Article

Plant density and stem pruning in greenhouse cucumber production

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Abstract

The density of plants or stems is a variable of agronomic management associated with the productivity of vegetables under protected conditions. The research was carried out with the objective of knowing the influence of plant density and stem pruning on plant growth and yield of cucumber fruits grown under greenhouse conditions. The design of complete blocks was used randomly in factorial arrangement, with two levels each factor: plant density (1.68 and 2.22 plants m^{-2}) and stem pruning (one and two stems $plant^{-1}$). The treatments: T1) 1.68 plants m^{-2} with pruning to a stem $plant^{-1}$, T2) 1.68 plants m^{-2} with pruning to two stems $plant^{-1}$, T3) 2.22 plants m^{-2} with pruning to a stem $plant^{-1}$ and T4) 2.22 plants m^{-2} with pruning to two stems $plant^{-2}$, were established with four repetitions. The results indicated that fresh biomass of plant stem and dry leaves $plant^{-1}$ decreased with increasing plant density, but increased in plants with pruning to two stems $plant^{-1}$. Stem length, dry stem biomass, plant leaves, fresh leaf $plant^{-1}$ biomass and flower $plant^{-1}$ production also increased with two stems $plant^{-1}$, while leaf greenery decreased, but no influence on those variables by density of plants. Both factors caused a decrease in the diameter of the fruit. However, the best cucumber yields: total (112.8 t ha^{-1}), select (22.4 t ha^{-1}) and super select (53.6 t ha^{-1}), were positively influenced by plant density as well as by pruning of stems.

Keywords: *Cucumis sativus*, fruit yield, plant growth, plants m^{-2}, stems $plant^{-1}$.

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Introduction

Cucumber (*Cucumis sativus*) is the sixth horticultural product with the highest production worldwide, after potatoes (*Solanum tuberosum*), cassava (*Manihot esculenta*), tomatoes (*Solanum lycopersicum*), watermelon (*Citrullus lanatus*) and sweet potatoes (*Ipomea batatas*). In 2014, 74.98 million tons (t) of cucumbers were produced in 2.18 million hectares (ha) harvested. In Mexico, 16 808 ha were harvested and produced 707 632 t (FAO, 2016), of which Sinaloa, the main national producer, accounts for 24.5% of the harvested area and 43.1% of the production obtained (SIAP, 2016).

The protected crop represents the best option to increase the production of cucumber, by promoting a less restrictive environment for the growth and development of the plants than the one that occurs in the open sky (Smitha and Sunil, 2016). Due to the high costs of the facilities and management it is necessary to develop and apply specific agricultural practices, such as optimizing the density of plants per unit area, for a maximum expression of the productive potential of the crop (Ortiz *et al*., 2009).

Cucumber in a protected environment with plants tutored translates into a better arrangement of leaves to take advantage of light energy and greater ventilation, which promotes a lower incidence of pests and diseases, facilitates the harvest and allows the use of higher densities of population to obtain high yields of fruits with higher quality (Olalde *et al*., 2014). Although different types of trellises have been used in this crop, in a protected environment the support of plants is usually done with polypropylene thread (raffia) fixed in the basal part of the plant (bundle, knotted or with rings) and wire or horizontal tutor located at a certain height above the vegetal canopy (Grijalva *et al*., 2010).

In commercial greenhouse cucumber production, like indeterminate tomato cultivars, they are predominantly grown with a single main stem and axillary buds are eliminated on a regular basis (Maboko *et al*., 2011; Max *et al*., 2016; Mendoza-Pérez *et al*., 2018). The increase in the density of plants can be obtained, both by a greater number of plants m^{-2}, and by letting lateral stems develop to increase the number of stems m^{-2} (Kleinhenz *et al*., 2006; Rahmatian *et al*., 2014). The culture with low initial density of plants and then increased the effective density by developing lateral stems, seems to be a promising way to increase the number of fruits m^{-2} and has the additional advantage of using a smaller number of plants on the crop surface. Previous research indicates that, in general, the addition of lateral stems decreases the average weight of the fruits, reduces the variability of the average weight of the fruits, which turn out to be of more uniform size during the crop cycle, although it reduces the production of fruits larger (Peil and Gálvez, 2004).

