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Optimization of Spacing and Fertilizer Levels on Growth, Yield Parameters and Yield of Chia (*Salvia hispanica* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during *Kharif* season-2019 at Agricultural Research Station, Chintamani, Karnataka. The experiment consisted of four levels of spacing (45 × 15, 45 × 30, 60 × 15, and 60 × 30 cm) and three levels of fertilizer (40:20:20, 60:40:40 and 80:60:60 kg NPK ha^{-1}) to determine the influence of different spacing and fertilizer levels on growth and yield of chia (*Salvia hispanica* L). The experiment was arranged in a statistical design of Factorial Randomized Complete Block Design (FRCBD) with three replications. The report of the study indicated that among different spacings, 60 × 30 cm was recorded a significantly higher number of leaves $plant^{-1}$ (108), a number of primary and secondary branches $plant^{-1}$ (22.38 and 27.69, respectively), Dry

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matter accumulation plant^{-1} (146.09 g) and seed yield (1015 kg ha^{-1}) however, spacing of 45 cm × 15 cm produced significantly superior plant height (125.57 cm). Among different fertilizer levels, the application dose of 80:60:60 kg NPK ha^{-1} recorded significantly higher plant height (125.59 cm), number of leaves plant^{-1} (103.67), number of primary and secondary branches plant^{-1} (22.47 and 27.63, respectively), Dry matter accumulation plant^{-1} (131.47 g), seed yield (1020 kg ha^{-1}). Significantly higher seed yield (1122 kg ha^{-1}) was obtained in the treatment combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} compared to other treatments.

Keywords: Chia; fertilizer; spacing; growth parameters and yield.

1. INTRODUCTION

India is likely to be the most populous country on this planet by 2030 with 1.6 billion people. It currently accounts for more than 17 per cent of the global population and 456 million poor, or 41.6 per cent living on less than $1.25 a day [1]. Ensuring food and nutrition security is thus a challenge for India. Despite historically high levels of food production in India, the undernourishment problem persists. At present, 22.5 percent of adults are underweight and 38 percent are still stunted. Current high levels of malnutrition are often due to unbalanced diets with insufficient nutrition diversity.

Chia (*Saliva hispanica* L.) is an annual pseudo-cereal and oilseed crop belonging to the family of Lamiaceae originated in Mexico and Guatemala [2]. Chia is dicotyledonous, approximately a meter tall, with opposite, petiolate and serrated leaves that are 4 to 8 cm long and 3 to 5 cm wide. The plant has quadrangular stems that are ribbed and hairy. The flowers are hermaphrodites and grow in numerous clusters in a spike protected by small bracts with long pointed tips. The fruit of chia, as in other plants of the Lamiaceae family, is a schizocarp consisting of indehiscent locules that separate to form four fruitlets, referred to as mericarps or nutlets. As chia is a rich source of omega-3 and 6 fatty acids, dietary fiber (25 %), proteins (20 %), oil (35 %), minerals, vitamins, and a great source of antioxidants and amino acids particularly lysine, which are essential for normal human growth and development and further appears to be important for the prevention and treatment of several diseases, it has a major role to play in human nutrition and health [3].

Chia is very sensitive to low temperatures and day length, and the growing cycle is strictly depending on the latitude from where it is planted [4]. Chia seeds can be a food supplement and are widespread in vegetarian and gluten-free diets. Chia is a plant characterized by low water requirement and well adapted to arid and semiarid regions (Ayerza and Mealia, 1993) The flour, a by-product of oil extraction can be used as human and animal feed supplement and is high in fiber and constituents with antioxidant activity [5]. The cultivation of Chia (*Salvia hispanica* L.) is gaining popularity in the world due to its health benefits hence, this is recognized as a superfood crop for its superior nutritional value. It is consumed as seeds and can be used as food supplements [6].

Commercial cultivation of Chia is gaining momentum all over the world, but in India, it is in the budding stage. In recent years' cultivation of this crop was started in Karnataka by the farmers of Mysore and chamarajanagara districts under the technical guidance of the Central Food Technological Research Institute (CFTRI), Mysore about its nutritional quality. Agronomic management is one of the most important aspects for the success of any crop with efficient utilization of all the resources. Investigations of the past have clearly brought out the significance of the cultural practices viz., crop geometry, irrigation, weeding, and nutritional strategies are the major determinants of crop productivity. However, information regarding suitability of this crop under different agro-climatic conditions, optimum spacing and fertility levels *etc*. To be followed is not properly ascertained as it is a newly introduced crop to India in general and Karnataka in particular.

