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Influence of row spacing and organic nutrient management practices on growth, yield and nutrient uptake of chia (*Salvia hispanica*)

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ABSTRACT

The field experiment was conducted during rainy (*kharif)* seasons of 2020–21 and 2021–22 at Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya, Karnataka, to study the consequences of row spacing and organic nutrient management practices on growth, yield and nutrient uptake of chia (*Salvia hispanica* L.). The experiment was conducted in a factorial randomized complete block design (Factorial-RCBD), with 12 treatment combinations replicated thrice. The treatments comprised of 2 spacings (45 cm × 15 cm and 60 cm × 15 cm) and 6 organic nutrient management practices [application of 75 and 100% recommended dose of nitrogen (RDN) equivalent compost along with the application of *Jeevamrutha* at sowing and 30 days after sowing (DAS)]. The pooled mean results of 2-years revealed that row spacing and organic nutrient management practices significantly influenced the performance of chia. Plant height, number of branches/plant, total dry matter production, and yield variables such as spike number and spike length were all significantly greater in 60 cm × 15 cm spacing with the application of 100% RDN equivalent compost + application of *Jeevamrutha* at sowing and 30 DAS. The same treatment also recorded significantly higher nutrient uptake (66.35, 12.91, and 52.27, NPK kg/ha, respectively). Whereas, significantly higher seed yield (1015.47 kg/ha) and leaf area index (1.72) were gained with 45 cm × 15 cm + 100% RDN equivalent compost + application of *Jeevamrutha* at sowing and 30 DAS.

Keywords: Compost, *Jeevamrutha*, Organic nutrient management, Row spacing, Seed and haulm yield

Chia (*Salvia hispanica* L.) is a herbaceous plant belonging to the family Lamiaceae and is native to hilly regions of Mexico and Guatemala. This crop has the capacity to reach a height of up to 1.5 m, with its edible part being the seed. Renowned for its nutritional value, chia has gained popularity as a dietary supplement, particularly among individuals following vegetarian and gluten-free diets. The seeds boast an oil content of approximately 30–35%, making them the richest source of omega-3 fatty acids, with over 60% concentration, and are deemed essential polyunsaturated fatty acids (PUFAs) in high demand due to their significant market value (Mary *et al*. 2018a). In addition to their high omega-3 content, chia seeds are also abundant in proteins accounting for about 20–22%, dietary fibers around 40%, antioxidants, and various vitamins and minerals. This 'superfood' has witnessed a surge in global popularity, leading to a substantial increase in both cultivation and consumption. The international and Indian markets are witnessing a considerable demand for chia. With its profitable commercial cultivation, chia is now grown commercially in several countries, including the United States, Bolivia, Argentina, Ecuador, Peru, Colombia, Nicaragua, Guatemala, Australia, and Mexico. Its cultivation spans a global scale, covering a total area of 126’000 hectares and yielding a production of 103’000 tonnes.

Chia cultivation has experienced a notable increase in Karnataka in recent years, driven by the elevated market prices of the crops. This trend has extended beyond Karnataka, reaching other parts of the state and neighbouring regions, driven by the promise of greater returns compared to traditional crops. Among various agronomic practices, crop geometry and nutrient management emerge as crucial techniques for enhancing crop yield (Aliveni *et al*. 2020). Despite the increasing demand for chia, its cultivation in India is not yet widespread. The available information on growth, phenology, nutritional needs, and optimal management strategies is notably insufficient, especially when considering the distinct edaphoclimatic conditions prevailing in each region. This gap is particularly significant for organically grown chia crop. To bridge these knowledge gaps, the present study was carried out to evaluate planting

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space and organic nutrient management practices in the growth and yield of chia, providing valuable insights into effective cultivation strategies for this crop.

MATERIALS AND METHODS

The field study was carried out during rainy (*kharif)* seasons of 2020–21 and 2021–22 at Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya (latitudes 11° 30' to 13° 05' N and longitudes 76° 05' to 77° 45' E; altitude 695 m amsl), Karnataka. This location falls within the southern dry zone (SDZ) of Karnataka (agro climatic zone-VI) and region III, located amidst. The soil in the research location was red sandy loam having *p*H 7.71 and low electrical conductivity (0.35 dS/m) and 0.66% of organic carbon content. Moreover, the soil exhibited diminished levels of accessible nitrogen (278.24 kg/ ha), moderate levels of accessible phosphorus (32.3 kg/ha), and elevated levels of available potassium (291.56 kg/ha). The compost used in the experiment contained 0.5, 0.44, and 1.0% of nitrogen, phosphorus, and potassium, respectively.

