academicJournals

Vol. 11(43), pp. 4384-4388, 27 October, 2016
DOI: 10.5897/AJAR2016.11588
Article Number: 55ABB6461399
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Development and production of chia (*Salvia hispanica* L.) in different space arrangements

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Received 22 August, 2016; Accepted 7 September, 2016

The development of management methods appropriate for the culture of chia (*Salvia hispanica* L.) is essential to improve productivity. This research aimed to evaluate and quantify the development and productivity of chia plants in different row spacing and planting density in Western region of Paraná. As the treatments used were four row spacing (0.15, 0.30, 0.45 and 0.60 m) in three plant densities (200,000, 400,000 and 600,000 plants ha^{-1}), totaling 12 treatments. The experiment was conducted in a randomized block design with four blocks, in which the vegetative growth and the productivity were evaluated. The results were submitted to the Tukey test (p> 0.05). The number of ears per plant was higher in the population of 40 plants m^{2} with row spacing of 30 and 45 cm, and in the population of 60 plants m^{2}, with the row spacing of 15 and 45 cm. The number of spikelets per spike was superior for the population of 40 and 60 plants m^{-2} when grown in the row spacing of 15 and 45 cm. The population of 60 plants m^{2} with the row spacing of 15 cm, stood out for thousand grain weight and productivity. Development of variables of chia showed no significant difference.

Key words: Chia, plant population, productivity, row spacing, *Salvia hispanica* L., vegetative growth.

INTRODUCTION

Chia (*Salvia hispanica* L.) is an oleaginous, annual and summery plant, belonging to the Lamiaceae family, native to southern Mexico and northern Guatemala (Ayerza and Coates, 2009). It is a staple food of the Central America civilizations in pre-Columbian period, along with corn, beans and amaranth (Fernandez et al., 2006). Chia is a plant characterized by low water consumption and well adapted to arid and semiarid regions (Ayerza, 1995).

In the last few years, the plant seeds have attracted importance for human nutrition and health due to its high fatty acid content of α-linolenic and also due to the beneficial health effects by the consumption of ω-3 fatty

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acids they contain, in addition to protein, glutamic acid, arginine, lipids, fibers, and, thereby, gaining space in the Brazilian agriculture (Ayerza, 2011). In this context, therefore, chia is a profitability alternative to farmers and industry.

The flour, a byproduct of oil extraction, can be used in human and animal nutrition and is high in fiber and constituents with antioxidant activity (Ayerza and Coates, 1996; Olivos-Lugo et al., 2010), which gives it an emulsifier character, intensifying the feeling of satiety when eating the grain (Antruejo et al., 2011).

The chia oil has superior quality than other oils such as soybean oil (*Glycine max*), sunflower oil (*Helianthus annuus* L.), rapeseed oil (*Brassica napus* L.) and olive oil (*Olea europaea* L.) (Ayerza, 2013), it concentrates higher percentage of fatty α-linolenic acid, reaching 68% (Ayerza, 2011). Given the above, even if it is not cultivated on a large scale today, chia deserves to a great attention due to the universal applicability of its products and derivatives.

With regards to the cultivation, the species adapts to different locations in Brazil, provided the conditions of temperature, altitude and precipitation fall within the requirements of culture (Migliavacca et al., 2014). Pozo (2010) mentioned that the ideal conditions for the culture development are: temperature between 14 and 20°C, no frosts, good insolation and pluviometric incidence of 250 to 300mm. In general, chia find better development conditions when seeded in October and November (Migliavacca et al., 2014), coinciding with the soybean crop, which reduces the interest of its production by farmers.

According to Migliavacca et al. (2014), that sowed chia in March to April, after the first harvest of grains, and leading the same until the end of August, they noticed that the culture appears as a highly profitable option in the crop rotation system, with great accumulation of vegetable raw materials on the ground after the removal of crop seeds, promoting the formation of straw which acts as vegetation cover for the soil.

