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Impact of Spacing and Fertilizer Levels on Nutrient uptake and Soil Nutrient Status of Chia (*Salvia hispanica* L.) in Eastern dry Zone of Karnataka

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ABSTRACT: A field experiment was conducted during the *Kharif*-2019 at the research field of Agricultural Research station, Chintamani, Karnataka, to assess the effect of different spacing and fertilizer levels on nutrient uptake and soil nutrient status of chia (*Salvia hispanica* L.). 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}) with 12 treatment combinations, which was laid out in Factorial Randomized Complete Block Design (FRCBD) replicated thrice. The results of different different spacing and fertilizers were showed that spacing (60×30 cm) and fertilizer level (80:60:60 kg NPK ha^{-1}) had a significant effect on nutrient uptake, fertility status in soil and their values were statistically higher than all the other spacing and fertilizer levels. The findings of study reported that 60×30 cm spacing recorded significantly higher uptake of total nitrogen (114.25 kg ha^{-1}), phosphorus (17.54 kg ha^{-1}) and potassium (94.72 kg ha^{-1}). On contrary, 45×15 cm spacing recorded higher available soil nitrogen (286.29 kg ha^{-1}). Among different fertilizer levels the dosage of 80:60:60 kg NPK ha^{-1} recorded statistically higher total nitrogen, phosphorus and potassium uptake (104.43, 16.33 and 87.69 kg ha^{-1}, respectively) and available soil phosphorus (62.26 kg ha^{-1}) on contrary to that fertilizer level 40:20:20 kg NPK ha^{-1} obtained higher soil nitrogen (285.26 kg ha^{-1}) compared to others. However, there was no significant effect was observed with treatment combination of spacing and fertilizers.

Keywords: Chia, spacing, fertilizer, nitrogen, phosphorus and potassium.

INTRODUCTION

The world population is increasing at an alarming rate and demand- supply curve for food production is not intersecting each other, there is a lacuna for achieving food and nutrition security. Around 795 million people are undernourished around the world and its about 12.9 per cent for developing countries (Mary *et al.*, 2018). 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 (Chen and Ravallion 2010). 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. The chia (*Salvia hispanica* L.) is an annual plant belonging to family lamiaceae native to Mexico and Guatemala (Bilalis *et al.*, 2016). In pre-Columbian times, chia is one of the basic foods for Central American civilizations. Owing to the fact that it can grow in arid environments, it has been highly recommended as an alternative crop for the field crop industry **(**Peiretti and Gai 2009**).** The cultivation of chia is gaining popularity in Africa because it is considered as a healthy food and good nutrition (Ayerza and Coates 2005). Chiais the richest botanical oil source of α-linolenic acid (omega-3) known (Ayerza, 2013). Chia is an oilseed crop with potential use as human food (Coorey *et al.*, 2012; Zanqui *et al.*, 2015).

Chia can grow up to one meter tall and has opposite arranged leaves and having small flowers (3-4 mm) with small corollas and fused flower parts that contribute to a high self-pollination rate. The seed color varies from black, gray and black spotted to white and the shape is oval with size ranging from 1 to 2 mm (Bresson *et al.*, 2009; Ali *et al.*, 2012). 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. Owing to the fact that it can grow in arid environments, it has been highly recommended as an alternative crop for the field crop industry (Peiretti and Gai 2009). Chia seeds can be a food supplement and are widespread in vegetarian and gluten-free diets (Ayerza and Coates 1999). 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. The cultivation 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 (Ayerza and Coates 2000). In India, the cultivation of chia is still not very expressive and there is a lack of information regarding the growth, phenology, nutritional requirements, and management strategies for a better use of the edaphoclimatic characteristics of each region.

Commercial cultivation of chia is gaining momentum all over the world, but in India, it is in the budding stage. In recent times 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. However, information regarding suitability of this crop under different agro-climatic conditions, feasibility of 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. Considering the increasing international demand for chia, the information on agronomic management such as different planting geometries (spacing between chia plants) and nutrient uptake studies with response to different fertilizer regimes for chia cultivation in Karnataka (India) is meager. Hence, Experiment with different spacing and fertilizer levels was taken up to determine the most suitable spacing and optimum dose of fertilizer recommendations to optimizing soil fertility for chia cultivation in eastern dry zone of Karnataka.

