Investigation note

Plant densities and fertilization doses in the cultivation of amaranth

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Abstract

The objective of this research was to evaluate the response of *Amaranthus hypochondriacus* L. race Mercado to plant density and fertilization doses in the variables: yield, plant height, stem diameter, panicle size, and index of plants with lodging. The study factors were: planting density (D) (156 250, 208 333 and 260 417 plants ha^{-1}), nitrogen levels (40, 80 and 120 kg ha^{-1}), potassium levels (zero and 20 kg ha^{-1}) and application of 40 kg ha^{-1} of phosphorus as a constant. The arrangement of treatments consisted of a 3x3x2 factorial in an experimental design of completely random blocks with four repetitions and 18 treatments. The experiment was conducted in the 2017 and 2018 cultivation cycles in Tochimilco, Puebla, Mexico. The cultivation practices were carried out according to the technical itinerary of the conventional direct sowing system, which consists of placing in each sowing hole a variable number of seeds to ensure that in each hole several plants grow and then perform a thinning, in which the smallest plants are uprooted and three, four or five plants are left in each sowing hole depending on the experience of each farmer. The results show highly significant differences ($p < 0.01$) in yield, plant height, length and width of panicle by individual effects and interactions of D, N∗K and N∗K∗D. It was concluded that the decision made by producers to leave three, four or five plants per sowing hole is a decisive decision in the production of amaranth.

Keywords: *Amaranthus hypochondriacus* L., conventional direct sowing system, technical itinerary.

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Amaranth (*Amaranthus* spp.) is internationally recognized as a crop that can contribute to increasing global food security and be an alternative for areas that are affected by the adverse effects of climate change due to its nutraceutical properties and agronomic qualities (Alemayehu *et al*., 2015). In Mexico, *Amaranthus hypochondriacus* L. is one of the species domesticated by pre-Columbian cultures; currently, four native races of *A. hypochondriacus* (Azteca, Mercado, Mixteca and Nepal) have been identified, which have different geographical distribution and phenological and morphological characteristics (Espitia *et al*., 2020).

According to the information presented in the Agrifood and Fisheries Information System (SIAP, 2017), in Mexico, 3 190.95 ha of amaranth are sown in six states, with Puebla being the state with the largest area sown (1 975.1 ha). Also, within the state, the municipality of Tochimilco is the main producer with 1 467.2 t per year, an amount equivalent to 56.71% of state production and 29.20% of national production. However, Tochimilco has one of the lowest average yields in the country (1.31 t ha^{-1}), mainly due to the high incidence of pests and diseases (Romero *et al*., 2018) and the application of deficient fertilization doses (Sánchez *et al*., 2016).

In addition to these factors, the amaranth yield can also be affected by the characteristics of the production system used, in the case of Tochimilco, the system that is practiced is the conventional direct sowing. In this system, the sowing is carried out by means of the technique called mateado, which consists of placing in each sowing hole a variable number of seeds in order to ensure that in each hole several plants germinate and grow.

Subsequently, 30 days after sowing (dds), a thinning of plants is carried out, which consists of uprooting the smallest plants and leaving three, four or five plants in each sowing hole depending on the productive logic of each farmer (Romero *et al*., 2017), so that, considering the number of plants per sowing hole, the separation between holes (30 cm), the width of the furrows (40 cm) and the separation between each furrow (60 cm), the plant density can be 156 250, 208 333 or 260 417 plants ha^{-1}, respectively. Therefore, the objective of this research was to evaluate the response of *A. hypochondriacus* race Mercado to three planting densities and different fertilization doses in the variables grain yield, plant height, stem diameter, length and width of panicle, and index of plants with lodging.

Localization

The research was carried out during the spring-summer cultivation cycles of 2017 and 2018 on a plot of a cooperating producer located in the community of Santa Catarina Tepanapa, belonging to the municipality of Tochimilco, Puebla, in the central region of Mexico (18º 50’ and 19º 02’ north latitude and the meridians 97º 18’ and 97º 27’ west longitude) at an altitude of 2 280 masl, with sub-humid temperate climate with rains in summer C(w1) and annual precipitation of 1 100 mm. In February 2017, an analysis of the soil of the plot was carried out in the soil laboratory of the College of Postgraduates *Campus* Montecillo, to know its most relevant physico-chemical characteristics, the results are shown in Table 1.

