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Performance of Chia (*Salvia hispanica* L.) under Spacing and Nutrient Management Practices in Cauvery Command Area

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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

An investigation was carried out at the Zonal Agricultural Research Station, Vishweshwaraiah Canal Farm, Mandya, Karnataka, spanning from September to December in both 2020 and 2021. The purpose was to analyze how varying spacing and nutrient management practices affect the yield and growth rate of chia plants. The study involved two different spacings (S) and six levels of

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organic nutrients (N). Employing a 2 × 6 × 3 factorial experiment design within a randomized complete block framework with three replications, the experiment was conducted over a two-year period. The spacing of 60 cm × 15 cm (S_2) resulted in notably higher absolute growth rates (1.00 and 1.87 g/day, respectively at 30 – 60 and 60 – 90 DAS) and biomass duration (221.84, 893.45 and 2182.73 days, respectively at 0 – 30, 30 – 60 and 60 – 90 DAS). Conversely, for relative growth rate (1.67 and 1.19 g/g/day × 10^{-2}, respectively at 30 – 60 DAS and 60 – 90 DAS) and leaf area ratio (2180.90, 1967.19 and 1522.35 $cm^2/g \times 10^{-2}$, respectively at 30, 60 and 90 DAS), higher values were observed with 45 cm × 15 cm spacing (S_1). Among the various organic nutrient levels, the highest absolute growth rate (1.09 and 2.01 g/day, respectively at 30 – 60 and 60 – 90 DAS) and biomass duration (259.18, 1009.48 and 2403.23 days, respectively at 0 – 30, 30 – 60 and 60 – 90 DAS) were recorded with N_6, while greater relative growth rate (1.86 and 1.20 g/g/day × 10^{-2}, respectively at 30 – 60 DAS and 60 – 90 DAS) and leaf area ratio (2616.15, 2206.54 and 1723.31 $cm^2/g \times 10^{-2}$, respectively at 30, 60 and 90 DAS) were found with N_1. The interaction between spacing and organic nutrient levels did not yield any significant differences with respect to absolute growth rate, biomass duration, relative growth rate and leaf area ratio.

Keywords: Absolute growth rate; compost; leaf area ratio; relative growth rate and spacing.

1. INTRODUCTION

Chia (*Salvia hispanica* L.) belongs to the *Lamiaceae* family and the genus Salvia, garnering increased interest due to its positive impacts on human health [1]. Recognized as a functional food, chia boasts a composition rich in polyunsaturated fatty acids, abundant omega-3 and linoleic acids, antioxidant compounds and substantial protein and dietary fiber contents [2]. Therefore, gaining further insights into chia, particularly regarding appropriate fertilization practices, is crucial for reducing losses and costs while optimizing both quantity and quality of production [3,4]. Tropical and subtropical climates, with maximum and minimum growth temperatures ranging from 11°C to 36°C and an optimal range between 16°C and 26°C, are most conducive for chia cultivation. It thrives at elevations ranging from 400 to 2500 meters above mean sea level [5]. The crop typically has a duration of 140-180 days, with its growth cycle influenced by the latitude of cultivation due to its sensitivity to day length. Chia can be cultivated under both rainfed and irrigated conditions, with rainfall ranging from 300 to 1000 mm during the growing season proving beneficial for optimal crop development [6].

Spacing between chia plants can significantly affect plant development, branching and seed yield. Optimal spacing depends on factors such as soil fertility, climate and cultivar characteristics. Generally, wider spacing allows for better access to sunlight, airflow and nutrients, promoting larger plant size and potentially higher yields. However, excessively wide spacing may lead to competition among plants for resources and increased weed pressure. Narrower spacing can maximize land use efficiency but may require more intensive management practices to control weeds and ensure adequate nutrient supply. Proper nutrient management is essential for achieving high yields and maintaining chia plant health. Chia has specific nutrient requirements at different growth stages and deficiencies or imbalances can impact plant growth and seed production. Organic fertilizers, such as compost and manure, are commonly used in chia cultivation to improve soil structure and fertility while minimizing environmental impacts. Compost serves as a valuable source of organic matter and essential nutrients for chia plants. It contains a balanced mixture of nitrogen, phosphorus, potassium and micronutrients, supporting healthy growth and development. Jeevamrutha is a fermented microbial culture made from cow dung, cow urine, jaggery and water. It contains beneficial microorganisms like bacteria, fungi, and earthworms, which contribute to soil fertility and plant health.