2. MATERIALS AND METHODS

The field study was carried out in the Kharif season of 2019 at Agricultural research Station, Chintamani, Karnataka, situated at 13° 24' N Latitude and 78° 04' E Longitude with at elevation of 918 m above the mean sea level (MSL) In Eastern Dry Zone of Karnataka (EDZ). The average annual rainfall of the zone was 820.50 mm received in 54 rainy days. The other distinct climatic feature of the experimental site has a tropical climate, characterized by high temperature and low humidity. The soil chemical analysis revealed that the soil was sandy loam in texture with a water holding capacity of 38.60 percent, the pH of the soil is acidic (5.60) and electrical conductivity was normal (0.16 dSm^{-1} at 25°C). The soil was medium in organic carbon content (0.54 %), medium in available nitrogen (366.91 kg ha^{-1}), phosphorus (46.69 kg ha^{-1}), and high in potassium (373.10 kg ha^{-1}). The experiment was set up using Factorial Randomized Complete Block Design (RBD) having four spacing levels (45×15, 45×30, 60×15 and 60×30 cm) and three levels of fertilizers (40:20:20, 60:40:40, and 80:60:60 kg NPK ha^{-1}). There were twelve treatments replicated thrice, with a plot size of 19.44 m^2 (5.4 m × 3.6 m) each. The details of treatment combinations are T_1 – S_1F_1: 45 × 15 cm + 40:20:20 kg NPK ha^{-1}; T_2 – S_1F_2: 45 × 15 cm + 60:40:40 kg NPK ha^{-1}; T_3 – S_1F_3: 45 × 15 cm + 80:60:60 kg NPK ha^{-1}; T_4 – S_2F_1: 45 × 30 cm + 40:20:20 kg NPK ha^{-1}; T_5 – S_2F_2: 45 × 30 cm + 60:40:40 kg NPK ha^{-1}; T_6 – S_2F_3: 45 × 30 cm + 80:60:60 kg NPK ha^{-1}; T_7 – S_3F_1: 60 × 15 cm + 40:20:20 kg NPK ha^{-1}; T_8 – S_3F_2: 60 × 15 cm + 60:40:40 kg NPK ha^{-1}; T_9 – S_3F_3: 60 × 15 cm + 80:60:60 kg NPK ha^{-1}; T_{10} – S_4F_1: 60 × 30 cm + 40:20:20 kg NPK ha^{-1}; T_{11} – S_4F_2: 60 × 30 cm + 60:40:40 kg NPK ha^{-1}; T_{12} – S_4F_3: 60 × 30 cm + 80:60:60 kg NPK ha^{-1} with a plot size of 19.44 m^2 (5.4 m × 3.6 m) each.

Crop variety ‘CHIAmpion B-1’ seeds were collected from Central Food Technological Research Institute (CFTRI), Mysore, and seeded manually on the fourth week of June and harvested on the first week of November. The crop geometry was maintained as per the spacing prescribed for the treatments. Nitrogen, phosphorus, and potassium were provided through Urea, Single super phosphate (SSP), and Muriate of potash (MOP) according to treatments. A full dose of phosphorus, potassium, and half dose of nitrogen was applied as basal during sowing while, the remaining half of nitrogen was top dressed at 40 days after sowing.

Five plants were selected at random and labeled in each net plot for recording non-destructive observations on growth and yield parameters. The observations on growth parameters *viz.* plant height, number of primary and secondary branches, number of leaves and dry weight were taken at 30, 60, 90 DAS, and at harvest, and the data on yield characters *viz.* The number of spikes per plant, Number of spikelets per spike, Spike length per spike, test weight, and seed and haulm yield were recorded at harvest.

