowing density is an influential practice in this trait (20). These results coincide with the recommendation to use a planting density close to 7.8 plants m^{-2} (21) and to use 69 444 plants ha^{-1} to obtain high yields (19).

The significant interactions between factors, found in this research, are shown in Figures 1 and 2. In Figure 1, no significant differences are observed between the values of relative chlorophyll content when the distance between rows was 0.70 m; on the other hand, significant differences appear between the values when the distance between rows was 0.85 or 1.00 m, when the distances between plants were varied. When the distance between rows of 0.85 m was used, the distances between plants of 0.20 and 0.30 m showed significant differences for this variable; the same happened with the distances between plants of 0.25 and 0.30 m with 1.00 m distance between rows.

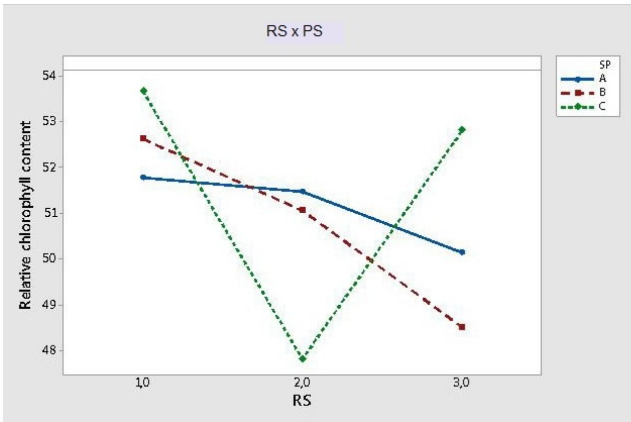

Figure 1. Effect of the interaction between row spacing (RS) and plant spacing (PS) on the relative chlorophyll content of INIAP H-603 hybrid maize under different planting densities

For the number of rows in the cob (Figure 2), significant differences were only observed when the inter-row distance of 0.70 m and the inter-plant distance of 0.20 and 0.25 m were used.

Although each factor separately influenced the estimated yields per hectare (with the highest values obtained at the smallest distances), the interaction of inter-row and inter-plant distances (RS x PS), with their corresponding factors, did not cause significant differences in the estimated yields per hectare. The reduction in planting distance, and, therefore, the increase in stocking density, generally increase yields in maize, being this the condition in which the best yields were achieved.

It seems that for the INIAP H-603 hybrid, the maximum productive potential has not been reached with 71 000 plants ha^{-1} and higher stocking densities can be tested to continue increasing yield per unit area, as far as the genetic potential of this hybrid allows.

The results allow recommending planting densities between 60 000 and 71 000 plants ha^{-1} for the hybrid INIAP H-603, planted in the dry season and with localized irrigation, with which yields double those reported by INEC, in 2020 (4). This is probably because this hybrid responds favorably to fertilization with nitrogen, phosphorus and potassium, and adequate irrigation, according to the phenological stage of plants (mainly in the formation of male and female inflorescences and pollination), in the presence of high levels of light for the production of photoassimilates. However, it is considered that high planting density, although important to increase yields, can also lead to greater competition for resources (22). Therefore, it will be necessary to continue searching for the point of equilibrium in which the plant makes the maximum use of these inputs, to achieve the highest possible yield, based on its productive genetic potential in interaction with the environment.

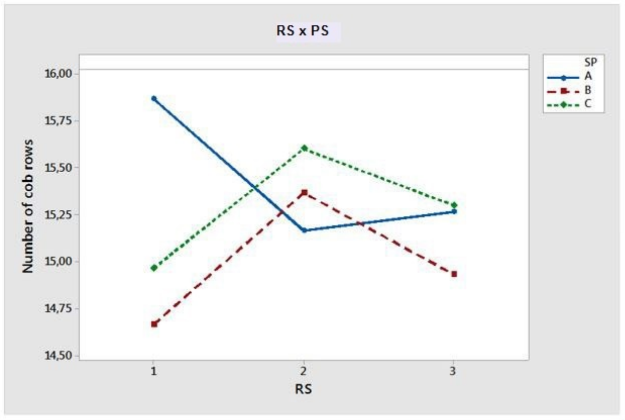

Figure 2. Effect of the interaction between row spacing (RS) and plant spacing (PS) on the number of rows in INIAP H-603 hybrid corn cobs under different planting densities

CONCLUSIONS

- The planting densities for the INIAP H-603 hybrid, evaluated in summer, with localized irrigation technology, did not because significant changes in the morpho-physiological variables as plant height and stem diameter, number and length of leaves and height of the female inflorescence.
- The highest estimated yield (10.72 t ha^{-1}) of the INIAP H-603 hybrid was obtained when the shortest inter-row and inter-plant spacing (0.70 x 0.20 m) was used, equivalent to the highest stocking density (71 000 plants per hectare).
- From variables used to estimate the yield of the INIAP H-603 hybrid, under different planting densities in summer and localized irrigation, the planting density defined the performance of the hybrid and not the average grain mass.

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