For slicer-type cucumber, grown under greenhouse conditions and commonly handled to a stem, spacings of 1.5 to 2 m between rows and 0.2 to 0.3 m between plants are used; that is, from 1.7 to 3.3 plants m^{-2}. However, few studies have been carried out to evaluate the effects of planting density of new varieties, and it is necessary to optimize plant density in cucumber production, especially in those varieties with high seed costs (López-Elias *et al*., 2011). In addition, there is limited information on cucumber production under protected conditions and agronomic management variables associated with its productivity, such as the number of stems.

The research was carried out with the objective of knowing the influence of plant density and stem pruning on plant growth and yield of parthenocarpic cucumber slicer grown under greenhouse conditions.

Materials and methods

The work was carried out in a greenhouse located in the experimental field of the Faculty of Agronomy of the Autonomous University of Sinaloa, geographically located at 24° 48' 30" North latitude, 107° 24' 30" West longitude and 38.54 m altitude. The greenhouse (Baticenital 740-350®, ACEA, Mexico) is oriented from North to South, with a metal structure, with 3.5 m of rainwater and 6.3 m of total height. It consists of three ships of 7.4 m wide in a total area of 1 480 m^2. The cover, in the form of a double arch, has translucent white plastic, LDPE 180 μ, UV stabilization type Hals, 91% of global transmission of visible light and 35% of visible light dispersion. It has ventilation on sides and headboards (3.3 m), as well as zenith (1.15 m), with anti-aphids mesh (16 x 16 cm^{-2}).

The soil of the site is of the chromic vertisol type with regular surface drainage. The field capacity of the soil is 64% and the point of permanent wilting of 39%, so that the usable humidity 25%, based on the weight of dry soil. Its content of organic matter is less than 1%; with less than 0.002% nitrogen, around 17.5 and 300 mg kg^{-1} of phosphorus and potassium, respectively, pH between 7.5 and 8 and electrical conductivity less than 1 dS m^{-1}. The climate of Culiacan is BS_1(h')w(w) (e): very hot semi-dry extreme with summer rains, percent of winter precipitation with respect to the annual total less than five (García, 2004).

After the preparation of the soil, beds of culture were formed separated to 1.8 m, to which was incorporated vermicompost in doses of 12.5 t ha^{-1}, on top of it were placed two irrigation tapes with drippers every 30 cm (1.5 L h^{-1}) and finally they were padded with white/black plastic. 'Alanis RZ F1' cucumber seed of the parthenocarpic slicer type was used. Planting was carried out in polystyrene trays of 128 cavities, filled with peat moistened with a solution of Bacillus subtilis [Agrobacilo® (4 x 10^{10} ufc mL^{-1}), Agrobiologica, Mexico] in doses of 500 mL m^{-3}. The seeds were covered with vermiculite.

From the appearance of the first true leaf, the cucumber seedlings were fertigated with 50 mg L^{-1} of NPK, increasing by 50 mg every third day until reaching 250, using the fertilizer 18N-18P-18K-1Mg-1S-0.04Fe-0.02Zn-0.02Mn-0.01Mo-0.01Cu-0.01B (Ultrasol Multi-purpose®, SQM, Mexico). Between each fertirrigation the foliar fertilizer 9N-45P-15K-0.5Mg-1S-0.01Cu-0.01Mn-0.05Fe-0.01Mo-0.01Zn-0.01B (Speedfol Starter®, SQM, Mexico), was applied, in doses of 0.3 to 0.5 g L^{-1}. The transplant was performed 22 days after sowing. After this, the water and nutrient inputs were made by fertigation.

The volume of water, amount of fertilizers and the periodicity of the irrigation depended on the climatic conditions, the phenology of the plants and the humidity of the soil measured with tensiometers (2725ARL, Soilmoisture Equipment Corp., USA). The irrigation application was made when the humidity tension reached values of 20 to 25 kPa in the tensiometers placed at 30 cm depth. At the end of the study 268, 109, 378, 182, 70 and 56 kg ha^{-1} of N, P, K, Ca, Mg and S, respectively, had been applied.