3. RESULTS AND DISCUSSION

3.1 Effect of Spacing and Fertilizer Levels on Growth Parameters of Chia

The data on growth parameters on different days after sowing as influenced by spacing and fertilizer levels are presented in Tables 1 to 5. During crop growth, the crop spaced at 45 × 15 cm attained a significantly taller plant (Table 1) at 30 DAS over 60 × 30 cm spacing but at par with the spacing of 45 × 30 and 60 × 15 cm. Also, at 60, 90 DAS and at harvest with spacing of 45 × 15 cm was attained significantly higher plants, which was on par with a spacing of 60 × 15 cm. Statistically, superior over other spacing of 45 × 30 cm and 60 × 30. Spacing plays an important role in crop production as non-monetary input. This was apparently because individual plants with narrow spacing did not get the opportunity to proliferate laterally due to the less lateral space. Hence plants were compelled to grow more in an upward direction for the fulfillment of the light requirement for photosynthesis. Significant increase in plant height from early stages of crop growth under closer spacing (45 × 15 cm) might be due to mutual shading because of the dense population which might have decreased the availability of light to the plants. These results are in close agreement with the findings of Singh et al. [7] in basil, Yeboah et al. [8], Bilalis et al. [9] and Mary et al. [10] in chia and Pooja et al. [11] in sacred basil.

The wider spacing of 60 × 30 cm produced a significantly higher number of leaves per plant (Table 2), and a number of primary and secondary branches per plant (Table 3) at all growth stages throughout the crop growth period as compared to 45 × 30, 45 × 15 cm and 60 × 15 cm spacing. Data pertaining to the number of leaves at a wider spacing of 60 × 30 cm was at par with 45 × 30 cm spacing at all the stages of crop growth while the number of secondary branches was on par with 45 × 30 cm spacing at the harvest stage. Plants at wider spacing received higher growth inputs (sunlight, water, and nutrient) and availability of more space for spreading of branches which helped in more interception of light due to higher leaf surface area with lesser competition as compared to plants grown under closer spacing. This resulted in an increased higher number of primary and secondary branches, this, in turn, resulted in the production of more leaves per plant. The results were in agreement with the findings of Kailash and kushwaha [12] in basil, Yeboah et al. [8] in chia, Mahantesh et al. [13] in Japanese mint, and Mary et al. [10] in chia.

Dry matter accumulation per plant (Table 4) was recorded significantly superior in 60 × 30 cm spacing than 45 × 30, 60 × 15 and 45 × 15 at 60, 90 DAS and at harvest. However, it was found on par with 45 × 30 cm spacing at 30 DAS. Data on dry matter accumulation in different plant parts had a significant influence on leaf, and stem, and the spike was recorded significantly higher in 60 × 30 cm compared with others but at par with 45 × 30 cm spacing. (Table 4). The significant increase in total dry matter accumulation per plant at wider spacing (60 × 30 cm) was ascribed to the production of more primary and secondary branches, and more leaves per plant under wider spacing (60 × 30 cm). The major portion of dry matter was accumulated in the stem at all growth stages due to more branching patterns and more inter-row intra-row row spacing (60 × 30 cm). These results are in accordance with the findings of Kailash and kushwaha [12] in basil and Mary et al. [10] in chia.

Table 1. Effect of spacing and fertilizer levels on plant height (cm) at different growth stages of chia

Treatments	30 DAS	60 DAS	90 DAS	At harvest
Spacing (S)				
S_1: 45 × 15 cm	22.00	68.98	101.47	125.57
S_2: 45 × 30 cm	19.81	57.55	90.86	112.96
S_3: 60 × 15 cm	20.08	64.02	94.44	118.60
S_4: 60 × 30 cm	18.07	52.83	83.29	108.93
S.Em±	**0.82**	**2.30**	**2.89**	**2.70**
CD (P=0.05)	**2.42**	**6.77**	**8.48**	**7.92**
Fertilizer levels (F)				
F_1: 40:20:20 kg NPK ha^{-1}	17.48	53.64	83.20	108.35
F_2: 60:40:40 kg NPK ha^{-1}	19.84	59.45	93.40	115.60
F_3: 80:60:60 kg NPK ha^{-1}	22.65	69.45	100.95	125.59
S.Em±	**0.71**	**2.00**	**2.50**	**2.33**
CD (P=0.05)	**2.10**	**5.86**	**7.35**	**6.86**
Interaction (S×F)				
S.Em ±	**1.43**	**3.99**	**5.01**	**4.67**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**

Table 2. Influence of spacing and fertilizer levels on number of leaves per plant at different growth stages of chia