Investigating the impact of spacing and nutrient management strategies on chia cultivation is essential for enhancing the growth and yield of chia seeds. This study aimed to assess the performance of chia under subtropical conditions, considering the effects of spacing and organic nutrient levels.

2. MATERIALS AND METHODS

The experiment took place during the *kharif* seasons (2020-21 and 2021-22) employing a Factorial Randomized Complete Block Design

(Factorial-RCBD) with three replications. It was conducted at the organic farming block (G-block) of the Zonal Agricultural Research Station, situated in the Mandya district of Karnataka, specifically within the Southern Dry Zone of Karnataka. The research station is located at an altitude of 695 meters above MSL. The experiment consisted of Factor 1: Two spacings (S_1: 45 cm × 15 cm and S_2: 60 cm × 15 cm) and Factor 2: Six organic nutrient levels (N_1: 75% RDN equivalent compost; N_2: 100% RDN equivalent compost; N_3: 75% RDN equivalent compost + jeevamrutha application at sowing; N_4: 100% RDN equivalent compost + jeevamrutha application at sowing; N_5: 75% RDN equivalent compost + jeevamrutha application at sowing and 30 DAS; N_6: 100% RDN equivalent compost + jeevamrutha application at sowing and 30 DAS). The identical treatments were administered over two consecutive years. The recommended NPK dose (RDF) for chia is 40:20:20 kg/ha, with the prescribed doses of nitrogen (RDN) applied in compost form based on the equivalent nitrogen value. The experiment was conducted on red sandy loam soil. The gross plot size for the experiment measured 7.2 meters between rows and 3.3 meters between individual plants. However, the net plot size was 4.8 × 2.7 m^2 for a spacing of 60 cm × 15 cm and 5.4 × 2.7 m^2 for a spacing of 45 cm × 15 cm.

Well-decomposed compost was sourced from the College of Agriculture, V. C. Farm, Mandya, and applied to the respective individual plots according to the treatments (8 t/ha), 15 days before sowing. Jeevamrutha was prepared following the procedures outlined by Palekar [7]. This involved mixing 10 kg of local cow dung with 10 litres of cow urine, adding 2 kg of local jaggery, 2 kg of pulse flour and a handful of garden soil and adjusting the volume to 200 litres. The mixture was placed in a drum, covered with a wet gunny bag and stirred clockwise three times a day. After approximately 10 days of incubation, it was ready for soil application (500 L/ha), diluted with irrigation water in a 1:10 ratio. Laboratory analyses were conducted on soil and jeevamrutha samples using serial dilution and plate count techniques, focusing on three groups of microorganisms: bacteria, fungi and actinomycetes (list 1).

2.1 Parameters Studied

The observations on seed yield, absolute growth rate (AGR, g/day), relative growth rate (RGR, g/g/day × 10^{-2}), leaf area ratio (LAR, $cm^2/g \times 10^{-2}$) and biomass duration (BMD, days) were recorded at different growth stages of chia *i.e.*, 30 DAS, 60 DAS, 90 DAS and at harvest. Also, correlation analysis was done for microbial population (bacteria, fungi and actinomycetes) at 30 and 60 DAS.

The absolute growth rate was calculated using the formula given by Power et al. [9].

$$AGR = W2 – W1 / t2 – t1$$

Where AGR = absolute growth rate expressed in g/day, W_1 and W_2 = dry weight of plant at time t_1 and t_2, respectively.

The relative growth rate was calculated by the formula as given by Radford [10]. It is expressed as gram of dry matter produced by g of existing dry matter in a day.

$$RGR = Loge\ W2 – Loge\ W1 / t2 – t1$$

Where RGR = relative growth rate expressed in g/g/day × 10^{-2}, W_1 and W_2 = dry weight of plant at time t_1 and t_2, respectively.

Leaf area ratio was calculated by the formula as suggested by Radford [10].

$$LAR = LA / W$$

Where LAR = leaf area ratio expressed in $cm^2/g \times 10^{-2}$, LA = leaf area per plant, W = plant dry weight.