Treatment details, layout, and observation recorded: The experiment was laid out in factorial randomized complete block design (Factorial-RCBD) comprised of 2 row spacings (S_1, 45 cm × 15 cm; S_2, 60 cm × 15 cm) and 6 organic nutrient management practices (N_1, 75% RDN equivalent compost; N_2, 100% RDN equivalent compost; N_3, N_1 + application of *Jeevamrutha* at sowing; N_4, N_2 + application of *Jeevamrutha* at sowing; N_5, N_1 + application of *Jeevamrutha* at sowing and 30 DAS; N_6, N_2 + application of *Jeevamrutha* at sowing and 30 DAS) replicated thrice. Prescribed quantities of nitrogen (40 kg/ha); phosphorus (20 kg/ha) and potassium (20 kg/ha) were administered through farmyard manure (FYM) and compost, considering their N equivalent value. The gross plot size of the experiment was 7.2 m × 3.3 m.

The field preparation involved two rounds of deep ploughing using a tractor-drawn disc plough, followed by clod crushing with a cultivator, and two harrowing with a blade harrow. The experiment's layout was implemented in accordance with the planned design, with individual plots tailored to the specified seed-sowing dimensions. *Jeevamrutha* and well-decomposed compost were sourced from the field unit of the College of Agriculture, Mandya, University of Agricultural Sciences, Bengaluru. Approximately 15 days before sowing, well-decomposed compost was administered at a proportion of 8 t/ha to the respective experimental plots, as prescribed by the treatments. It was meticulously mixed with the topsoil after application. Table 1 provides detailed information on the composition of nutrients for both compost and *Jeevamrutha*. Compost quantities were determined based on the nitrogen dose, aiming to meet the recommended NPK dose (40:20:20 kg NPK/ha) for chia crops. The compost was then integrated into the soil following the specified treatments. The preparation of *Jeevamrutha* involved blending of cow dung (10 kg), cow urine (10 litres), local jaggery (2 kg), pulse flour (2 kg), and a handful of soil from the farm. This mixture was applied in a plastic drum of 200 litres capacity, thoroughly blended, and allowed to ferment under shade. Consistent daily clockwise agitation in the morning, afternoon, and evening over a period of 10 days, with the container protected by a damp gunny bag, resulted in the formation of *Jeevamrutha*. The solution, diluted in a 1:10 ratio with irrigation water, was administered at a dosage of 500 litre/ha to the experimental plots, following the specified treatments. Chia variety GKVK1 was sown with row spacings of 45 cm and 60 cm. For data collection on growth parameters, yield attributes, and nutrient uptake (NPK), 5 plants chosen at random from each plot were assessed. Statistical analysis of the experimental data employed Duncan's Multiple Range Test (DMRT) in both R software and SPSS software (Statistical Package for the Social Sciences). Additionally, a comparative study of different yield attributes involved correlation analysis in R software.

RESULTS AND DISCUSSION

Growth attributes: Upon examining data spanning two years, it was evident that different treatments led to a substantial enhancement in diverse growth parameters, encompassing plant height, number of branches/plant, leaf area index, and overall dry matter production (Table 2). The most effective treatment, among all tested, was found to be a plant spacing of 60 cm × 15 cm combined with 100% RDN equivalent compost, along with the application of *Jeevamrutha* at sowing and 30 days after sowing (DAS). This treatment demonstrated superior results, recording enhanced plant height, number of branches/plant, and total dry matter production (115.49 cm, 19.01, and 95.60 g/ plant, respectively). Furthermore, a higher leaf area index (1.72) was observed with a spacing of 45 cm between the rows × 15 cm between the plants along with 100% RDN equivalent compost, and the application of *Jeevamrutha* at sowing and 30 DAS. The escalated plant height can be credited to a reduction in the competition among plants for nutrients, resulting in more efficient utilization of growth resources, enhanced solar radiation absorption, improved photosynthesis, and overall increased plant height.