Treatments	30 DAS	60 DAS	90 DAS	At harvest
Spacing (S)				
S_1: 45 × 15 cm	38.73	109.81	131.24	79.56
S_2: 45 × 30 cm	42.77	145.13	176.12	101.89
S_3: 60 × 15 cm	41.40	130.87	142.05	88.56
S_4: 60 × 30 cm	44.12	154.50	187.41	108.00
S.Em±	**0.90**	**5.21**	**4.54**	**4.25**
CD (P=0.05)	**2.64**	**15.27**	**13.31**	**12.48**
Fertilizer levels (F)				
F_1: 40:20:20 kg NPK ha^{-1}	38.20	126.32	133.60	81.83
F_2: 60:40:40 kg NPK ha^{-1}	41.52	133.50	167.32	98.00
F_3: 80:60:60 kg NPK ha^{-1}	45.55	145.42	176.68	103.67
S.Em±	**0.78**	**4.51**	**3.93**	**3.68**
CD (P=0.05)	**2.29**	**13.22**	**11.53**	**10.81**
Interaction (S×F)				
S.Em±	**1.56**	**9.02**	**7.86**	**7.37**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**

Table 3. Influence of spacing and fertilizer levels on number of primary and secondary branches per plant at different growth stages of chia

Treatments	30 DAS	60 DAS		90 DAS		At harvest	
		Primary	Secondary	Primary	Secondary	Primary	Secondary
Spacing (S)							
S_1: 45 × 15 cm	2.22	13.24	15.13	18.40	20.79	20.76	23.69
S_2: 45 × 30 cm	3.43	14.30	18.01	19.20	23.06	21.60	26.80
S_3: 60 × 15 cm	3.14	13.89	16.74	18.81	22.26	21.02	25.59
S_4: 60 × 30 cm	4.07	15.63	19.83	20.51	25.80	22.38	27.69
S.Em±	**0.22**	**0.36**	**0.29**	**0.37**	**0.44**	**0.27**	**0.55**
CD (P=0.05)	**0.63**	**1.06**	**0.84**	**1.09**	**1.31**	**0.78**	**1.61**
Fertilizer levels (F)							
F_1: 40:20:20 kg NPK ha^{-1}	2.48	13.08	15.39	18.35	20.07	20.35	24.22
F_2: 60:40:40 kg NPK ha^{-1}	3.20	13.98	17.28	19.09	22.80	21.50	25.98
F_3: 80:60:60 kg NPK ha^{-1}	3.98	15.74	19.61	20.25	26.07	22.47	27.63
S.Em±	**0.19**	**0.31**	**0.25**	**0.32**	**0.38**	**0.23**	**0.48**
CD (P=0.05)	**0.55**	**0.91**	**0.73**	**0.94**	**1.13**	**0.68**	**1.39**
Interaction (S×F)							
S.Em±	**0.37**	**0.63**	**0.49**	**0.64**	**0.77**	**0.46**	**0.95**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**2.26**	**NS**	**NS**

Among the fertilizer levels, application of 80:60:60 kg NPK ha^{-1} noticed significantly higher plant height, number of leaves, primary, secondary branches and dry matter accumulation compared to other fertilizer levels *i.e.,* 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1} at all the stages of crop growth. Whereas, the number of leaves per plant was at par with 60:40:40 kg NPK ha^{-1} at 60, 90 DAS, and at harvest. The increased growth components might be nitrogen which triggers the growth of meristematic tissue and efficient utilization of resources by the plants manifested in the production of taller plants. Split application of nitrogen at higher dosage might have contributed production of more branches per plant particularly secondary branches due to the availability of nitrogen in optimum quantities. Increased number of branches per plant at higher fertility levels resulted in the production of more the number of leaves per plant. The outcomes of these studies agreed with the findings of Singh et al. [7] in french basil, Coates et al. [4], Kailash and kushwaha [12] in basil, Mahantesh et al. [13] in mint, Mary et al. [10] in chia, Pooja et al. [11] in sacred basil and Salman et al. [14] in chia.