Biomass duration constitutes a measurement of biomass persistence with time. It is calculated by the formula given by Kvet et al. [11].

$$BMD = (BM1 + BM2) \times (t2 – t1) / 2$$

Where BMD = Biomass duration expressed in days, BM_1 and BM_2 = dry matter per plant at time t_1 and t_2, respectively.

2.2 Statistical Analysis

All data underwent statistical analysis to ensure the derivation of valid conclusions, following the guidelines outlined by Gomez and Gomez [12]. In cases where the F-test revealed significance in the comparison among treatment means, the appropriate critical difference (CD) value was determined. Conversely, if the F-test did not yield significance, the abbreviation NS

List 1. Biological properties of soil and jeevamrutha in the experimental site

Particulars	Methods followed
Bacterial population (cfu × 10^5 g^{-1} of soil) Fungal population (cfu × 10^4 g^{-1} of soil) Actinomycetes population (cfu × 10^3 g^{-1} of soil)	Serial dilution plate count technique [8]

(non-significant) was noted alongside the CD values. Correlation analysis was conducted using R software [13] to elucidate the relationships between microbial populations at 30 and 60 DAS, employing Pearson's correlation coefficient.

3. RESULTS AND DISCUSSION

3.1 Seed Yield (kg/ha)

The seed yield of chia shows significant variation based on both spacing and organic nutrient levels. However, the interaction between these factors was found to be non-significant. Table 1 presents the combined data from two years of study. S_1 spacing resulted in the highest seed yield at 843 kg/ha, followed by S_2 at 752 kg/ha. This increase in yield could be attributed to a higher density of plants per unit area, as noted by Anbarasu et al. [14] in castor and Chaitanya et al. [5] in chia. Similar findings were also reported by Yeboah et al. [6], who found that a planting density of 0.5 m x 0.5 m (40,000 plants/ha) led to the highest biomass and seed yield across both years of their study (2012 and 2013), aligning with the conclusions of Njoka et al. [15] and Kundu et al. [16]. Furthermore, seed yield was highest with N_6 at 972 kg/ha, followed by N_4 at 903 kg/ha, while the lowest yield of 607 kg/ha was observed with N_1. The superior performance of organic manures in enhancing yield attributes was evident, as noted by Chaitanya et al. [5], who found that the combined application of farmyard manure (FYM) and vermicompost benefited crop growth throughout the entire growth period compared to the sole application of manures. These results were consistent with the findings of Thongney et al. [17]. Moreover, Gowthami et al. [18] observed that the significant increase in yield was linked to the release of macro and micro nutrients during microbial decomposition. Organic matter serves as a source of energy for soil microflora, facilitating the transformation of nutrients into forms readily accessible to plants, ultimately boosting seed yield. These findings were corroborated by Aravind et al. [19].

3.2 Absolute Growth Rate (g/day)

AGR represents the rate at which size changes over a given time period, making it the most straightforward growth indicator. Table 1 displays the data concerning absolute growth rate. There was no significant effect observed regarding spacing or their interaction. However, organic nutrient levels had a notable impact except during the year 2020 (30 – 60 DAS). Notably, statistically higher AGR was recorded in treatment S_2 (1.00 and 1.87 g/day, respectively) between 30 – 60 and 60 – 90 DAS compared to S_1. Within the spectrum of organic nutrient levels, notably higher AGR values (1.09 and 2.01 g/day, respectively) were observed in the N_6 treatment between 30 – 60 and 60 – 90 DAS. Conversely, lower values (0.85 and 1.51 g/day, respectively) were recorded with N_1. The increased AGR associated with higher nutrient levels can be attributed to the application of organic manures, which likely enhanced soil quality and water retention capacity, facilitating a sustained nutrient supply throughout the crop growth stages. This gradual release of nitrogen might have contributed to improved dry matter production in chia plants. These findings are consistent with the conclusions drawn by Chaitanya et al. [20] and Ramesh et al. [21] in their studies on quinoa. AGR is determined by the quantity of growing material available and is subject to environmental influences, providing absolute measurements of biomass between specified intervals. It is primarily utilized for individual plants or plant organs such as leaf growth or overall plant weight. The mean AGR values offer compelling evidence of the impact of organic fertilization treatments. In terms of yearly trends, the mean value was higher in 2021 (1.15 g/day) compared to 2020 (1.04 g/day) between 30 – 60 DAS, while it was higher in 2020 (2.07 g/day) than in 2021 (1.96 g/day) between 60 – 90 DAS. Similarly, alterations in plant density were found to correlate with changes in growth rates like AGR and RGR for individual plants, as noted by Al-Suhaibani et al. [22].