A phytosanitary control was carried out with emphasis on prevention, through a program of applications of *Allium* sp. extract, *Azadirachta indica* seed extract, *Cinnamomum zeylanicum* extract and potassium salts of fatty acids, against insect pests (*Bemisia* sp., *Frankliniella occidentalis*, *Polyphagotarsonemus latus* and others), as well as *Bacillus subtilis*, *Trichoderma* sp., potassium bicarbonate, potassium phosphite, *Larrea tridentata* extract, among others, against pathogens causing diseases (*Oidium* sp. and *Pseudoperonospora cubensis*) common cucumber grown in the region.

The cucumber plants were pruned to one and two stems per plant. In the plants with pruning to a stem all axillary shoots of the main stem were eliminated. While in the plants with pruning to two stems one of the first axillary buds was allowed to grow, which became the second stem, then in both stems the axillary shoots were eliminated and they were tutored with raffia and plastic rings. At 78 days after the transplant (ddt) the stems were blunted, when they reached the height of the horizontal tutors of the greenhouse, delimiting with it the crop cycle.

A randomized complete block experimental design with a 2 x 2 factorial arrangement was used. Factor A corresponded to the density of plants m^{-2}, with two levels: 1.68 and 2.22 plants m^{-2} (0.33 and 0.25 m between plants, respectively). The factor B was the pruning of stems, with two levels: pruning to one and two stems $plant^{-1}$. The treatments: T1 (A^1 x B^1)= 1.68 m^{-2} plants with pruning to one stem, T2 (A^1 x B^2)= 1.68 plants m^{-2} with pruning to two stems (3.37 stems m^{-2}), T3 (A^2 x B^1)= 2.22 plants m^{-2} with pruning to one stem, and T4 (A^2 x B^2)= 2.22 plants m^{-2} (4.44 stems m^{-2}), were established with four repetitions in 216 m^2 of experimental area (23 and 30 plants per repetition in the respective densities of 1.68 and 2.22 plants m^{-2}).

The growth of the plants was evaluated, every 15 ddt, through the following response variables: stem length in centimeters, considered from the base of the stem to the distal end, basal diameter and apical stem in millimeters (Mitutoyo, Kanawaga, Japan, precision ± 0.01 mm), measured at an intermediate position of the first basal internode and internode forming the third and fourth leaf counted from the apex of the stem, respectively; number of leaves $plant^{-1}$, foliar area $plant^{-1}$ measured with an integrator (LI-3000A, LI-COR Inc., USA), leaf area index (IAF) in m^2 of leaf area per m^2 of soil surface, obtained by dividing the plant leaf area between the surface occupied by each plant, according to its density (0.59 m^2 for 1.68 plants m^{-2} and 0.45 m^2 for 2.22 plants m^{-2}) and foliar verdure (SPAD-502, Konica Minolta, Japan), obtained from leaves of the low, medium and high strata of each side (east and west) of the plants. The accumulation of fresh and dry biomass of leaves and stems (Sartorius, Goettingen, Germany; precision ±0.001 g) after drying in oven (FE-292, Felisa, Mexico) was also obtained up to constant dry weight of 16 plants per treatment, at the end of the crop cycle.

Flower $plant^{-1}$ production was also evaluated every third day and weekly growth of selected fruits, measuring their length and diameter from anthesis to harvest, of 16 plants per treatment. To determine the yield of cucumber, the harvested fruits were weighed (Sartorius, Goettingen, Germany, precision ± 0.01 g) and classified into sizes: small (19.1-20.3 cm long and 3.81-5.08 cm in diameter), select (20.3 -21.6 cm long and 5.08-6.03 cm in diameter), super select (21.6-22.8 cm long and 5.08-6.03 cm in diameter), large (22.8-24.1 cm long and 4.8-5.7 cm in diameter) and extra-large (24.1-25.4 cm long and 5.71-6.98 cm in diameter).

The results of the variables evaluated were processed with the Statistica 7.0 package (StatSoft, 2004); through the analysis of variance and the Tukey test ($p \leq 0.05$) for the separation of means.

Results and discussion

Stem growth

The density of plants did not significantly affect (Tukey, $p \leq 0.05$) the stem length. However, plants with pruning to two stems were taller than those with one stem (Table 1), which could be explained as effects caused by competition between plants by sunlight (Cruz *et al*., 2009; Grijalva *et al*., 2010).