MATERIAL 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 AMSL in Eastern Dry Zone of Karnataka (EDZ). During, the crop growing period (July 2019-November 2019), the actual total rainfall recorded was 497.5mm, which was higher than the normal rainfall of 394.5 mm. The mean maximum temperature fluctuated between 29.0°C and 30.9°C, while the minimum temperature ranged from 18.9°C to 20.9°C. In terms of relative humidity, the highest value of 82% was recorded in November. The soil was sandy loam with a water holding capacity of 38.60%, pH was acidic (5.60), normal in electrical conductivity (EC) (0.16 dSm^{-1} at 25°C), and medium in organic carbon content (0.54%), medium in nitrogen and phosphorus (366.91 and 46.69 kg ha^{-1}, respectively) and high in potassium (373.10 kg ha^{-1}). The experiment was set up by using Factorial Randomized Complete Block Design (FRBD) with 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 plot size of 19.44 m^2 (5.4 m × 3.6 m) each. The treatment details 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}. The experimental field was thoroughly ploughed with MB plough, cultivator and rotavator to obtain fine tilth. The chia seeds (CHIAmpion B-1) were collected from Central Food Technological Research Institute (CFTRI), Mysore) and seeded manually duringII FN of June and harvested on I FN of November. The crop geometry and fertilizer were maintained as per prescribed treatments. Nitrogen, phosphorus and potassium were applied through Urea, Single super phosphate (SSP) and Muriate of potash (MOP) according to treatments. Full dose of phosphorus, potassium and half dose of nitrogen were applied as basal during sowing while; the remaining half of nitrogen was top dressed at 40 DAS.Plant sample collected at harvest were dried in hot air oven at 60°C for 24 hours after sun drying. The oven dried samples of plants and air-dried samples of seed were grounded to pass through 40 mesh sieve in macro wiley mill. The sample were analysed for their nutrient content in seed and haulm of chiaby using different standard methods and it was converted into nutrient uptake multiplying with yield and divided by 100 following formula. Uptake of nitrogen, phosphorus and potassium was computed using formula

Nutrient uptake (N, P and K kg ha^{-1})

$$= \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

The uptake of nitrogen, phosphorus and potassium by seed and haulm was calculated separately and the sum of uptake of nutrients in seed and haulm was considered as the total uptake by the crop and expressed in kilograms per hectare. Representative soil samples were collected from each experimental plot after harvest at depth of 0-15 cm, then shade dried, powdered and passed through 2 mm sieve and analysed for pH, electrical conductivity, organic carbon, available nitrogen, phosphorus and potassium content of soil.

Nitrogen, Phosphorous and potassium balance in soil was worked out at the end of crop by considering the initial soil available N, P_2O_5 and K_2O status and N, P_2O_5 and K_2O supplied through fertilizer and manures. Upon subtracting the crop uptake (P and K was converted in to P_2O_5 and K_2O form), the expected balance of nutrients was arrived. Net gain or loss of nutrients was worked by subtracting the expected balance from initial N, P_2O_5 and k_2O status (Mongia and Gangwar 1991; Prasad and Kerketta 1991).

Conversion of P into $P_2O_5$was done by using formula

% P_2O_5 = % P (seed or haulm) × 2.29

Similarly, K into K_2O by using formula % K_2O = % K in seed or haulm × 1.20.

The data collected was statistically analyzed by adopting Fisher's method of Analysis of Variance (ANOVA) as suggested by Gomez and Gomez (1984). Whenever the 'F' test was found significant at 5 per cent level Critical Difference (CD) values were calculated.