3.3 Relative Growth Rate (g/g/day × 10^{-2})

The Relative Growth Rate (RGR) represents the increase in dry weight per unit of original dry weight over a specific time interval. As the crop ages, RGR gradually diminishes, as noted by Kumar et al. [22]. The periodic observations of data pertaining to RGR are presented in Table 2. Spacing, organic nutrient levels and their interaction did not exhibit a significant effect at 30 - 60 and 60 - 90 DAS. However, numerically higher RGR was observed with narrower spacing (S_1), i.e., (1.67 and 1.19 g/g/day × 10^{-2}, respectively) at 30 – 60 DAS and 60 – 90 DAS compared to wider spacing (S_2), which recorded (1.62 and 1.18 g/g/day × 10^{-2}, respectively). Within the spectrum of organic nutrient levels, the highest RGR was observed with N_1 (1.86 g/g/day × 10^{-2} at 30 – 60 DAS), whereas both N_1 and N_2 exhibited increased RGR at 60 – 90 DAS (1.20 g/g/day × 10^{-2}). However, at 30 - 60 DAS in 2021, N_6 demonstrated a significant effect in relation to organic nutrient levels. Kumar et al. [23] found that employing a treatment consisting of 100% nitrogen through a combination of 1/3 vermicompost, 1/3 farmyard manure (FYM) and 1/3 poultry manure at the basal stage resulted in the highest growth parameters such as Leaf Area Index (LAI), Crop Growth Rate (CGR) and Relative Growth Rate (RGR). This outcome could be attributed to the direct and enhanced availability and translocation of nutrients during the crop's developmental phase, which boosted the plant's metabolic and physiological activities. Consequently, the plant exhibited increased growth by assimilating higher nutrient quantities,

Table 1. Effect of spacing and organic nutrient levels on seed yield and absolute growth rate at different growth stages of chia

Treatments	Absolute growth rate (g/day)						Seed yield (kg/ha)		
	30 – 60 DAS			60 – 90 DAS			At harvest		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor 1: Spacing (S)									
S_1	0.95	0.98	0.96	1.81	1.78	1.79	842	844	843
S_2	0.98	1.02	1.00	1.89	1.85	1.87	750	753	752
SE (m) ±	0.04	0.02	0.03	0.05	0.04	0.05	12	12	12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	36	36	36
Factor 2: Organic nutrient levels (N)									
N_1	0.85	0.84	0.85	1.51	1.51	1.51	606	608	607
N_2	0.95	0.95	0.95	1.80	1.80	1.80	756	758	757
N_3	0.91	0.96	0.94	1.78	1.74	1.76	702	704	703
N_4	1.02	1.07	1.04	1.98	1.93	1.96	902	904	903
N_5	1.01	1.04	1.03	1.96	1.94	1.95	842	845	844
N_6	1.04	1.15	1.09	2.07	1.96	2.01	971	974	972
SE (m) ±	0.07	0.04	0.05	0.09	0.08	0.08	21	21	21
CD (P=0.05)	NS	0.12	0.15	0.27	0.23	0.24	63	62	62
Interaction (S × N)									
S_1N_1	0.86	0.85	0.85	1.47	1.48	1.48	635	637	636
S_1N_2	0.90	0.90	0.90	1.71	1.71	1.71	833	834	833
S_1N_3	0.89	0.92	0.90	1.75	1.72	1.73	741	743	742
S_1N_4	1.00	1.05	1.03	1.95	1.90	1.93	954	956	955
S_1N_5	1.01	1.03	1.02	1.93	1.93	1.93	877	880	878
S_1N_6	1.03	1.12	1.07	2.03	1.94	1.98	1014	1017	1015
S_2N_1	0.84	0.84	0.84	1.54	1.54	1.54	577	578	578
S_2N_2	0.99	0.99	0.99	1.90	1.89	1.89	680	683	682
S_2N_3	0.94	1.00	0.97	1.82	1.76	1.79	662	665	664
S_2N_4	1.03	1.08	1.06	2.01	1.96	1.99	849	852	851
S_2N_5	1.00	1.06	1.03	1.99	1.95	1.97	807	810	809
S_2N_6	1.05	1.17	1.11	2.10	1.97	2.04	927	931	929
SE (m) ±	0.10	0.06	0.07	0.13	0.11	0.12	30	30	30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details of the experiment are furnished in Material and Methods