Similarly, at 30 DAS application of 80:60:60 kg NPK ha^{-1} attained significantly higher dry matter accumulation per plant but was found statistically on par with 60:40:40 kg NPK ha^{-1}. Significantly superior in a higher amount of leaf, stem, and spike dry matter accumulation per plant was at a fertilizer level of 80:60:60 kg NPK ha^{-1} compared to all others at the harvest stage. The dry matter production of the entire plant (Table 4) increased linearly with the time up to 90 DAS and then reduced due to the defoliation of the majority of the leaves from the plants. However, the persistence of leaves was higher at higher fertilizer levels, hence dry matter existed more compared to lower fertilizer levels. Out of the total dry matter produced per plant, a major portion of dry matter was contributed by the stem, which was increased at the rate of 19.80 percent at harvest in higher fertilizer level (80:60:60 kg NPK ha^{-1}) compared to lower fertilizer level. Spike weight also linearly increased with increased fertilizer levels. This was ascribed to better availability of metabolites and nutrients, which synchronized to the demand for growth and development of each reproductive structure of the plant. These results are in line with the findings of Kailash and Kushwaha, [12] in basil, Bilalis et al. [9] and Mary et al. [15] in chia.

Treatment combinations of spacing and fertilizer levels did not attain the level of significance with respect to plant height, the number of leaves, primary, and secondary branches, dry matter accumulation per plant at all the growth durations, and its distribution at harvest.

Table 4. Influence of spacing and fertilizer levels on dry matter accumulation per plant (g) at different growth stages of chia

Treatments	30 DAS	60 DAS	90 DAS	At harvest			
				Leaf	Stem	Spike	Total
Spacing (S)							
S_1: 45 × 15 cm	13.61	57.45	99.86	9.37	57.35	20.34	87.06
S_2: 45 × 30 cm	16.01	78.25	147.36	20.19	70.67	40.40	131.26
S_3: 60 × 15 cm	15.00	69.34	129.91	17.11	65.99	33.49	116.60
S_4: 60 × 30 cm	16.68	85.59	163.16	21.60	72.14	52.36	146.11
S.Em±	**0.34**	**0.96**	**2.18**	**0.87**	**2.16**	**2.41**	**3.17**
CD (P=0.05)	**1.02**	**2.83**	**6.41**	**2.54**	**6.35**	**7.08**	**9.30**
Fertilizer levels (F)							
F_1: 40:20:20 kg NPK ha^{-1}	14.49	65.61	115.67	14.25	59.88	32.98	107.08
F_2: 60:40:40 kg NPK ha^{-1}	15.38	72.78	135.58	17.25	68.00	35.93	121.17
F_3: 80:60:60 kg NPK ha^{-1}	16.11	79.59	153.97	19.69	71.74	41.03	132.52
S.Em±	**0.30**	**0.83**	**1.89**	**0.75**	**1.87**	**2.09**	**2.75**
CD (P=0.05)	**0.88**	**2.45**	**5.55**	**2.20**	**5.50**	**6.13**	**8.06**
Interaction (S×F)							
S.Em±	**0.60**	**1.67**	**3.78**	**1.50**	**3.75**	**4.18**	**5.49**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

But a treatment combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} produced a significantly higher number of secondary branches per plant at 90 DAS when compared to all other interactions.

3.2 Effect of Spacing and Fertilizer Levels on Yield and Yield Parameters of Chia

3.2.1 Yield attributes

The perusal data on yield attributes presented in Table 5, indicated that chia sown at a wider spacing of 60 × 30 cm has produced significantly more spikes per plant, spikelets per spike, and seed yield per plant than other spacing levels of 45 × 30 cm, 60 × 15 cm and 45 × 15 cm. However, spikelets per spike were sown at wider spacing were found on par with 45 × 30 cm. Among the fertilizer dosage of 80:60:60 kg NPK ha^{-1} has produced a significantly greater number of spikes per plant, spikelets per spike, and seed yield per plant which were statistically superior over 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1}.

However, spacing, fertilizer levels, and their interaction failed to register a significant difference in spike length per spike and test weight (1000 seed weight) though the maximum spike length and test weight was recorded when the crop was maintained at wider spacing at 60 × 30 cm. The treatment combination of wider spacing of 60 × 30 cm and application of a higher dose of 80:60:60 kg NPK ha^{-1} produced a significantly higher number of spikes per plant and seed yield per plant as compared to other levels.