RESULTS AND DISCUSSION

A. Effect of spacing and fertilizer levels on nutrient uptake of chia

It was evident from the table1, that significantly greater nutrient uptake by seed, haulm, and the total uptake of nitrogen (37.39, 76.86, and 114.25 kg ha^{-1}, respectively), phosphorus (7.21, 10.33, and 17.54 kg ha^{-1}, respectively), and potassium (24.99, 69.72 and 94.72 kg ha^{-1}, respectively) was observed with spacing of 60 × 30 cm, in comparison to other spacing configurations. However, these results were found statistically at par with a spacing of 45 × 30 cm, for nitrogen uptake (67.04 kg ha^{-1}) and for potassium uptake (63.31 kg ha^{-1}) in the haulm. Significant increase in nitrogen uptake associated with the 60 × 30 cm spacing in the seed, haulm, and overall uptake, amounting to 55.9%, 77.09% and 69.56%, respectively, when compared to the 45 × 15 cm spacing. Similarly, 60 × 30 cm spacing, resulted in a 53.07%, 53.94% and 53.45% increase in P uptake (seed, haulm, and total respectively) and a 51.91%, 65.01% and 61.36% increase in K uptake (seed, haulm, and total respectively) in comparison to the 45 × 15 cm. This notable rise in nutrient uptake associated with the 60 × 30 cm spacing can be attributed to the maximized production of both seed and haulm yield coupled with higher nitrogen, phosphorous and potassium content in seed and haulm compared to other spacing configurations. Among the varied crop geometries, 15 × 10 cm was recorded significantly higher N, P, K uptake than other crop geometries followed by 30 × 10cm spacing and the lower N uptake was recorded with 60 × 10cm spacing supported by Ramesh *et al*. (2017) in quinoa. These finding align closely with the results reported by Lone *et al.* (2009 in soybean and Mary *et al*. (2018) in chia.

Nutrient uptake increased with increased fertilizer levels (Fig. 1). The fertilizer dosage of 80:60:60 kg NPK ha^{-1} was resulted significantly higher uptake of nitrogen by seed, haulm and total (37.11, 67.32 and 104.43 kg ha^{-1}), uptake of phosphorus (7.22, 9.11 and 16.33 kg ha^{-1}) and uptake of potassium (24.26, 63.42 and 87.69 kg ha^{-1}) was registered respectively during *Kharif*-2019. But it was found statistically on par with 60:40:40 kg NPK ha^{-1} with respect to haulm uptake by nitrogen and phosphorus (60.45 and 8.36 kg ha^{-1} respectively). While, significantly lower seed, haulm and total uptake of nitrogen (23.73, 52.69 and 76.42 kg ha^{-1}), phosphorus (4.80, 7.47 and 12.27 kg ha^{-1}) and potassium (17.10, 50.87 and 67.97 kg ha^{-1}, respectively) registered with dosage of 40:20:20 kg NPK ha^{-1}.

Significantly, higher NPK uptake was recorded with 80:60:60 kg NPK ha^{-1} and N, P and K uptake by seed (56.38, 50.41 and 41.87 per cent), in haulm (27.76, 21.95 and 24.67 per cent) respectively was significantly more over fertilizer level of 40:20:20 kg NPK ha^{-1}. The increase in total N, P and K uptake with 80:60:60 kg NPK ha^{-1} was to the tune of 36.65, 33.08 and 29.01 per cent more as compared to 40:20:20kg NPK ha^{-1}. The increased uptake of nutrients and its accumulation in different plant parts and in whole plant was attributed to more canopy spread and branching in wider spacing which lead to more number of spikes and seed yield, which ultimately resulted in higher nutrient uptake. The increased accumulation of nutrients in various parts of the plant may be due to the more application of fertilizers by which more amounts of nutrients were made available to the plant. These results are in close conformity with findings of Montemurro and Giorgio (2005); Mary *et al*. (2018); Jaybhay (2019) in soybean.

The interaction between spacing and fertilizer levels did not show significant difference in nutrient uptake by seed, haulm and total uptake. However, the maximum uptake of nutrient was attained by the treatment combination of 60 × 30 cm along with 80:60:60 kg NPK ha^{-1} during *Kharif*-2019.