In order to better manage soil and climatic conditions with the crop needs, studies have been performed in order to adjust row spacing and density of plants and to obtain, therefore, an increase in productivity. Some studies have shown that the best row spacing range for the culture would be between 30 and 50 cm, with an amount of five kilograms of seed per hectare (Ayerza and Coates, 2005; Kentucky, 2012).

In a study by Ayerza (1995), it was confirmed that the productivity of chia, as well as many cultures, is dependent on the local climate, and especially, the planting date. However, in the literature, information on cultivation and management pre and post-harvest of chia are still insufficient, so that research involving culture aimed mostly at the nutritional composition of the seeds, as well as the benefits it provides to the animal and human health.

Since the culture is highly dependent on the environment to express its maximum agronomic potential, additional studies are needed to determine the factors that really affect the chia yield. Thus, the most appropriate geographic regions for the production of chia may be identified. In this context, there is a need for further study on the mentioned subject, since each location can have different characteristics for the development of plants, and consequently for final production.

Therefore, the present study aims to quantify the growth and productivity of chia under different row spacings and populations of plants, the development of management methods appropriate for the culture of *Salvia hispanica* L., as well as show appropriate management techniques for the culture established in Brazil.

MATERIALS AND METHODS

The experiment was conducted in the municipality of Toledo - PR, with the following coordinates: altitude of 570 m, with latitude 24° 43'13 "S and longitude 53° 46'45" W. The climate is characterized by the Koppen method as subtropical CFA (subtropical, humid climate with hot summers and with four distinct seasons). The soil of the experimental local is classified as a Distroferric Red Latosol, characterized by a good natural fertility and clay texture.

After collection, chemical analysis and soil correction, they marked 36 experimental parcels in experimental design of randomized blocks, each one with 5 m in length and 2.55 m wide, totaling 25.5 m^2. The effective surface of the plot was of 7.2 m^2 (4 x 1.8 m), being the center lines used for evaluation of the productivity and the laterals used for culture growth assessments. Fifteen days after the soil correction, the culture was seeded by tillage system, being at that time, the experiment was implanted in a factorial 3 x 4, being the first factor, the plant population (200,000, 400,000 and 600,000 plants ha^{-1}) and the second factor, the row spacing (0.15, 0.30, 0.45 and 0.60 m).

The monitoring of pests, diseases and weed plants was performed every two days from the date of emergence of the crop, with the need for manual weeding once a week to keep the area free of weed plants. From the 28th day after emergence (DAE) and every 28 days, three plants were collected for each experimental unit for analysis of the variables: leaf area and dry weight of plants.

Leaf area (cm^2)

The leaves were collected and scanned on a graph paper and, then, digitized and casted into the QUANT program (Vale et al., 2001), such that the area sum of all the leaves of each plant represented the leaf area per plant.

Dry mass (g)

The plants were collected without roots and separated into stems, stalk, leaves and reproductive structures. After that, they were kept in a air forced circulation stove at 65°C until they reach a constant weight in order that, then, they were measured dry mass of leaves; dry mass of stem and stalk; dry mass reproductive structures; and total dry weight of shoot.

To determine the productivity of the culture, 10 plants were collected per plot and the number of floral branches, number of grains per floral branch and weight of 1000 grains (g) were calculated. The productivity (kg ha^{-1}) was estimated manually, harvesting the useful area of the plot. The value was obtained after the humidity correction to 13%, on a wet basis. From data of dry mass and of leaf area, leaf area index (LAI), specific leaf area (SLA), leaf area ratio (LAR), net assimilation rate (NAR) and relative growth rate (TCR) were calculated according to the equations proposed by Benincasa (2003).

After tabulating, the data were submitted to analysis of variance (p= 0.05) and were estimated by regression equations and compared by Tukey test (p<0.05) using the statistical program SISVAR.

RESULTS AND DISCUSSION

There was no interaction effect between population and row spacing of chia plants for the variables dry mass of stems, leaves and reproductive parts, leaf area, leaf area index, leaf area ratio, relative growth rate of plants and assimilation rate liquid of chia plants.