This yield attributing characters may be attributed to greater inputs resulted in profused branching which in turn production of higher number of spike per plant and also ascribed to the increased branching and translocation of photosynthates to reproductive parts. The results are agreeing with the findings of Mary et al. [15] in chia and Jaybhay [16] in soybean. Similar result was reported by Robin et al. [17] stated that longest inflorescences were observed on plants sown by 20 × 20 cm with 16.62 cm length compared to broadcasted plants had shortest inflorescence. Production of seed yield per plant due to better interaction of nitrogen, phosphorus and potassium at higher levels. These results are confirmed with the findings of Malik et al. [18], Mary et al. [15] in chia, Kwizera et al. [19] in sunflower, Sewnet [20] recognized that lesser seed yield per plant in closer spacing due to the proportion of non-photosynthetic area in the plant is increased by an increase in plant density and carbohydrate production was inhibited. Thus, seed formation is also reduced. This was attributed to higher uptake of nutrients at higher fertilizer levels as a result of which foliage cover and canopy spread was more which resulted in higher dry matter per plant due to better interaction of nitrogen, phosphorus, and potassium. These results are consistent with the finding of Mary et al. [15] in chia.

3.2.2 Yield and harvest index

The seed and haulm yield (Table 5) were influenced significantly due to varying spacings. The percent increase in seed yield of chia due to wider spacing of 60 **×** 30 cm was 24.69, 10.92, and 43.97 moreover of 60 × 15 cm, 45 × 30 cm, and 45 × 15 cm spacing, respectively, (Table 4). In percentage of haulm yield of chia due to wider spacing of 60 **×** 30 cm was 37.83, 15.09, and 59.58 percent more over of 60 × 15 cm, 45 × 30 cm and 45 × 15 cm spacings, respectively. Higher seed yield achieved from the wider spacing of 60 **×** 30 cm might be due to a number of spikes and spikelets per plant, spike length, and seed yield per plant and the haulm yield were probably due to significant improvement in the parameters like a number of branches and leaves per plant, dry matter accumulation than the narrow spacing of 60 × 15 cm, 45 × 30 cm and 45 × 15 cm. Yeboah et al. [8] also reported significantly higher seed yield with wider spacing of 50 × 50 cm and 60 × 45 cm spacing, respectively. These results are in accordance with the findings of Mary et al. [15] who found the application of fertilizers as high as 90:60:75 kg NPK ha^{-1} increased the productivity of chia. The harvest index in contrast to the higher straw yield was noticed in the closer spacing of 45 × 15 cm and 60 × 15 cm (0.19 similar for both the spacing) was mainly due to higher economic yield (seed yield).

Seed and haulm yield of chia crops significantly increased with an increase in fertilizer levels (Table 4). The highest fertilizer level **F_1** (80:60:60 kg NPK ha^{-1}) gave the highest seed yield at the rate of 43.86 percent as compared to the lower fertilizer level (**F_3**) and 19.01 percent higher as compared to the moderate level (**F_2**). This was attributed to increased fertilizer application which led to nutrient uptake by plants and increased synthesis of photosynthates and better translocation of nutrients. The higher yield levels associated with the application of higher levels of fertilizers were related to higher yield attributes such as a number of spikes, longer spikes, a higher number of spikelets per plant, and seed weight per plant. These results are in accordance with the findings of Mary et al. [15] who found the application of fertilizers as high as 90:60:75 kg NPK ha^{-1} increased the productivity of chia.

Haulm yield was significantly lower at lower fertilizer levels (**F_2** and **F_3**) which was reduced at the rate of 14.11 per cent at 40:20:20 and 7.86 per cent at 60:40:40 kg NPK ha^{-1}, respectively as compared to highest dose of fertilizer (80:60:60 kg NPK ha^{-1}). Haulm yield at harvest mainly depends on the dry matter production per plant. It increased linearly with time up to 90 DAS and then declined due to defoliation of leaves. But, the persistence of leaves was more at higher fertilizer levels, therefore dry matter was higher compared to lower fertilizer levels. Such as increase in dry matter production could be attributed to increase in number of leaves, number of branches (primary and secondary) and number of spikes per plant.

Various levels of fertilizer were shown significant effect on the harvest index. However, appreciable improvement of harvest index with a higher dose of fertilizer (80:60:60 kg NPK ha^{-1}) was mainly due to higher economic yield (seed yield). Among interactions 60 × 30 cm with 80:60:60 NPK kg ha^{-1} found significantly higher seed yield as compared to other treatments and was noticed statistically on par with **S_4F_2** (60 × 30 cm with 60:40:40 kg NPK ha^{-1}), **S_3F_3** (60 × 15 cm with 80:60:60 kg NPK ha^{-1}) and **S_2F_3** (45 × 30 cm with 80:60:60 kg NPK ha^{-1}). With respect to haulm yield and harvest index did not show any significant influence chia.