Table 1. Influence of plant density (A), stem pruning (B) and their interaction (A x B) on stem growth of cucumber plants grown under greenhouse conditions (75 days after transplant).

Variation factor/ Significance	Length (cm)	Diameter (mm)		Biomass (g)	
		Basal	Apical	Fresh	Dry
A	ns	ns	ns	**	ns
A[1]) 1.68 plants m^{-2}	261.3	10.7	7.3	314.5 a[(1)]	43.8
A[2]) 2.22 plants m^{-2}	258.3	10.5	7.2	283.3 b	42.5
B	**	ns	ns	***	***
B[1]) one stem $plant^{-1}$	257.1 b	10.5	7.1	241.8 b	38.4 b
B[2]) two stems $plant^{-1}$	262.5 a	10.8	7.3	356 a	47.8 a
A x B	**	ns	ns	*	***
T1 (A^1 x B^1)	261.9 a	10.7	7.1	246 c	38.6 b
T2 (A^1 x B^2)	260.8 a	10.8	7.4	383 a	48.9 a
T3 (A^2 x B^1)	252.2 b	10.3	7.2	237.5 c	38.3 b
T4 (A^2 x B^2)	264.3 a	10.7	7.2	329 b	46.6 a

(1)= means with different letters in a column for each factor and their interaction are statistically different (Tukey, $p \leq 0.05$); ns, *, **, ***= not significant at $p \leq 0.05$, significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively.

Stem diameter, measured in the basal or apical part of the plants (Table 1), was not significantly affected (Tukey, $p \leq 0.05$). This agrees with Diaz *et al*. (1999); Ortiz *et al*. (2009); Grijalva *et al*. (2010), who also did not observe influence of density on the stem thickness of pepper, cucumber and tomato plants, respectively. This morphological characteristic has shown greater genetic propensity, as Ortiz *et al*. (2009) detected differences between cucumber varieties.

With the lowest density (1.68 plants m^{-2}), the stalk accumulated more fresh biomass. This result confirms what was reported by Díaz *et al*. (1999), who pointed out that biomass production decreases as the density increases, due to greater competition between plants for light, CO_2, water and minerals. However, the management of the plants to two stems caused that organ to have a greater accumulation of fresh and dry biomass, both with 1.68 and with 2.22 plants m^{-2} (Table 1), which manifests a compensatory effect on the weight of the stem, product of the largest number of stems $plant^{-1}$.

Growth of leaves

Plant density did not significantly affect (Tukey, $p\leq 0.05$) the number of leaves produced by cucumber plants. However, the management of the plants to two stems and their interaction with the two plant densities, led to the formation of greater amounts of leaves per plant. Therefore, the crop with a density of 2.22 plants m^{-2}, pruning two stems $plant^{-1}$, as well as their interaction, also led to increases in the leaf area $plant^{-1}$ and in the IAF (Table 2). Studies have shown that the leaf area $plant^{-1}$ increased together with the decrease in plant density (Gomes *et al*., 2017), but in the present study a capacity of the cucumber plants was shown to adapt to the management of two stems $plant^{-1}$ and grow competitively. There is general acceptance about the foliar area as one of the most important parameters in the evaluation of plant growth, hence the proper determination of it is essential for the correct interpretation of the processes in a plant species.

Table 2. Influence of plant density (A), stem pruning (B) and their interaction (A x B) on leaf growth of cucumber plants grown under greenhouse conditions (75 days after transplant).

Variation factor/ Significance	Leaves $plant^{-1}$ (#)	Leaf area (dm^2 $plant^{-1}$)	IAF[(1)] (m^2 m^{-2})	Biomass (g)		Greenery (spad values)
				Fresh	Dry	
A	ns	***	***	ns	**	ns
A^1) 1.68 plants m^{-2}	40.9	100.4 b[(2)]	1.69 b	1039.5	149.8 a	50.5
A^2) 2.22 plants m^{-2}	40.2	110.2 a	2.45 a	1057.8	131.3 b	49.6
B	***	***	***	**	***	***
B^1) one stem $plant^{-1}$	29.6 b	78.8 b	1.55 b	944 b	125.6 b	52.6 a
B^2) two stems $plant^{-1}$	51.5 a	131.8 a	2.59 a	1153.3 a	155.5 a	47.5 b
A x B	***	***	***	*	**	*
T1 (A^1 x B^1)	30.4 b	76.1 c	1.28 d	900.5 b	135.4 bc	54.3 a
T2 (A^1 x B^2)	51.5 a	124.7 b	2.1 b	1178.5 a	164.2 a	46.7 b
T3 (A^2 x B^1)	28.9 b	81.5 c	1.81 c	987.5 ab	115.8 c	50.9 ab
T4 (A^2 x B^2)	51.6 a	139 a	3.09 a	1128 ab	146.8 ab	48.3 b