B. Effect of spacing and fertilizer levels on fertility status of soil after the harvest of chia

The data on soil pH, EC and OC revealed that the different levels of spacing and fertilizer and their interaction did not influence significantly (Table 2). However, the greater pH was observed with spacing level of 60 ×30 cm (5.87) and least was in spacing of 45 × 15 cm (5.80). However, the maximum EC and OC was recorded with spacing level of 45 × 15 cm (0.539 dSm^{-1} and 0.49%) and lower in 60 × 30 cm (0.516dSm^{-1} and 0.40%). The higher pH was noticed when the application of fertilizer at lower dosage 40:20:20 kg NPK ha^{-1} (5.92). Fertilizer level of 80:60:60 kg NPK ha^{-1} was recorded higher EC (0.673 dSm^{-1} and 0.47%) and lower in 60:40:40 kg NPK ha^{-1} (0.408 d Sm^{-1}and 0.41%). Among interactions the higher pH was recorded in combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} (6.04) and lower in 45 × 15 cm with 60:40:40 kg NPK ha^{-1} (5.69) and on contrary the maximum EC was recorded in treatment combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} (0.747 dSm^{-1}) and least in 45 × 30 cm with 40:20:20 kg NPK ha^{-1} (0.373dSm^{-1}). Whereas, higher OC was recorded in treatment combination of 45 × 30 cm with 40:20:20 kg NPK ha^{-1}(0.58 %) and lower in 45 × 15 cm with 60:40:40 kg NPK ha^{-1} (0.36%).

Spacing and fertilizer levels did not significantly influence pH of soil, organic carbon content and electrical conductivity of soil after harvest during 2019. Variation might be due to the inconsistency in values of organic carbon content in soil during the year of testing. Mansour *et al.* (2017); Mary *et al.* (2018); Jaybhay (2019) supported these findings.

C. Effect of spacing and fertilizer levels on available soil N, P_2O_5 and K_2O status

The data pertaining to available nitrogen, phosphorus and potassium status in the soil was presented in the table 2. revealed that the spacing 45×15 cm registered significantly superior available nitrogen (286.29 kg ha^{-1}) in the soil as compared to 45×30 cm (267.93 kg ha^{-1} and 60×30 cm (255.78 kg ha^{-1}) but found statistically at par with 60×15 cm (278.31 kg ha^{-1}) spacing. However spacing levels had shown no significant influence with respect to available P_2O_5 and K_2O in the soil. Significantly, the higher amount of available nitrogen and P_2O_5 status was observed with application of fertilizer of 40:20:20 kg NPK ha^{-1} (285.26 N kg ha^{-1}) and 80:60:60 kg NPK ha^{-1} (62.26 P_2O_5 kgha^{-1}) respectively, which were statistically superior over other fertilizer levels. Maximum amount of available K_2O was recorded in the soil with fertilizer level of 80:60:60 kg NPK ha^{-1} (327.89 K_2O kg ha^{-1}) but failed to influence significantly due to other fertilizer levels. Similarly, interaction between spacing and fertilizer levels did not influence the available N, P_2O_5 and K_2O content in soil. However, the maximum amount of nutrient status has recorded in treatment combination of 45 × 15 cm with 40:20:20 kg NPK ha^{-1} (297.87 N kg ha^{-1}), 60 × 15 cm with 80:60:60 kg NPK ha^{-1} (65.24 P_2O_5 kg ha^{-1}) and 45 × 15 cm with 60:40:40 kg NPK ha^{-1} (365.00 K_2O kg ha^{-1}) Mary *et al*. (2018) in chia. Mansour *et al.* (2017) also reported similar results and Jaybhay (2019) in soybean reported that available soil nitrogen might be high due to the high activity of root nodules, which ultimately resulted in increase in nitrogen status of soil. Similarly, phosphorus and potassium content of soil might have resulted due to its fixation into the soil and shedding of leaves and decay of root biomass helped in increase in phosphorus and potassium content.

D. Effect of spacing and fertilizer levels on NPK balance in soil

The nutrient status of soil before and after harvest of the chia was analyzed and nutrient balance was worked out and presented in the Table 3-5.