Table 1 Nutrient composition of compost and *Jeevamrutha*

Particular	Parameter (%)						
	*p*H	EC (dS/m)	OC (%)	N (%)	P (%)	K (%)	C: N ratio
Compost	8.78	0.49	10.03	0.5	0.44	1.0	20.1:1
Jeevamrutha	7.1	2.03	0.68	0.09	0.02	0.01	-

EC, Electrical conductivity; OC, Organic carbon; N, Nitrogen; P, Phosphorus; K, Potassium; C: N ratio, Carbon: Nitrogen ratio.

Table 2 Effect of row spacing and organic nutrient management practices on growth parameters of chia at harvest (Pooled mean of two years)

Treatment	Plant height (cm)	No. of branches/ plant	Leaf area index (LAI)	Total dry matter production (g/plant)
T_1, $S_1 + N_1$	87.12[cd]	12.06[c]	1.38[cde]	70.60[g]
T_2, $S_1 + N_2$	91.45[cd]	15.85[ab]	1.48[abcd]	80.03[def]
T_3, $S_1 + N_3$	91.02[cd]	14.75[bc]	1.45[bcd]	78.55[ef]
T_4, $S_1 + N_4$	99.34[bc]	17.68[ab]	1.66[ab]	88.76[abc]
T_5, $S_1 + N_5$	96.55[bcd]	16.90[ab]	1.56[abc]	86.09[bcd]
T_6, $S_1 + N_6$	106.48[ab]	18.50[a]	1.72[a]	93.56[a]
T_7, $S_2 + N_1$	85.89[d]	12.71[c]	1.07[f]	74.38[fg]
T_8, $S_2 + N_2$	94.94[bcd]	17.54[ab]	1.22[def]	83.13[cde]
T_9, $S_2 + N_3$	91.19[cd]	16.46[ab]	1.15[ef]	81.35[de]
T_{10}, $S_2 + N_4$	111.89[b]	18.91[a]	1.30[cdef]	91.84[ab]
T_{11}, $S_2 + N_5$	98.39[bcd]	18.01[a]	1.26[def]	88.64[abc]
T_{12}, $S_2 + N_6$	115.49[a]	19.01[a]	1.33[cde]	95.60[a]

Treatment details are given under Materials and Methods.

Additionally, the application of *Jeevamrutha* may have stimulated soil microbial activities, consequently improving nutrient availability, particularly nitrogen. This, coupled with the influence of growth-promoting hormones such as IAA and GA_3, likely encouraged expedited cell growth and multiplication, leading to heightened efficiency in terms of plant height. These findings are consistent with the outcomes reported by Mary *et al*. (2018b) and Gangadhar *et al*. (2020). The noticeable increase in plant height observed in the 75 cm × 15 cm spacing can be attributed to the higher plant density of 90,909 plants/ha. This high density reduces the available space for branches and leaves, forcing the plants to grow vertically instead of horizontally. This phenomenon is in line with the findings of Mounika *et al*. (2021) and Kundu *et al*. (2023). In contrast, wider row spacing, as reported by Njoka *et al*. (2022), lead to an increased number of branches due to more space, nutrients, light, and water, resulting in less competition among plants. Closer spacing between plants causes shading, suppressing lateral growth and promoting apical dominance. Mary *et al*. (2018b) discovered a 29% rise in branch count when cultivating chia with a broader spacing of 60 cm × 45 cm. The application of compost and *Jeevamrutha* significantly enhances nutrient availability, increasing the assimilatory surface area and allowing for more plants per unit area. This contributes to a higher leaf area index, as noted by Prakash *et al*. (2018). The addition of compost and *Jeevamrutha* ensures optimal and timely nutrient supply, leading to increased dry matter. The use of organic nutrients enhances microbial activity, facilitating the rapid decomposition of organic manures and the timely release of nutrients, as reported by Sweta *et al*. (2017). Thongney *et al.* (2020) witnessed that higher utilization of FYM and vermicompost improve soil's physical, chemical, and biological properties, providing an ample nutrient supply to plants. This promotes higher growth attributes, as increased concentrations of FYM and vermicompost enhance biological and sink efficiency, leading to higher photosynthetic efficiency and nutrient absorption. A spacing of 60 cm × 15 cm + 75% RDN equivalent compost resulted in lower plant height (85.89 cm) and leaf area index (1.07). Additionally, fewer branches per plant (12.06) and lower total dry matter production (70.60 g/plant) were documented with treatment 45 cm × 15 cm + 75% RDN equivalent compost. Closer plant spacing reduces lateral growth, increases internodal distance, and intensifies competition for space, moisture, light, and nutrients. Enhanced nutrient accessibility, as indicated by Yeboah *et al*. (2014) and De Freitas *et al*. (2016), provokes a substantial augmentation in branch count/plant.