From the 28 days after emergence, there was a great dry matter accumulation for reproductive parts + leaf + stem, leaf + stem and stem. This accumulation was constant from 28 to 56 days after emergence for the variables leaf + stem and stem during which time the plants were in the vegetative phase and was stabilized from 56 days after emergence, when the plants went into the reproductive phase, which occurred only to increase reproductive parts + leaf + stem.

The leaf area of chia plants was increased to approximately 56 days after emergence, phase in which the plants are in full vegetative development. After the vegetative phase, the plant set its size and then passes to the reproductive stage, in which the leaf area growth was not present, and the the plant started the development of reproductive parts. The same was observed for the variable leaf area index (m m^2) of chia plants, which was increased until the 56 days after emergence and stabilized after that period.

The leaf area ratio was maximum at the 28 days after emergence, decreasing in the reproductive stage. Such fact shows the source-drain relation between leaves and fruits (Taiz and Zeiger, 2004). The relative growth rates and net assimilation of chia plants were growing from 28 to 56 days after emergence, a considerably high reduction after that time until the end of the cycle, indicating that the initial period of development is the limiting factor for the species production, whereas in this phase, the plants make their full photosynthetic role, in order to accumulate photosynthates to the next stage.

For number of ears per plant (Table 1), there was no row spacing effect for the population of 20 plants m^2. For the population of 40 plants m^2, the 30 and 45 cm row spacings stood out, while for the population of 60 plants m^2, the row spacings of 15 and 45 cm showed the best results.

For the row spacing of 15 cm, the population of 60 plants m^2 had the highest number of ears per plant. For the row spacing of 30 cm, the higher average was presented by the population of 40 plants m^2. For the row spacing of 45 cm, populations of 40 to 60 plants m^2 showed no significant difference, being greater than population of 20 plants m^2. There was no effect for plant population spacing of 60 cm.

There was an increase of number of spikelets per spike (Table 2) for the population of 20 plants m^2 grown on rows spaced in 15, 30 and 60 cm among them; for the population of 40 plants m^2 when cultivated in row spacings of 15 and 45 cm; and for the population of 60 plants m^2 when cultivated in the spacings of 15, 45 and 60 cm among them.

For row spacing of 15 cm and population of 40 plants m^2, there was no beneficial effect on the studied variable. The same was concluded for row spacing of 30 cm and populations of 20 and 40 plants m^2; row spacing of 45 cm and population of 40 plants m^2; and spacing of 60 cm and population of 20 and 60 plants m^2 between rows. The number of grains per spikelets of chia plants was not affected by population (Table 3). However, there was influence of the row spacings, so that culture better responded to the spacings of 15 and 45 cm between rows.

For thousand grain weight (Table 4), there was no effect of the row spacings on the population of 40 plants m^2. In the population of 20 plants m^2, the 30 cm row spacing was best adapted, whereas for population of 60 plants m^2, row spacing of 15 cm, showed the best result. There was no interaction between the row spacings of 45 and 60 cm and the three studied populations, and, in these cases, all possible combinations showed beneficial effect on the variable in question. The thousand grain weight average was very similar to other works developed with the culture of chia. Singh and Goswami (1996) and Ista (2003) obtained an average of 1.31 g of thousand grain weight. In a study developed by Ixtaina et al. (2008), the average for the variable in question was of 1.32 g, whereas for Guiotto et al. (2011), the average was of 1.35 g.

Regarding the productivity of chia (Table 5), there was no difference between the row spacings tested for the population of 20 plants m^2. For the population of 40 plants m^2, the productivity was higher in the row spacings of 30 and 45 cm, while in the population of 60 plants m^2, the highest values were obtained in the spacings of 15, 45 and 60 cm between rows. There was no interaction between population and row spacing for variables dry mass of vegetative and reproductive parts. At 56 days of the emergency, the complete plant vegetative growth results in the reproductive phase.

The population of 60 plants m^2 was best adapted to the row spacings tested, except for the row spacing of 30 cm, for which the population of 40 plants m^2 was better. In general, the population of 60 plants m^2 was the one which had the highest productivity, in particular, when

Table 1. Number of ears per plant of chia conducted in different space arrangements.