Nitrogen balance. The initial soil nitrogen before sowing of crop was 366.91 kg ha^{-1} and addition of N through FYM (5 t ha^{-1}) was 25 kg ha^{-1} and inorganic fertilizer (3 levels) at the rate of 40 kg ha^{-1}, 60 kg ha^{-1} and 80 kg ha^{-1}. Available N in the soil ranged from 235.85 kg ha^{-1} to 297.87 kg ha^{-1}. Combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} resulted the higher removal of crop nitrogen (137.17 kg ha^{-1}). The net gain or loss, all the treatments shown the nitrogen loses ranged from -62.42 to -126.71 kg ha^{-1} and the higher loss of nitrogen was in treatment combination of 45 × 15 cm with 80:60:60 kg NPK ha^{-1} (-126.71 kg ha^{-1}) and lower in 60 × 30 cm with 40:20:20 kg NPK ha^{-1} (-62.42 kg ha^{-1}). The higher net loss of nitrogen was might be due to volatilization, leaching and denitrification losses of nitrogen fertilizer which was applied in the form of urea (amide) resulted in higher loss of nitrogen.

Phosphorus balance. The initial soil phosphorus before sowing of crop was 46.69 kg ha^{-1} and addition of phosphorus through FYM (5 t ha^{-1}) is 10 kg ha^{-1} and inorganic fertilizer (three levels) at the rate of 20, 40 and 60 kg ha^{-1}. Available phosphorus in the soil ranged from 54.60 to 65.24 kg ha^{-1}. Combination of 60 × 30 cm spacing with 80:60:60 kg NPK ha^{-1} fertilizer level resulted the higher phosphorus removal by crop (47.62 kg ha^{-1}). All treatments were shown the phosphorus net losses ranged between -0.07 to -24.48 kg ha^{-1} except 45 × 30 cm with 40:20:20 kg NPK ha^{-1} (1.17 kg ha $^{-1}$) and 45 × 15 cm with 40:20:20 kg NPK ha^{-1} (1.05 kg ha^{-1}) net gain in phosphorus. Higher loss of phosphorus was noticed in treatment combination of 45 × 15 cm with 80:60:60 kg NPK ha^{-1} (-37.38 kg ha^{-1}) and lower loss in 45 × 15 cm with 80:60:60 kg NPK ha^{-1} (-24.48 kg ha^{-1}) and lower in combination of 60 × 30 cm with 40:20:20 kg NPK ha^{-1} (-0.07 kg ha^{-1}). Net loss of phosphorus was might be due to fixation of phosphorus in soil as Fe-P and Al-P due to higher acidic condition of the soil.

Potassium balance. The initial soil potassium content before sowing of crop was 373.1 kg ha^{-1} and addition of K through FYM (5 t ha^{-1}) is 25 kg ha^{-1} and inorganic fertilizer (three levels) at the rate of 20, 40 and 60 kg ha^{-1}. Available potassium in soil ranged between 285.00 kg ha^{-1} to 365.00 kg ha^{-1}. Combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} resulted higher potassium removal by crop (126.15 kg ha^{-1}). Further, all treatments were shown the potassium net loses ranged from -1.62 to -41.62 kg ha^{-1} and the higher loss of potassium recorded in treatment combination of60 × 15cm with 60:40:40 kg NPK ha^{-1} (-41.62 kg ha^{-1}) and lower loss in 45 × 30 cm with 80:60:60 kg NPK ha^{-1} (-1.62 kg ha^{-1}).