Yield attributes: The combined average of two years for the spike count/plant, length of the spike, and seed yield was statistically examined (Table 3). A significantly higher number of spikes/plant (44.08) and longer spikes (30.26 cm) were observed when using 60 cm × 15 cm spacing, along with the application of 100% RDN equivalent compost and *Jeevamrutha* at sowing and 30 DAS. Conversely, lower values were recorded with 45 cm × 15 cm, combined with the application of 75% RDN equivalent compost (30.82 and 21.29 cm, respectively). The increased availability of soil nutrients during the crop cultivation period likely contributed to the higher spike count/plant and length of spike. This, in turn, led to a higher accumulation of dry matter in the leaves and stems, with the total dry matter efficiently translocated to the seeds. Comparable results were documented by Aravind *et al*. (2020) and Garjila *et al*. (2020). Among the various treatments, the row spacing of 45 cm × 15 cm with 100% RDN equivalent compost and *Jeevamrutha* at sowing and 30 DAS recorded a higher seed yield (1015.47 kg/ha), and this was significant compared to all other treatments except for the row spacing of 45 cm × 15 cm with 100% RDN equivalent compost and *Jeevamrutha* at sowing (954.83 kg/ha) and 60 cm × 15 cm with 100% RDN equivalent compost and *Jeevamrutha* at sowing and 30 DAS (928.83 kg/ha). The higher seed yield was primarily ascribed to an enhanced number of plants/hectare and the adequate delivery of plant nutrients to the crop during the growth period, resulting in favourable increase in yield-contributing factors, ultimately leading to an increase in economic yield (Table 3). Equivalent results were outlined by Keerthi *et al*. (2015). The addition of farmyard manure (FYM) and vermicompost increased the nutrient concentration in the soil, enhancing the soil's adsorption capacity for cations and anions, particularly phosphates and nitrates. These nutrients were released slowly throughout the entire growth period, benefiting the crop. The uncovered trend is congruent with the findings outlined by Verma *et al*. (2017) and Chaitanya *et al*. (2022).

Nitrogen, phosphorus and potassium uptake: Among various treatments, the combination of a row spacing of 45 cm × 15 cm, 100% RDN equivalent through compost,

Table 3 Effect of row spacing and organic nutrient management practices on yield parameters and NPK uptake of chia (Pooled mean of two years)

Treatment	Spike count/ plant	Length of the spike (cm)	Seed yield (kg/ ha)	Nitrogen uptake (kg/ha)	Phosphorus uptake (kg/ha)	Potassium uptake (kg/ha)
T_1, $S_1 + N_1$	30.82^{e}	21.29^{d}	636.00^{gh}	45.53^{g}	6.19^{de}	30.96^{f}
T_2, $S_1 + N_2$	35.95^{cd}	26.84^{bc}	833.17^{de}	57.40^{bcde}	9.64^{bc}	42.10^{bcd}
T_3, $S_1 + N_3$	35.40^{cde}	26.65^{c}	741.83^{ef}	54.14^{def}	8.60^{bcd}	38.80^{cde}
T_4, $S_1 + N_4$	40.34^{abc}	27.64^{abc}	954.83^{ab}	63.38^{ab}	11.36^{ab}	49.01^{ab}
T_5, $S_1 + N_5$	38.46^{bc}	27.80^{abc}	878.33^{bcd}	59.70^{bcd}	10.45^{abc}	44.66^{abc}
T_6, $S_1 + N_6$	42.15^{ab}	29.76^{ab}	1015.47^{a}	66.35^{a}	12.91^{a}	52.27^{a}
T_7, $S_2 + N_1$	33.13^{de}	23.50^{d}	577.67^{h}	43.25^{g}	4.90^{e}	29.02^{f}
T_8, $S_2 + N_2$	39.12^{abc}	27.24^{bc}	681.50^{fg}	53.09^{ef}	8.25^{bcd}	36.38^{def}
T_9, $S_2 + N_3$	37.65^{bcd}	27.00^{bc}	663.50^{fgh}	51.15^{f}	7.39^{cde}	33.89^{ef}
T_{10}, $S_2 + N_4$	43.54^{a}	29.35^{abc}	850.67^{cd}	58.29^{bcde}	9.99^{abc}	44.18^{bcd}
T_{11}, $S_2 + N_5$	41.16^{ab}	28.08^{abc}	808.67^{de}	55.82^{cdef}	9.21^{bcd}	40.57^{cde}
T_{12}, $S_2 + N_6$	44.08^{a}	30.26^{a}	928.83^{abc}	60.78^{abc}	10.91^{ab}	46.83^{abc}