Table 1. Physico-chemical characteristics of the soil of the experimental plot located in Santa Catarina Tepanapa, Tochimilco, Puebla.

pH	CE (dS m^{-1})	Nt (%)	P (ppm)	K (meq 100 g^{-1})	CIC (meq 100 g^{-1})	MO (%)	Texture
7.85	0.468	0.081	5.78	0.68	7.76	1.45	Sandy loam

Data from the soil analysis carried out in the laboratory of the College of Postgraduates, Campus Montecillo (2017). Ce= electrical conductivity; Nt= total nitrogen; P= phosphorus; K= potassium; CIC= cation exchange capacity; MO= organic matter.

Experimental and treatment design

The treatment arrangement consisted of a 3x3x2 factorial corresponding to three planting densities: 156 250, 208 333 and 260 417 plants ha^{-1} (equivalent to leaving three, four and five plants in each sowing hole, respectively); three doses of nitrogen: 40, 80 and 120 kg ha^{-1}; two doses of potassium: zero and 20 kg ha^{-1} and 40 kg ha^{-1} of phosphorus as a constant. In total, 18 treatments were evaluated. An experimental design of completely random blocks with four repetitions was used, the experimental unit was three furrows 1.2 m long by 0.4 m wide, distance between furrows 0.6 m (2.88 m^2), each furrow with five sowing holes spaced every 0.3 m. To avoid the effect of ridge, the central furrow was considered as a useful plot.

Cultivation practices and quantification of variables

In the experiment, *A. hypochondriacus* race Mercado was planted, which is one of the genetic materials grown by local producers. This race is characterized by stems and elliptical leaves of green color, white or golden seeds, it can reach up to two m of plant height, develops numerous lateral ramifications and has a biological cycle of 140 days (Espitia *et al*., 2010). The cultivation practices were carried out according to the technical itinerary of the conventional direct sowing system practiced by local producers. In the 2017 cultivation cycle, the sowing was carried out on May 30, while in the 2018 cultivation cycle, the sowing was carried out on June 3, once the annual rain cycle began because the production is rainfed.

In both cycles, fertilization doses were applied in two moments. The fertilizers used were urea (46-00-00), diammonium phosphate (18-46-00) and potassium chloride (00-00-60). The first fertilization was performed at 10 dds, at the time of the first ridging, with 50% of the dose of N and 100% of the dose of P and K. The second fertilization with the other 50% of the dose of N was applied 60 dds, in the second ridging. The weedings were manual and before each ridging. The thinning of plants was carried out at 30 dds, leaving three, four or five plants per sowing hole according to each of the treatments under study.

The last week of October, when more than 90% of the plants reached physiological maturity, in the useful plot, the plant height (cm) was measured from the base of the stem to the end of the panicle, with a Geosurv® levelling staff, the diameter of the stem (cm) at 10 cm on the base of the stem with a Surtek® digital vernier, the length (cm) and width (cm) of the panicle with a metal flexometer type 1-A, model: 334, ADIR, in addition, the number of plants with lodging (plants with an inclination of 45° or more) was counted and subsequently in cabinet, the index of plants with lodging (IPA) was calculated, dividing the number of plants with lodging by the total number of plants of the useful plot, with zero being the minimum value and one being the maximum value.

The panicle cutting was carried out in the second week of November, when 90% of the plants reached maturity, which is determined by the senescence and fall of leaves. The panicles were cut with a sickle and placed on the furrows to dry in the sun. A month after the cutting, the threshing of the grain was done manually, hitting the panicles with sticks to detach the seeds on a blanket. The detached grains were sifted with a 20 cm diameter stainless steel sieve with 16 mm holes to separate the straw. The seed was then weighed on a Medi data® electronic balance of 500 g, to quantify the grain yield (g).

Statistical analysis

An analysis of variance and a test of comparison of means for individual and interaction effects based on Tukey's test ($p< 0.05$) were performed with the Statistical Analysis System software (SAS, 2004).