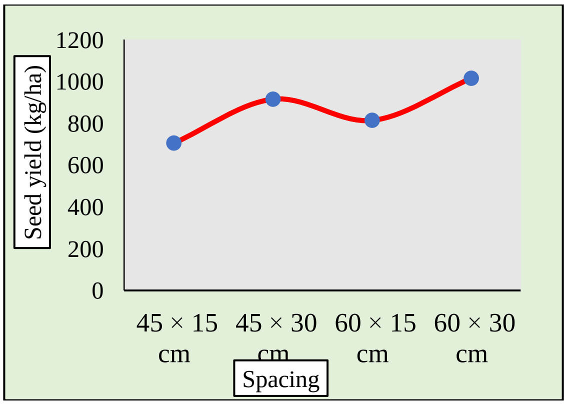

Fig. 1. Optimization of spacings on seed yield

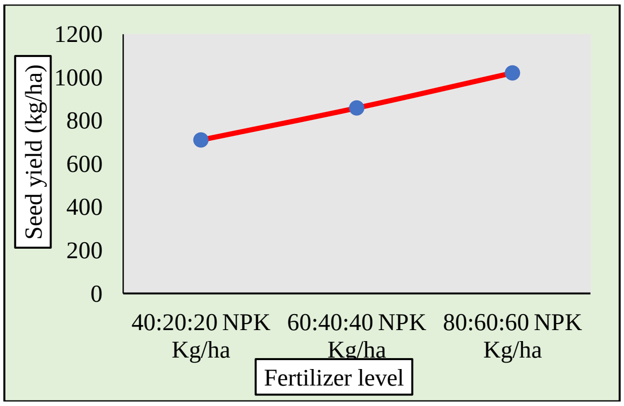

Fig. 2. Optimization of fertilizer levels on seed yield

3.2.3 Optimization of inputs

Optimization of spacing and fertilizer levels on seed yield (kg ha^{-1}) was presented in Fig. 1 and Fig. 2. Optimization of these inputs was based on a graphical presentation and the peak of the curve on seed yield was taken as optimum. The figures show that spacing of 60 × 30 cm and application of 80:60:60 kg NPK ha^{-1} depicted the maximum peak and maximum seed yield (1015 and 1020 kg ha^{-1}, respectively) during *Kharif*-2019. Hence, spacing of 60 × 30 cm and fertilizer level of 80:60:60 kg NPK ha^{-1} was found to be optimum in the present investigation.

Modern cultivars merit technologies that allow them to express their yield potential, require the right amount of water and optimal population density, which are decisive in the agronomic management of the crop [21-23]. In this sense, the density of plants aims to increase the efficiency of the canopy in intercepting radiation. De Sousa Mendes et al. [24] reported increases in the percentage of intercepted light and cowpea leaf area index between 50 and 206.5 %, respectively, when plant density increased from 41,666 to 166,666 plants ha^{-1}.

According to the results of Cardona et al. [25], the Distances Between Rows of 60 and 80 cm did not significantly influence the Plant Height and total Leaf Area of the plant, in contrast to the Leaf Area Index and the Crop Growth Rate, which were higher in the distance of 60 cm, due, in part, to the fact that the Leaf Area covers a smaller area of soil. The highest magnitude Leaf Area was present in the 40 cm spacing between plants, being 22.5 and 36.0 % higher than in the distances of 30 and 20 cm, respectively. It is evident that, since the plants had more space within the row, they developed a greater Leaf Area, but, in turn, a lower Leaf Area Index, which was a little more than 20% higher in the distances of 20 and 30 cm, inside the row.

The height of the plant is associated with the production of nodes, leaves and branches and reaches significant increases at the beginning of flowering [26], to subsequently divert the photo assimilates to the reproductive structures [27]. In semi-prostrate materials, such as the one in this study, the increase in Plant Height observed in the main stem continues as long as the plant continues to flower, to produce more pods and generate a second and third harvest. The highest Plant Height was found in the Plant Distance of 40 cm, which was 6.7 and 13.6 % higher than in the distances of 30 and 20 cm, respectively [25].