Treatment details are given under Materials and Methods.

and the application of *Jeevamrutha* at both sowing and at 30 days after sowing (DAS) triggered a pronounced elevation in nitrogen (66.35 kg/ha), phosphorus (12.91 kg/ha), and potassium assimilation (52.27 kg/ha) compared to alternative treatments. Conversely, treatments with 60 cm × 15 cm spacing and 75% RDN equivalent through compost recorded lower values (43.25, 4.90, and 29.02 NPK kg/ha, respectively). The enhanced microbial activity and improved nitrogen accessibility in the soil likely contributed to increase nutrient uptake by the plants. The continuous release of nutrients from organic sources due to mineralization further boosted nutrient availability and uptake. The identified patterns are consistent with the research conducted by Thumar *et al*. (2016) and Gangadhar *et al*. (2020), indicating that a well-established root system and increased nutrient supply promote enhanced nutrient uptake, leading to improved water and nutrient absorption. The application of *Jeevamrutha* to the soil may have played a role in creating a favourable environment for microorganisms, facilitating the accessibility of essential nutrients like nitrogen, phosphorus, and potassium for plant growth, as observed in studies by Yogananda *et al*. (2017) and Gangadhar *et al*. (2020).

The correlation analysis (Fig. 1) reveals strong associations among various yield-related attributes. Seed yield (kg/ha) exhibits a highly significant and positive correlation with key yield-related characteristics such as test weight (0.52), spike length (0.58), and the number of spikes/plant (0.52) while showing a negative correlation with harvest index (-0.54). On the other hand, harvest index (HI) demonstrates a low degree of positive correlation with test weight (0.01) and spike count/plant (0.04), and it does not correlate with spike length. Notably, spike length and the number of spikes/plant display highly significant and strong positive correlations with test weight (0.90 and 0.87, respectively).

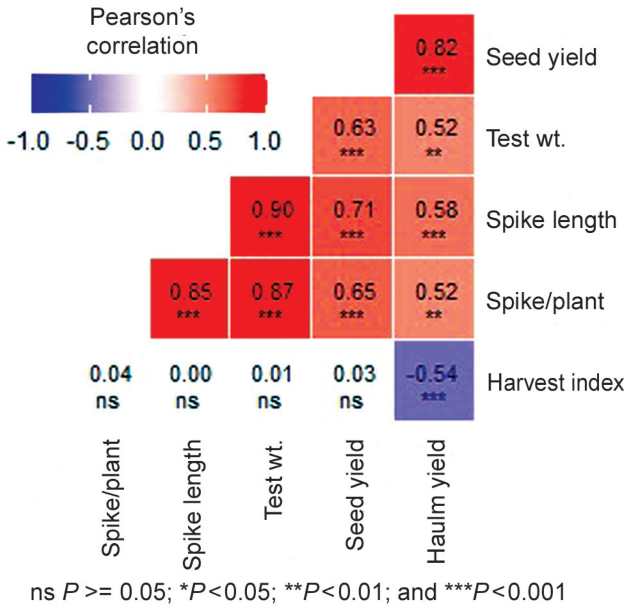

Fig. 1 Correlation analysis between different yield attributes.

After a 2-year investigation, it was concluded that the treatment involving a row spacing of 60 cm × 15 cm, 100% RDN equivalent compost, and the application of *Jeevamrutha* at both sowing and 30 days after sowing (DAS) demonstrated higher growth parameters (such as plant height, number of branches/plant, and total dry matter production) as well as yield parameters (number of spikes/ plant and spike length) compared to alternative treatments.

Furthermore, the treatment with 45 cm × 15 cm spacing, 100% RDN equivalent through compost, and the application of *Jeevamrutha* at sowing and 30 DAS exhibited statistically superior seed yield and NPK uptake when compared to the other treatments.

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