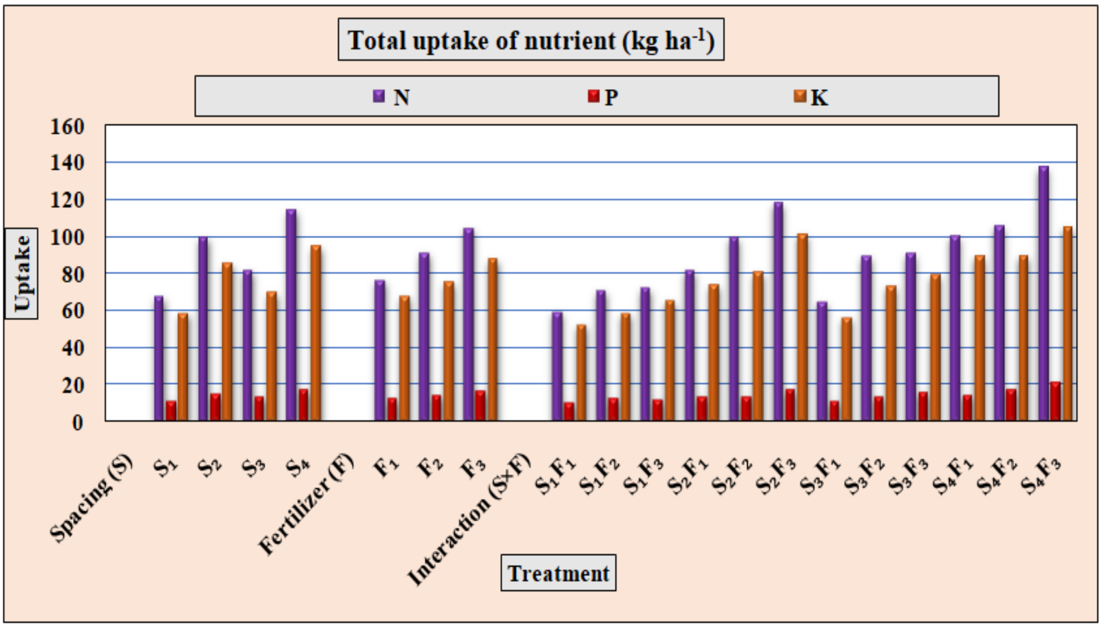

Fig. 1. Influence of spacing and fertilizer levels on nutrient uptake (N, P and K kg ha^{-1}) by chia.

Table 1: Influence of spacing and fertilizer levels on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) by seed, haulm and total uptake in chia.

Treatments	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})		
	Seed	Haulm	Total	Seed	Haulm	Total	Seed	Haulm	Total
Spacing (S)									
S_1: 45 × 15 cm	23.98	43.40	67.38	4.71	6.71	11.43	16.45	42.25	58.70
S_2: 45 × 30 cm	32.55	67.04	99.59	6.44	8.34	14.78	21.91	63.31	85.22
S_3: 60 × 15 cm	28.31	53.32	81.62	5.52	7.87	13.39	19.17	50.47	69.64
S_4: 60 × 30 cm	37.39	76.86	114.25	7.21	10.33	17.54	24.99	69.72	94.72
S.Em±	**1.03**	**3.38**	**3.89**	**0.20**	**0.46**	**0.48**	**0.68**	**2.30**	**2.34**
C.D at 5%	**3.02**	**9.91**	**11.41**	**0.59**	**1.34**	**1.41**	**2.01**	**6.76**	**6.88**
Fertilizer levels (F)									
F_1: 40:20:20 kg NPK ha^{-1}	23.73	52.69	76.42	4.80	7.47	12.27	17.10	50.87	67.97
F_2: 60:40:40 kg NPK ha^{-1}	30.83	60.45	91.28	5.89	8.36	14.25	20.53	55.03	75.56
F_3: 80:60:60 kg NPK ha^{-1}	37.11	67.32	104.43	7.22	9.11	16.33	24.26	63.42	87.69
S.Em±	**0.89**	**2.93**	**3.37**	**0.17**	**0.39**	**0.41**	**0.59**	**1.99**	**2.03**
C.D at 5%)	**2.62**	**8.58**	**9.88**	**0.52**	**1.16**	**1.22**	**1.74**	**5.85**	**5.96**
Interaction (S×F)									
S.Em±	**1.78**	**5.85**	**6.74**	**0.35**	**0.79**	**0.83**	**1.18**	**3.99**	**4.06**
C.D at 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 2: Influence of spacing and fertilizer levels on soil fertility status of the chia after harvest of the crop.