[(1)]= leaf area index; [(2)]= means with different letters in a column, for each factor and its interaction, they are statistically different (Tukey, 0.05); ns, *, **, ***= not significant at $p\leq 0.05$, significant at $p\leq 0.05$, $p\leq 0.01$ and $p\leq 0.001$, respectively.

It has been an object of interest in studies of agronomy, plant physiology and genetics, since it is closely related to the photosynthetic efficiency of crops (Blanco and Folegatti, 2005, Mamun-Hossain *et al*., 2017).

Although the density of plants did not significantly influence (Tukey, $p\leq 0.05$) the fresh biomass of leaves $plant^{-1}$, the dry leaf biomass of the plants cultivated with 1.68 plants m^{-2} was higher. Both, fresh and dry leaf biomass was higher in plants managed with two stems $plant^{-1}$. In the end, the highest number of leaves due to the handling of two stems in the plants cultivated at 3.37 stems m^{-2} (A^1 x B^2), caused the highest productions of fresh and dry biomass $plant^{-1}$, although statistically equal with respect to the cucumber plants managed with 4.44 stems m^{-2} (A^2 x B^2) (Table 2).

When considering that the previous ones represented the highest densities used in this study (1.68 and 2.22 plants m^{-2} with pruning to two stems $plant^{-1}$), the results indicate that increasing the density caused reductions in the fresh and dry biomass of the individual leaves (Díaz *et al*., 1999), as a result of the population pressure in the development of the plants; however, at the same density, a higher biomass production per plant or surface unit was obtained (Villegas *et al*., 2004; Goda *et al*., 2014). The production of foliar biomass of the cucumber plant is directly related to the foliar area that develops the crop, having as resources the water, light and nutrients of the soil that intervene in their physiological processes.

The density of plants did not significantly influence (Tukey, $p\leq 0.05$) the foliar verdure, but the pruning of stems, since the increase in leaf area per unit area, caused by the increase of stems $plant^{-1}$, caused the green index of the leaves will decrease (Table 2). Similar results were found in soybean leaves, observing a tendency to decrease the green index as the density was higher (Moreira *et al*., 2015). Ekinci *et al*. (2014); Cardoso *et al*. (2017) reported relatively low spad values (37.7 and 39.9) on cucumber leaves, while Pôrto *et al*. (2014) and Yasir *et al*. (2016) similar values (40 to 52.5 and 45.3 to 52.4, respectively) to those obtained in this investigation.

Flower production and fruit growth

The density of plants did not significantly affect (Tukey, $p\leq 0.05$) flower production by cucumber plants. However, the management of two stems caused the plants to produce 56.9% more flowers than the plants to a single stem and their interaction with the densities of 1.68 and 2.22 plants m^{-2} exceeded in 66.2 and 51.8% the number of flowers generated by plants grown at the same densities, but with one stem per plant (Table 3).

Table 3. Influence of plant density (A), stem pruning (B) and their interaction (A x B) on flower production and fruit growth of cucumber plants grown under greenhouse conditions.

Variation factor/ Significance	Flowers/plant(1) (#)	Fruit length(cm)			Diameter of fruit(cm)		
		0(2)	7	14	0	7	14
A	ns	ns	ns	ns	ns	**	ns
A^1) 1.68 plants m^{-2}	29.1	3.6	11	19.4	0.7	2.2 a	3.8
A^2) 2.22 plants m^{-2}	28.7	3.6	10.6	18.7	0.7	2 b	3.6
B	***	ns	ns	ns	ns	ns	*
B^1) one stem $plant^{-1}$	22.5 b(3)	3.5	10.8	19	0.7	2.1	3.8 a
B^2) two stems $plant^{-1}$	35.3 a	3.7	10.8	19.1	0.7	2	3.6 b
A x B	***	ns	ns	ns	ns	ns	**
T1 (A^1 x B^1)	22.2 b	3.5	10.6	19	0.7	2.2	3.7 a
T2 (A^1 x B^2)	36 a	3.7	11.3	19.7	0.7	2.2	3.8 a
T3 (A^2 x B^1)	22.8 b	3.5	10.9	19.1	0.7	2.1	3.9 a
T4 (A^2 x B^2)	34.6 a	3.6	10.3	18.3	0.7	1.9	3.3 b