The variables stem diameter and IPA did not show statistically significant differences. However, significant differences ($p< 0.05$) were found in the variables yield, plant height, length and width of panicle (Table 2). The maximum yield (1 970.24 kg ha^{-1}) that was achieved with applications of 120 kg ha^{-1} of N, 40 kg ha^{-1} of P, 20 kg ha^{-1} of K and a density of 260 417 plants ha^{-1} exceeded by 50.4% the average yield recorded by SIAP (2017) in the municipality (1 310 kg ha^{-1}). These results confirm what Sánchez *et al*. (2016) proposed, who mention that yields close to 2 000 kg ha^{-1} are achievable in the environmental conditions of Tochimilco with adequate crop nutrition.

Table 2. Mean values of the variables evaluated in two cultivation cycles (2017 and 2018).

Treatment N-P-K-D	Yield (kg ha^{-1})	Plant height (m)	Stem diameter (cm)	Panicle length (cm)	Panicle width (cm)	IPA
40-40-0-3	876.49 d	1.2 ab	0.97 a	25.34 ab	5.99 ab	0.08 a
80-40-0-3	924.11 cd	1.18 ab	0.83 a	24.12 ab	5.34 ab	0 a
120-40-0-3	1489.58 abcd	1.65 a	1.02 a	29.04 ab	8.51 a	0.17 a
40-40-20-3	1452.38 abcd	1.3 ab	0.93 a	25.78 ab	6.43 ab	0.08 a
80-40-20-3	1840.77 ab	1.42 ab	1.09 a	28.53 ab	8.01 ab	0.14 a
120-40-20-3	944.94 bcd	1.16 ab	0.91 a	23.42 ab	6.46 ab	0 a
40-40-0-4	958.33 bcd	1.25 ab	0.9 a	24.1 ab	6.23 ab	0.04 a
80-40-0-4	910.71 cd	1.13 ab	0.8 a	21.73 ab	5.95 ab	0.08 a
120-40-0-4	1794.64 abc	1.5 ab	1 a	25.88 ab	7.07 ab	0.15 a
40-40-20-4	1052.08 bcd	1.26 ab	0.93 a	27.22 ab	6.17 ab	0.06 a
80-40-20-4	1610.12 abcd	1.22 ab	1.04 a	29.95 a	6.72 ab	0 a
120-40-20-4	1126.49 abcd	1.29 ab	0.87 a	22.5 ab	5.53 ab	0.1 a
40-40-0-5	922.62 cd	0.98 b	0.8 a	21.66 ab	4.39 b	0.05 a
80-40-0-5	1133.93 abcd	1.14 ab	0.79 a	23.09 ab	5.07 ab	0.05 a
120-40-0-5	1050.6 bcd	1.22 ab	0.8 a	20.26 b	5.02 ab	0.05 a

Treatment N-P-K-D	Yield (kg ha^{-1})	Plant height (m)	Stem diameter (cm)	Panicle length (cm)	Panicle width (cm)	IPA
40-40-20-5	1046.13 bcd	1.33 ab	0.89 a	23.67 ab	6.52 ab	0.15 a
80-40-20-5	974.7 bcd	1.21 ab	0.78 a	22.33 ab	5.43 ab	0.09 a
120-40-20-5	1970.24 a	1.21 ab	0.88 a	22.5 ab	6.28 ab	0.07 a

N= nitrogen; P= phosphorus; K= potassium; D= plant density; IPA= index of plants with lodging. Different letters indicate statistically different means (Tukey, 0.05).

The studies that have been carried out to determine the optimal dose of nitrogen in *A. hypochondriacus* are numerous; however, the results have been diverse. For example, Ojo *et al*. (2007); Ramírez *et al*. (2011) reported higher grain yields with applications in the range of 60 and 80 kg ha^{-1}, while Ansari and Aghaalihkani (2012) obtained higher yields with doses of 180 kg ha^{-1}. Therefore, it can be said that the response interval of the amaranth crop to nitrogen fertilization is quite wide or that in each of these experiments, different races or varieties of *A. hypochondriacus* were used, whose nutritional requirements of this element are different.