Table 2. Effect of spacing and organic nutrient levels on relative growth rate at different growth stages of chia

Treatments	Relative growth rate (g/g/day × 10^{-2})					
	30 – 60 DAS			60 – 90 DAS		
	2020	2021	Pooled	2020	2021	Pooled
Factor 1: Spacing (S)						
S_1	1.67	1.68	1.67	1.21	1.17	1.19
S_2	1.61	1.63	1.62	1.20	1.16	1.18
SE (m) ±	0.06	0.03	0.04	0.04	0.03	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Factor 2: Organic nutrient levels (N)						
N_1	1.88	1.84	1.86	1.20	1.20	1.20
N_2	1.66	1.64	1.64	1.20	1.20	1.20
N_3	1.60	1.64	1.62	1.22	1.16	1.19
N_4	1.59	1.61	1.60	1.20	1.15	1.18
N_5	1.58	1.62	1.60	1.21	1.18	1.19
N_6	1.50	1.58	1.54	1.20	1.10	1.15
SE (m) ±	0.11	0.05	0.07	0.07	0.05	0.06
CD (P=0.05)	NS	0.15	NS	NS	NS	NS
Interaction (S × N)						
S_1N_1	2.02	1.99	2.01	1.20	1.21	1.21
S_1N_2	1.65	1.63	1.64	1.20	1.20	1.20
S_1N_3	1.59	1.62	1.61	1.23	1.18	1.21
S_1N_4	1.59	1.60	1.59	1.20	1.15	1.17
S_1N_5	1.62	1.64	1.63	1.21	1.19	1.20
S_1N_6	1.51	1.58	1.55	1.20	1.10	1.15
S_2N_1	1.74	1.68	1.71	1.19	1.19	1.19
S_2N_2	1.66	1.64	1.64	1.21	1.20	1.20
S_2N_3	1.61	1.65	1.63	1.20	1.15	1.17
S_2N_4	1.59	1.61	1.60	1.20	1.15	1.18
S_2N_5	1.55	1.60	1.57	1.21	1.16	1.19
S_2N_6	1.50	1.57	1.54	1.20	1.09	1.14
SE (m) ±	0.15	0.07	0.10	0.10	0.08	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Treatment details of the experiment are furnished in Material and Methods

facilitating enhanced photosynthesis processes and ultimately leading to increased growth parameters, including LAI, CGR and RGR, in scented rice. Similar conclusions were drawn by Pandey et al. [24] and Lal et al. [25]. During the initial stages of plant growth, there is a high ratio of living to dead tissues, with nearly all cells in productive organs actively engaged in producing vegetative matter. As the plant grows, the RGR decreases, reaching its lowest level around 108-118 days after planting, as noted by Sharifi and Pirzad [26]. The decline in RGR during the final stage may be attributed to an increase in dead and woody tissues compared to living and active tissues, accompanied by a reduction in leaf area index. Similar observations have been documented by Shukla et al. [27] in Indian mustard and Jeffrey et al. [28] in corn. RGR serves as a critical parameter, representing one of the most ecologically significant indices of plant growth. It reflects the plant's efficiency in producing new tissues from existing ones [29]. The decrease in RGR with increasing plant age is due to the progressive accumulation of non-assimilatory tissues.