Treatments	pH	Electrical conductivity (dSm^{-1})	Organic carbon (%)	Available soil nutrient status		
				Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Spacing (S)						
S_1: 45 × 15 cm	5.80	0.539	0.42	286.29	57.31	346.07
S_2: 45 × 30 cm	5.85	0.530	0.49	267.93	53.17	322.37
S_3: 60 × 15 cm	5.93	0.532	0.49	278.31	54.68	315.55
S_4: 60 × 30 cm	5.87	0.516	0.40	255.78	50.45	301.47
S.Em±	**0.09**	**0.08**	**0.04**	**3.30**	**3.59**	**13.23**
C.D at 5%	**NS**	**NS**	**NS**	**9.68**	**NS**	**NS**
Fertilizer levels (F)						
F_1: 40:20:20 kg NPK ha^{-1}	5.92	0.408	0.46	285.26	48.94	308.86
F_2: 60:40:40 kg NPK ha^{-1}	5.81	0.507	0.41	272.44	50.51	327.35
F_3: 80:60:60 kg NPK ha^{-1}	5.86	0.673	0.47	258.53	62.26	327.89
S.Em±	**0.08**	**0.07**	**0.04**	**2.86**	**3.11**	**11.45**
C.D at 5%	**NS**	**NS**	**NS**	**8.38**	**9.11**	**NS**
Interaction (S×F)						
S.Em±	**0.15**	**0.13**	**0.07**	**5.72**	**6.21**	**22.91**
C.D at 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3: Influence of spacing and fertilizer levels on nitrogen balance (kg ha^{-1}) in soil after the harvest of chia.

Treatments		Initial soil N (kgha^{-1}) (A)	Applied N through FYM (5 t ha^{1}) + Fertilizer (kg ha^{-1}) (B)	Total N (A+B=C)	Crop uptake N (D)	Expected N balance (C-D=E)	Actual balance N (F)	Net gain (+) or loss (-) (F-E=G)
T_1	**S_1F_1**	366.91	25+40	431.91	59.26	372.65	297.87	-74.78
T_2	**S_1F_2**	366.91	25+60	451.91	70.88	381.03	287.80	-93.23
T_3	**S_1F_3**	366.91	25+80	471.91	72.00	399.91	273.20	-126.71
T_4	**S_2F_1**	366.91	25+40	431.91	81.53	350.38	281.91	-68.47
T_5	**S_2F_2**	366.91	25+60	451.91	99.33	352.58	263.14	-89.44
T_6	**S_2F_3**	366.91	25+80	471.91	117.91	354.00	258.75	-95.25
T_7	**S_3F_1**	366.91	25+40	431.91	64.81	367.10	291.87	-75.23
T_8	**S_3F_2**	366.91	25+60	451.91	89.42	362.49	276.76	-85.73
T_9	**S_3F_3**	366.91	25+80	471.91	90.63	381.28	266.30	-114.98
T_{10}	**S_4F_1**	366.91	25+40	431.91	100.09	331.82	269.40	-62.42
T_{11}	**S_4F_2**	366.91	25+60	451.91	105.48	346.43	262.08	84.35
T_{12}	**S_4F_3**	366.91	25+80	471.91	137.17	334.74	235.85	98.89

Note: Spacing (cm) Fertilizer levels (kg ha^{-1})

S_1: 45 × 15 cm — F_1: 40:20:20 kg NPK ha^{-1}

S_2: 45 × 30 cm — F_2: 60:40:40 kg NPK ha^{-1}

S_3: 60 × 15 cm — F_3: 80:60:60 kg NPK ha^{-1}

S_4: 60 × 30 cm

Table 4: Influence of spacing and fertilizer levels on nitrogen balance (kg ha^{-1}) in soil after the harvest of chia.

Treatments		Initial soil P_2O_5 (kgha^{-1}) (A)	Applied P_2O_5 through FYM (5 t ha^1) + Fertilizer (kg ha^{-1}) (B)	Total P_2O_5 (A+B=C)	Crop uptakeP_2O_5 (D)	Expected balance (C-D=E)	Actual balance P_2O_5(F)	Net gain (+) or loss (-) (F-E=G)
T_1	S_1F_1	46.69	10+20	76.69	23.14	53.55	54.6	1.05
T_2	S_1F_2	46.69	10+40	96.69	28.35	68.34	52.07	-16.27
T_3	S_1F_3	46.69	10+60	116.69	27.00	89.69	65.21	-24.48
T_4	S_2F_1	46.69	10+20	76.69	31.16	45.53	46.7	1.17
T_5	S_2F_2	46.69	10+40	96.69	31.33	65.36	52.31	-13.05
T_6	S_2F_3	46.69	10+60	116.69	39.03	77.66	60.42	-17.24
T_7	S_3F_1	46.69	10+20	76.69	25.08	51.61	50.84	-0.77
T_8	S_3F_2	46.69	10+40	96.69	30.99	65.70	47.98	-17.72
T_9	S_3F_3	46.69	10+60	116.69	35.93	80.76	65.24	-15.52
T_{10}	S_4F_1	46.69	10+20	76.69	32.99	43.70	43.63	-0.07
T_{11}	S_4F_2	46.69	10+40	96.69	39.89	56.80	49.65	-7.15
T_{12}	S_4F_3	46.69	10+60	116.69	47.62	69.07	58.17	-10.90