Row spacing (cm)	Plant population (m²)			Average
	20	40	60	
15	8^{aB}	$7b^{C}$	11^{aA}	9
30	8^{aB}	15^{aA}	8^{bB}	10
45	10^{aB}	13^{aA}	12^{aA}	12
60	11^{aA}	8^{bA}	8^{bA}	9
Average	9	11	10	10

Averages followed by same letter, lowercase for the column and uppercase for the row, do not differ significantly at 5% in the Tukey test.

Table 2. Number of spikelets per spike of chia conducted in different space arrangements.

Row spacing (cm)	Plant Population (m²)			Average
	20	40	60	
15	51^{aB}	63^{aA}	47^{abB}	54
30	56^{aA}	47^{bAB}	39^{bB}	47
45	36^{bC}	52^{abA}	45^{abB}	44
60	58^{aA}	48^{bB}	57^{aA}	54
Average	50	52	47	50

Averages followed by same letter, lowercase for column and uppercase for row, do not differ significantly at 5% in the Tukey test.

Table 3. Number of grains per spikelet of chia plant conducted in different space arrangements.

Row spacing (cm)	Number of grains per spikelet
15	3.3^{a}
30	2.9^{c}
45	3.2^{ab}
60	3.1^{bc}
Average	3.1

Averages followed by same letter in column do not differ significantly at 5% in the Tukey test.

Table 4. Mass of a thousand seeds of chia (g) conducted in different space arrangements.

Row spacing (cm)	Plant population (m²)			Average
	20	40	60	
15	1.3^{bB}	1.4^{aB}	1.6^{aA}	1.4
30	1.8^{aA}	1.4^{aB}	1.3^{dC}	1.5
45	1.4^{bA}	1.4^{aA}	1.5^{bA}	1.4
60	1.4^{bA}	1.4^{aA}	1.4^{cA}	1.4
Average	1.5	1.4	1.5	1.4

Averages followed by same letter, lowercase for column and uppercase for row, do not differ significantly at 5% in the Tukey test.

Table 5. Productivity of chia (kg ha^{-1}) conducted in different space arrangements.

Row spacing (cm)	Plant population (m²)			Average
	20	40	60	
15	489^{aB}	770^{bB}	1446^{aA}	902
30	577^{aC}	1025^{aA}	732^{bB}	778
45	491^{aC}	1083^{aB}	1321^{aA}	965
60	584^{aB}	690^{bB}	$1083a^{bA}$	786
Average	536	892	1146	858

Averages followed by same letter, lowercase for column and uppercase for row, do not differ significantly at 5% in the Tukey test.

subjected to a spacing of 15 cm between rows. The lowest productivity was obtained by the population of 20 plants m^2 at a spacing of 45 cm between rows, so that the difference between these arrangements was of 955 kg ha^{-1}.

This fact emphasizes the importance of the culture studied, particularly for cultivation in different spatial arrangements, and it is able to express its maximum physiological potential and, therefore, its maximum productive capacity.

The average productivity gained was of 858 kg ha^{-1}, higher than the Brazilian productivity, which is usually 500 to 600 kg ha^{-1} of seeds. However, Ayerza and Coates (2005) reported on results exceeding 1266, 2031 and 2120 kg ha^{-1} for experimental parcels seeded in Argentina, Venezuela and Colombia, respectively. These values can only be obtained if the climate and soil of the region are appropriate for culture, favoring it for the fertility of the soil, temperature and luminosity.

Therefore, the chia may be adopted as an alternative to traditional crop, in order to diversify and stabilize the local agricultural economy, as it grows well in the region and has potential for expansion in each harvest, due to its industrial, medicinal and food applications.

Conclusions

There was no significant difference for chia plants development variables when they were cultivated in different spatial arrangements. There was a significant difference for chia plants production variables, and higher grain yield was obtained by the population of 60 plants m^2 in a spacing of 15 cm between rows.

Conflict of Interests

The authors have not declared any conflict of interests.

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