3.4 Leaf Area Ratio ($cm^2/g \times 10^{-2}$)

Leaf area ratio (LAR) serves as a morphological indicator of a plant's leafiness, defined as the ratio between the total leaf area per plant and the total weight per plant. LAR was notably affected by organic nutrient levels, except at 30 and 60 DAS in the year 2020 (Table 3). However, spacing and their interaction did not show a significant influence. The highest LAR values were observed with S_1 (2180.90, 1967.19 and 1522.35 $cm^2/g \times 10^{-2}$, respectively) at 30, 60 and 90 DAS. Concerning organic nutrient levels, N_1 exhibited the highest LAR (2616.15, 2206.54 and

1723.31 cm^2/g × 10^{-2}, respectively at 30, 60 and 90 DAS), while N_6 showed the lowest values (1896.26, 1772.90 and 1397.43 cm^2/g × 10^{-2}, respectively at 30, 60 and 90 DAS). The interaction effect between spacing and organic nutrient levels was found to be non-significant. Initially, LAR values were higher in the early stage (30 DAS), gradually declining at 60 DAS, followed by a steep decrease at 90 DAS. LAR provides insights into the efficiency of a system in growth, reflecting the ratio of photosynthesizing to respiring material within the plant [30].

3.5 Biomass Duration (days)

Biomass duration (BMD) serves as a metric for assessing the persistence of biomass over time. The two-year data for BMD is detailed in Table 4. Spacing significantly influenced BMD at various growth stages of chia, except during the year 2020 at 0 – 30 DAS and 30 – 60 DAS. The highest BMD was observed with S_2 (221.84, 893.45 and 2182.73 days, respectively) at 0 – 30 DAS, 30 – 60 DAS and 60 – 90 DAS. Among organic nutrient levels, N_6 exhibited higher values (259.18, 1009.48 and 2403.23 days, respectively), while N_1 showed lower values (148.34, 678.06 and 1736.68 days, respectively) at 0 – 30 DAS, 30 – 60 DAS and 60 – 90 DAS. This indicates that BMD was minimal during the initial stages of crop growth and increased rapidly with the age of the chia crop. However, interaction was found to be non-significant concerning BMD. Biomass duration is akin to leaf area duration (LAD). When the area under the time curve for biomass production is calculated as LAD, the value for biomass persistence over time is obtained [31]. It serves as an approximate measure for stand vitality, with computations based on the dry matter per plant (BM) obtained at successive harvests.

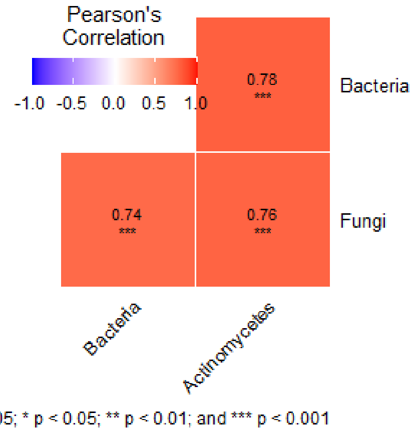

Fig. 1. Correlation analysis between soil microbial population at 30 DAS

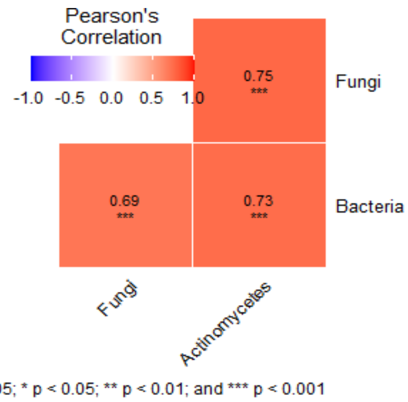

Fig. 2. Correlation analysis between soil microbial population at 60 DAS

Note: Colour indicates nature of correlation. Dark blue – highly negative correlation; Light blue – low level negative correlation; White – no correlation; Light red – low level positive correlation; Dark red – highly positive correlation

Table 3. Effect of spacing and organic nutrient levels on leaf area ratio at different growth stages of chia