In the case of the yield variable, a highly significant response ($p < 0.01$) to the factors N, K, and the interactions N∗K and N∗K∗D was found (Table 3), this information is important when generating future fertilization recommendations because Tochimilco producers do not perform potassium fertilization in the cultivation of amaranth (Sánchez *et al*., 2015). Likewise, D did not influence by itself the yield of amaranth, which coincides with the results obtained by Kumar and Yassin (2014) but contrast with what was reported by Pourfarid *et al*. (2014); Olofintoye *et al*. (2015); Moshaver *et al*. (2016), who reported that factor D by itself does have a significant effect on yield.

Table 3. Mean squares of the variables evaluated in two cultivation cycles.

Factor	gl	Yield	Plant height	Stem diameter	Panicle length	Panicle width	IPA
REP	3	5764.42 ns	0.34^{**}	0.11^{**}	275.9^{**}	17.04^{**}	0.01 ns
N	2	20143.06^{**}	0.12 ns	0 ns	6.6 ns	1.78 ns	0.01 ns
K	1	24017.01^{**}	0 ns	0.04 ns	25.21 ns	3.51 ns	0 ns
D	2	991.43 ns	0.11 ns	0.11^{**}	95.65^{**}	10.98^{**}	0 ns
N∗D	4	6482.45 ns	0.02 ns	0 ns	2.96 ns	0.97 ns	0.01 ns
N∗K	2	14686.06^{**}	0.29^{**}	0.07 ns	59.66^{**}	6.96^{*}	0.02 ns
K∗D	2	3942.76 ns	0.06 ns	0 ns	12.81 ns	3.55 ns	0.01 ns
N∗K∗D	4	31241.12^{**}	0.07 ns	0.04 ns	32.1 ns	4.26 ns	0.02 ns
Error	51						
Total	71						
CV		28.13	19.18	17.43	15.09	22.62	127.28

gl= degrees of freedom; IPA= index of plants with lodging; REP= repetition; N= nitrogen; K= potassium; D= plant density. *= $p < 0.05$; **= $p < 0.01$; ns= not significant.

Therefore, the effect that D has on amaranth yield may also depend on factors such as the genetic material grown, or by the type of production system used, whether the case of the conventional direct sowing system in which there are 3 to 5 plants per sowing hole, the conventional transplant system in which, in each sowing hole, only one plant is transplanted so there is less competition (Espitia *et al*., 2010).

It is important to mention that the maximum yield was obtained in plants of low height (1.21 m), a characteristic that is desirable in amaranth plants, because plants with higher height have greater susceptibility to lodging. Plants with lodging that come into direct contact with the soil are more susceptible to the disease known as ‘amaranth smut’, which is caused by two species of the fungus *Thecaphora*: *amaranthi* and *amaranthicola* (Bernal *et al*., 2000).

Regarding the plant height, a significant effect ($p < 0.01$) by the interaction N∗K was found and in this case, the factor D did not influence this variable (Table 3), situation that contrasts with what was reported by other researchers, who found significant individual effects of D on the height of *A. hypochondriacus*, although in different ways, for instance: Torres *et al*. (2006) ; Ramírez *et al*. (2011) concluded that height increases with a higher density of plants; on the contrary, Gimplinguer *et al*. (2007); Romero *et al*. (2017) determined that plant height decreases with the increase of density.

In relation to panicle length, D and N∗K interaction influenced significantly (Table 3). These results are different from those reported by Ramírez *et al*. (2011); Kumar and Yassin (2014), who concluded that the size of the panicle is a function of the characteristics of the genetic material used and not of the fertilization doses or the plant density.

Conclusions

Plant density significantly influences producing plants of *A. hypochondriacus* race Mercado with greater stem diameter, length and width of panicle produced following the technical itinerary used in the conventional direct sowing system. When the density interacts with the fertilization dose, there are significant differences in yield, reaching the highest production (1 970.24 kg ha^{-1}) with the application of 120-40-20 kg ha^{-1} of N-P-K and a density of 260 417 plants ha^{-1}. Therefore, the decision made by producers to leave three, four or five plants per sowing hole at the time of the practice of thinning is not trivial but it is a decision that significantly impacts the yield of the crop.

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