(1)= 75 days after the transplant; (2)= days after anthesis; (3)= Means with different letters in a column, for each factor and its interaction, are statistically different (Tukey, 0.05); ns, *, **, ***: not significant at $p\leq 0.05$, significant at $p\leq 0.05$, $p\leq 0.01$ and $p\leq 0.001$, respectively.

Since the partenocarpic ginoic cucumbers, such as the one used in this research, produce only female flowers (usually a flower in the axilla of each leaf present in the stem of the plant), hypothetically the number of leaves per plant should correspond to the number of flowers. However, the number of flowers that reached anthesis only corresponded to 76 and 68.5% of leaves developed in plants with one and two stems, respectively. This indicates that the plants aborted, prematurely, from 24% of flower buds in the plants with a single stem to 31.5% in the plants with two stems.

This phenomenon occurs naturally in Cucurbitaceae species and reaches 60 to 70% as the supply of nutrients decreases (Peil and Gálvez, 2005), since under these conditions there may be less meristematic activity in the plant , which has as a consequence that new flowers do not appear or that they did not give rise to fruit (Schapendonk and Brouwer, 1984; Marcelis, 1991, 1992), due to the lack of strength of the source capable of sustaining it as a consequence of poor transportation of photoassimilated, related to low nutritional availability (Liebig, 1980).

The length of the fruit did not show differences (Tukey, $p \leq 0.05$) because of the treatments (Table 3). At the beginning of the study on the growth of the fruit, the day of anthesis, neither the diameter of the fruit showed differences due to the factors studied. However, 7 days after anthesis (dda) the density of 1.68 plants m^{-2} increased the diameter of the fruit and at 14 dda the management of a stem $plant^{-1}$ also favored the fattening of the fruit, so that the fruits of the plants of treatment 4 (2.22 plants m^{-2} with two stems $plant^{-1}$) were from 12 to 18% less thick than the fruits of the plants of treatments 1, 2 and 3. This lower growth can be explained by the greater competition between the stems within the plant by water and nutrients, as well as limiting the root of the plant to cope with the increased demand for water and nutrients (Ara *et al*., 2007; Azevedo *et al*., 2010), which it can be modulated by increases in soil fertility and water availability (Mourão *et al*., 2017).

Little significant effects of plant density on the fruit growth of various vegetables were reported by Lujan and Chávez (2003), who observed that the length and width of the fruit and the pericarp thickness of the jalapeño pepper were little affected by the minor spacings between plants and furrows, Lopez-Elias *et al*. (2015) indicated that the length and diameter of the cucumber fruit, as well as the firmness and concentration of soluble solids were similar for the evaluated plant densities.

Fruit yield

The higher density of plants m^{-2} and the pruning of two stems $plant^{-1}$ caused significant increases (Tukey, $p \leq 0.05$) in the total yield of cucumber (Table 4). Similar results were obtained in tomato plants by increasing the density of stems m^{-2} (Peil and Gálvez, 2004; Mendoza-Pérez *et al*., 2018). However, such a response is different depending on whether the crop is carried out in the open field or in the greenhouse, because while in the open field the yield decreases with increasing density, under greenhouse conditions it increases (Villegas *et al*., 2004). Although in both cases, the pruning management is transcendental for the plants to obtain increases in the leaf area index and, therefore, in the interception of light, which in turn increases the biomass assigned to the fruits (Villegas *et al*., 2004; Kinoshita *et al*., 2014).