Treatments	**Leaf area ratio ($cm^2/g \times 10^{-2}$)**								
	30 DAS			**60 DAS**			**90 DAS**		
	2020	**2021**	**Pooled**	**2020**	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
Factor 1: Spacing (S)									
S_1	2220.18	2158.87	2180.90	1996.40	1942.05	1967.19	1522.29	1522.40	1522.35
S_2	2127.73	2075.78	2097.09	1950.45	1883.37	1915.52	1488.35	1488.45	1488.40
SE (m) ±	95.06	56.93	70.27	63.60	52.23	56.42	25.28	25.28	25.28
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Factor 2: Organic nutrient levels (N)									
N_1	2665.12	2575.96	2616.15	2209.73	2203.73	2206.54	1723.26	1723.36	1723.31
N_2	2211.14	2160.04	2174.02	1997.70	1982.94	1990.12	1524.32	1524.44	1524.38
N_3	2070.55	2039.42	2053.00	2003.05	1925.74	1962.79	1522.14	1522.23	1522.19
N_4	2141.43	2050.87	2083.41	1897.23	1824.03	1859.27	1439.65	1439.76	1439.70
N_5	2024.73	2007.11	2011.10	1881.84	1833.16	1856.51	1425.19	1425.29	1425.24
N_6	1930.76	1870.55	1896.26	1850.99	1706.65	1772.90	1397.38	1397.48	1397.43
SE (m) ±	164.65	98.61	121.71	110.16	90.47	97.73	43.78	43.78	43.78
CD (P=0.05)	NS	289.22	356.97	NS	265.34	NS	128.42	128.42	1.28.42
Interaction (S × N)									
SE (m) ±	232.86	139.46	172.13	155.79	127.94	138.21	61.92	61.92	61.92
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details of the experiment are furnished in Material and Methods

Table 4. Effect of spacing and organic nutrient levels on biomass duration at different growth stages of chia

Treatments	Biomass duration (days)								
	0 – 30 DAS			30 – 60 DAS			60 – 90 DAS		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor 1: Spacing (S)									
S_1	203.60	205.50	204.55	833.45	852.36	842.90	2073.26	2094.73	2081.76
S_2	219.93	223.74	221.84	879.36	907.53	893.45	2170.54	2199.11	2182.73
SE (m) ±	8.77	4.55	6.11	19.34	13.61	16.02	24.35	21.10	22.34
CD (P=0.05)	NS	13.33	NS	NS	39.91	46.98	71.43	61.87	65.53
Factor 2: Organic nutrient levels (N)									
N_1	145.73	150.95	148.34	674.30	681.83	678.06	1735.53	1742.18	1736.68
N_2	201.33	204.15	202.74	827.93	835.53	831.73	2064.43	2073.88	2066.81
N_3	202.65	205.25	203.95	816.18	842.08	829.13	2029.68	2057.63	2041.33
N_4	234.80	237.90	236.35	927.35	956.58	941.96	2277.23	2307.58	2290.29
N_5	229.63	227.60	228.61	912.78	924.63	918.70	2248.20	2266.15	2255.14
N_6	256.48	261.88	259.18	979.90	1039.05	1009.48	2376.35	2434.13	2403.23
SE (m) ±	15.19	7.87	10.59	33.51	23.57	27.74	42.18	36.54	38.70
CD (P=0.05)	44.55	23.09	31.06	98.27	69.13	81.37	123.72	107.17	113.51
Interaction (S × N)									
SE (m) ±	21.48	11.14	14.98	47.38	33.33	39.24	59.66	51.68	54.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details of the experiment are furnished in Material and Methods.

3.6 Correlation Analysis

The correlation analysis illustrated in Fig. 1 and Fig. 2 indicates robust associations among various microbial populations at 30 and 60 DAS, respectively. Soil microbial populations including bacteria, fungi and actinomycetes at 30 and 60 DAS demonstrate highly significant and positive correlations. Bacteria exhibit a notably high level of positive correlation with fungi and actinomycetes. Similarly, fungi and actinomycetes also display strong positive correlations. These results align with the findings of Verma et al. [32] and are consistent with the conclusions drawn by Dey et al. [33] and Rundan et al. [34].

4. CONCLUSION

The findings of the current study validate that yield and growth rates, such as AGR, RGR, LAR and BMD, were influenced by both spacing and organic nutrient levels. However, spacing and their interaction did not significantly affect AGR, RGR, LAR and BMD. In terms of growth rates, the highest values of AGR and BMD were observed with S_2 spacing and N_6 treatment, while S_1 and N_1 exhibited the highest RGR and LAR. Additionally, positive correlations were observed among bacteria, fungi and actinomycetes. In summary, integrating organic nutrient management practices such as compost and jeevamrutha into chia cultivation can yield numerous benefits for plant growth, yield and soil health. These practices endorse sustainable farming approaches, diminish dependency on synthetic inputs and enhance the production of high-quality chia seeds. However, it is crucial to implement these practices thoughtfully, considering factors such as soil properties, climatic conditions and specific crop demands to optimize their effectiveness fully.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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