Note: Spacing (cm) Fertilizer levels (kg ha^{-1})

S_1: 45 × 15 cm — F_1: 40:20:20 kg NPK ha^{-1}
S_2: 45 × 30 cm — F_2: 60:40:40 kg NPK ha^{-1}
S_3: 60 × 15 cm — F_3: 80:60:60 kg NPK ha^{-1}
S_4: 60 × 30 cm

Table 5: Influence of spacing and fertilizer levels on potassium balance (kg ha^{-1}) in soil after the harvest of chia.

Treatments		Initial soilK_2O (kgha^{-1}) (A)	Applied K_2O through FYM (5 t ha^1) + Fertilizer (kg ha^{-1}) (B)	Total K_2O (A+B=C)	Crop uptake K_2O (D)	Expected balance (C-D=E)	Actual balance K_2O(F)	Net gain (+) or loss (-) (F-E=G)
T_1	S_1F_1	373.1	25+20	418.1	62.75	355.35	330.00	-25.35
T_2	S_1F_2	373.1	25+40	438.1	70.36	367.74	365.00	-2.74
T_3	S_1F_3	373.1	25+60	458.1	78.22	379.88	343.12	-36.76
T_4	S_2F_1	373.1	25+20	418.1	88.62	329.48	305.00	-24.48
T_5	S_2F_2	373.1	25+40	438.1	96.70	341.40	327.00	-14.40
T_6	S_2F_3	373.1	25+60	458.1	121.48	336.62	335.00	-1.62
T_7	S_3F_1	373.1	25+20	418.1	67.61	350.49	315.34	-35.15
T_8	S_3F_2	373.1	25+40	438.1	88.06	350.04	308.42	-41.62
T_9	S_3F_3	373.1	25+60	458.1	95.04	363.06	323.00	-40.06
T_{10}	S_4F_1	373.1	25+20	418.1	107.27	310.83	285.00	-25.83
T_{11}	S_4F_2	373.1	25+40	438.1	107.57	330.53	309.00	-21.53
T_{12}	S_4F_3	373.1	25+60	458.1	126.15	331.95	310.36	-21.59

Note: Spacing (cm) Fertilizer levels (kg ha^{-1})

S_1: 45 × 15 cm — F_1: 40:20:20 kg NPK ha^{-1}
S_2: 45 × 30 cm — F_2: 60:40:40 kg NPK ha^{-1}
S_3: 60 × 15 cm — F_3: 80:60:60 kg NPK ha^{-1}
S_4: 60 × 30 cm

CONCLUSIONS

On findings of the above-summarized results from one-year experimentation, the following conclusions have been drawn that increased N, P and K uptake in seed and haulm and total uptake were recorded with 60 × 30 cm spacing over rest of the spacings and higher available nitrogen was recorded with 45 × 15 cm spacing as compared to other spacings. However, significantly higher N, P and K uptake was recorded with higher dose of fertilizer 80:60:60 kg NPK ha^{-1}. On contrary the higher available nitrogen was recorded with the fertilizer level of 40:20:20 kg NPK ha^{-1}. Findings indicate that nitrogen, phosphorus and potassium dynamics in the soil were influenced by spacing and fertilizer application. Most treatments resulted in a net loss of nitrogen, phosphorus and potassium from the soil, highlighting proper management practices are essential to optimize nutrient retention and ensure sustainable crop production.

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