The density of 2.22 plants m^{-2} significantly increased the yield of small fruits (Table 4). These results coincide with others obtained in tomato (Grijalva *et al*., 2010), where the highest density of plants used in this research (3.78 plants m^{-2}) led to the largest harvests of small tomatoes. Other research on the effect of planting density in tomato under greenhouse conditions (Grasso *et al*., 2004), showed a positive response in yield as the number of plants m^{-2} increased, with the disadvantage of reducing the size of the fruit it has also been described that the high density of plants, besides that the fruits produced are smaller, increases precocity and reduces the biological cycle (Villegas *et al*., 2004; El-Hamed and Elwan, 2011).

Table 4. Influence of plant density (A), stem pruning by plant (B) and their interaction (A x B) on leaf growth of cucumber plants grown under greenhouse conditions.

Variation factor/ Significance	Yield (t ha^{-1})					
	Total	Small	Select	Super select	Large	Extra large
A	**	*	**	**	ns	ns
A^1) 1.68 plants m^2	92.6 b[(1)]	2 b	14.1 b	41.1 b	19.8	15.5
A^2) 2.22 plants m^2	106.5 a	3.8 a	20.1 a	51 a	17.5	14.1
B	*	ns	ns	**	ns	ns
B^1) one stem plant^{-1}	94.9 b	2.7	16	42 b	19.8	14.3
B^2) two stems plant^{-1}	104.2 a	3.1	18.2	50.1 a	17.4	15.3
A x B	**	ns	*	**	ns	ns
T1 (A^1 x B^1)	89.6 b	2.2	14.2 b	35.7 b	22.3	15.2
T2 (A^1 x B^2)	95.5 b	1.9	14 b	46.6 a	17.3	15.8
T3 (A^2 x B^1)	100.2 ab	3.2	17.9 ab	48.4 a	17.4	13.3
T4 (A^2 x B^2)	112.8 a	4.3	22.4 a	53.6 a	17.6	14.9

[(1)]Means with different letters in a column for each factor and their interaction are statistically different (Tukey, 0.05); ns, *, **, ***= not significant at $p\leq 0.05$, significant at $p\leq 0.05$, $p\leq 0.01$ and $p\leq 0.001$, respectively.

The interaction of 2.22 plants m^{-2} with two stems plant^{-1} (T4) promoted significantly more performance of select and super select cucumber, fruit sizes with greater demand in the international market, up to 57.5 and 50.1% higher than the yield obtained with 1.68 plants m^{-2} managed to a stem plant^{-1} (Table 4). However, none of the factors under study, plant density or stem pruning, or their interaction, significantly affected the yield of large and extra-large cucumbers.

The optimum density; that is, the population of plants capable of optimally using available resources depends on several factors, including the genotype, the environment and the crop management strategy. According to Peil *et al*. (2014), the increase in the productivity of the densest crops is due to a greater interception of the photosynthetically active light and higher levels of photosynthesis, which stimulates the growth of the plants, increases the total photoassimilates and favors the growth of fruit. The highest yield obtained with densities of 2.22 plants m^{-2} managed to two stems plant^{-1} was the result of a higher density of plants per area. Although the narrower spacing of the plant decreased the average weight of the fruit, it provided gains in overall productivity, corroborating the results of several studies (Gonsalves *et al*., 2011; Campagnol *et al*., 2012; Peil *et al*., 2014) in solanaceae and cucurbitaceae species.

However, it should be emphasized that, even with the increase in yield as a function of narrower spacing, the cultivation of plants at very high density is not always adequate because it hampers management activities, increases the need for pruning, increases the probability of phytopathogenic bacteria and fungi, and makes monitoring and control difficult (Gomes *et al*., 2017).

Conclusions

The basal and apical stem diameter, fruit length, and large and extra-large cucumber yield were not significantly influenced by plant density and stem pruning. The fresh biomass of stem plant^{-1} and dry leaves plant^{-1} decreased with increasing plant density, but increased in plants with two stems. The length and dry biomass of stem, leaves plant, fresh biomass of leaves plant and production of flowers plant^{-1} increased, while leaf greenery decreased, with two stems plant^{-1}. Both factors caused decreases in the diameter of the fruit. However, the yield of cucumber was positively influenced both by the density of plants and by the pruning of stems. The total yield, as well as select and super select cucumber, were obtained when the density of 2.22 plants m^{-2} was used with pruning to two stems plant^{-1}.

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