The Leaf Area is an important parameter in determining the optimal level, with which the greatest interception of solar radiation can be maximized and higher productivity of a crop can be achieved [28,29]. The french bean has two stages: one, in which the number of leaves on the plant increases at a slower rate, and the other, with a higher rate of leaf production per plant, which is related to the appearance of primary and secondary branches. The existence of significant differences in the Leaf Area between the levels of Distance Between Plants, of 20, 30, and 40 cm, is possibly due to differences in the phyllochron, which could be higher in the greater distance between plants, that is, in lowest plant density [26]. On the other hand, greater spacing implies less competition for light and the possibility of the formation of a greater number of branches and leaves. The Leaf Area presented a positive correlation with the crop growth rate and a negative correlation with the yield according to Cardona et al. [25].

Table 5. Influence of spacing and fertilizer levels on yield attributes and yield of chia

Treatments	No. of spikes per plant	No. of spikelets spike^{-1}	Spike length (cm)	Seed yield plant^{-1} (g)	Test weight (g)	Seed yield (Kg ha^{-1})	Haulm yield (Kg ha^{-1})	Harvest index
Spacing (S)								
S_1: 45 × 15 cm	48.69	19.60	11.00	5.06	1.34	705	2986	0.19
S_2: 45 × 30 cm	67.32	27.17	14.17	12.81	1.37	915	4140	0.18
S_3: 60 × 15 cm	60.72	21.51	13.43	7.82	1.36	814	3457	0.19
S_4: 60 × 30 cm	81.68	28.50	14.82	18.62	1.40	1015	4765	0.17
S.Em±	**0.97**	**0.84**	**0.96**	**0.21**	**0.03**	**28.78**	**152.44**	**0.01**
CD (P=0.05)	**2.85**	**2.47**	**NS**	**0.61**	**NS**	**84.42**	**447.10**	**NS**
Fertilizer levels (F)								
F_1: 40:20:20 kg NPK ha^{-1}	55.57	22.21	12.55	9.56	1.35	709	3542	0.17
F_2: 60:40:40 kg NPK ha^{-1}	65.97	24.05	12.77	11.02	1.36	857	3844	0.18
F_3: 80:60:60 kg NPK ha^{-1}	72.26	26.33	14.75	12.65	1.38	1020	4124	0.20
S.Em±	**0.84**	**0.73**	**0.84**	**0.18**	**0.02**	**24.93**	**132.02**	**0.007**
CD (P=0.05)	**2.47**	**2.14**	**NS**	**0.53**	**NS**	**73.11**	**387.20**	**0.02**
Interaction (S×F)								
S.Em±	**1.69**	**1.46**	**1.67**	**0.36**	**0.04**	**49.85**	**264.04**	**0.01**
CD (P=0.05)	**4.95**	**NS**	**NS**	**1.06**	**NS**	**146.21**	**NS**	**NS**

It is a true fact that progress in breeding programs depends on the precise selection of rare genotypes that have new or improved attributes [28,30], which means that an adequate phenotypic characterization will continue to be one of the pillars of improvement. There are some processes that can be used for the improvement of this type of plants, among them: (1) greater movement of the water available in the topsoil due to root action [31]; (2) acquisition of more carbon (biomass) in exchange for the water transpired by the crop, or transpiration efficiency [32,33] and (3) greater mobilization of the accumulated biomass to the cultivated product (Hernandez et al. 2017) [34,35] found that some plant characteristics improve adaptation to drought conditions, especially a vigorous root system. Greater access to available water guarantees high rates of transpiration and growth [36-38].

4. CONCLUSION

On findings of the above-summarized results from one-year experimentation, the following conclusions have been drawn that the crop which was grown at 60 × 30 cm and 45 × 30 spacings were found that increased all the growth parameters (except plant height) yield and yield attributes. However, the higher plant height was more in the spacing of 45 × 15 cm. Among the different fertilizer dosages, the application of 80:60:60 kg NPK ha^{-1} recorded all the growth components, yield, and yield characteristics compared to others. A combination of 60 × 30 cm + 80:60:60 kg NPK ha^{-1} recorded higher seed yield under the eastern dry zone of Karnataka.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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