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INTEGRATED ANALYSIS OF DEVELOPMENT AND YIELD OF CHIA (*Salvia hispanica* L.) BASED ON AGROMETEOROLOGICAL INDICES, CROP GEOMETRIES AND ORGANIC NUTRIENT REGIMES

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ABSTRACT

Realizing maximum productivity of any crop can be achieved by agronomic manipulation and studying the agromet indices, a field trial was done at the University of Agricultural Sciences, GKVK, Bangalore, during *Rabi* 2020-2021 and *Rabi* 2021-2022. The treatments were five crop geometries (S_1 - 60 cm × 30 cm, S_2 - 75 cm × 15 cm, S_3 - 75 cm × 30 cm, S_4 - 90 cm × 15 cm and S_5 - 90 cm × 30 cm) and three organic nutrient regimes (N_1 - 60 kg N equivalent ha^{-1}, N_2 - 80 kg N equivalent ha^{-1} and N_3 - 100 kg N equivalent ha^{-1}). The results established that significantly higher seed and haulm yield (1099 and 1855 kg ha^{-1}, respectively) was with S_4 and remained on par with S_2, which recorded the highest grain and haulm thermal use efficiencies (0.71 and1.16 kg ha^{-1} ^0C day^{-1}, respectively) and helio thermal use efficiencies (0.097 and 0.158 kg ha^{-1} ^0C day hrs^{-1}, respectively). However, significantly higher yield attributes, seed yield per plant were recorded under the wider row spacing of S_5. Among nutrient regimes, significantly higher yield attributes, yield, agrometeorological indices and more days to development of Chia were recorded in N_3.

Key words : Agrometeorological indices, Crop geometry, Development, Organic nutrients, Yield attributes.

Introduction

Chia (*Salvia hispanica* L.) is an annual herbaceous, potential crop which has been rediscovered as a source of omega (ω) - 3 fatty acid (Patel *et al*., 2021). It is a short-day plant which has strong sensitivity to photoperiod and temperature (Kaur *et al*., 2019). Chia is a newly introduced crop and is being popularised as “super food” or “nutraceutical” as it is a rich plant-based source of fatty acids like ω -3 and 6 (50 - 57 and 17- 26 per cent, respectively). Seeds are a rich source of oil (29.36 to 33. 50 per cent), protein (18 to 25 per cent), carbohydrates (26 to 41 per cent) and dietary fibre (18 to 30 per cent) (Prathyusha *et al*., 2019). Chia seeds also play a key role in preventing several long-term diseases, so they are considered a “functional food that would shield nutritional security’’ (Kundu *et al*., 2023).

Plant growth and development depend on surrounding temperature, so measuring the accumulated heat over a period of time is crucial for the estimation of crop phenophase rather than counting calendar days (Bharat *et al*., 2022). Agronomic practices can cause differences in thermal utilisation by changing crop growth and development. The chia crop needs to have well-defined and standardised cultivation protocols, like planting geometry and nutrient management, which influence the utilisation of resources efficiently. So far, much of the research on Chia is related to seed quality and genetic aspects, whereas there is less research done on crop management correlating agromet indices (Attia *et al*., 2023). Due to a huge spike in the awareness of consumers about organic products and their health benefits, there is a critical need to develop an organic package of practices to Chia crop. The current research embarked on a

comprehensive assessment of development and yield based on different agrometeorological indices under different plant spacings and organic nutrient regimes.

Materials and Methods

A research trial was done during two *Rabi* seasons of 2020-21 and 2021-22 at the research and demonstration block of Research Institute on Organic Farming, University of Agricultural Sciences, Gandhi Krishi Vignan Kendra (GKVK), Bengaluru. The site was red sandy loam, which had an initial available nitrogen (N), phosphorus and potassium (313.60, 27.08 and 149.45 kg ha^{-1}, respectively). The layout of the field was made as per a factorial randomised complete block design (two factors) with 15 treatment combinations and replicated thrice. The two factors were Factor A – Five different spacings *viz*., S_1- 60 cm × 30 cm, S_2-75 cm × 15 cm, S_3- 75 cm × 30 cm, S_4- 90 cm × 15 cm and S_5- 90 cm × 30 cm, Factor B- three nutrient levels (N_1 - 60 kg ha^{-1}, N_2 - 80 kg ha^{-1} and N_3 - 100 kg ha^{-1}) applied based on N equivalent. The soil was ploughed; farmyard manure @ 10 t ha^{-1} was commonly applied in all the treatments before 15 days of sowing. Chia (Local variety) was line sown with a spacing according to the treatment in each plot. Nutrients were applied on an N equivalent basis through 2 nutrient sources, *i.e.*, Farm yard Manure (FYM), Vermicompost (VC), after analysing the concentration of nutrients present in them. 75 per cent of N is supplied through FYM as the basal dose, and 25 per cent of N was supplemented through top dressing of VC at 30 DAS. Irrigations were given based on the crop requirement. Developmental analysis, *i.e.*, days to fifty per cent flowering and maturity, was calculated by considering the day from which plants start flowering or maturity to the day when 50 per cent of the plant population attains flowering or maturity from each net plot and expressed in days. The total number of spikes plant^{-1}, spike length (cm) of randomly selected 5 plants from the net plot were counted, and the mean was computed in each treatment. The one thousand seeds were counted with the help of an electric seed counter from a randomly drawn sample from each treatment. The weight of the sample was recorded and expressed as test weight in grams (g). The grain weight of sundried seed from five plants, which were taken, and the average of the five plants was considered as the seed yield plant^{-1} in grams. Crop from each net plot was harvested manually when the spikes attained maturity and threshed separately and weighed according to treatments and computed on a hectare basis. The meteorological data pertaining to daily maximum as well as minimum temperatures and Bright Sunshine hours (BSS) were recorded during the crop period at the RIOF unit, UAS, GKVK, Bangalore. The Growing Degree Days (GDD) from time of sowing to harvest were calculated by summation of daily mean temperature above base temperature, taking 10^{0}C as base temperature for the Chia crop (Ahmed *et al*., 2020). Agrometeorological indices were calculated using equations detailed below on a daily basis and accumulated from sowing to harvesting as per Kumar and Kumar (2022).

$$\text{Growing Degree Days (GDD)} = \sum_{i=1}^{n} \left\{ \frac{T_{Max} + T_{Min}}{2} \right\} - T_b$$

T_{max} = Maximum temperature, T_{min} = Minimum temperature, T_b = Base temperature

Helio Thermal Unit (HTU) = Growing Degree Days (GDD) × Bright sunshine hours (BSS)

Thermal Use Efficiency (TUE) = Seed or Haulm yield (kg ha^{-1}) /Accumulated GDD

Helio Thermal Use Efficiency (HTUE)= Seed or haulm yield (kg ha^{-1}) / Accumulated HTU

The data recorded from the experiment were subjected to analysis by statistical procedures as described by Gomez and Gomez (1984). If the F-test was found significant for comparison among treatment means, an appropriate value of critical difference (CD) was worked out. Otherwise, the Non-Significant (NS) was indicated against the CD values.

Results and Discussion

Developmental analysis based on spacing and organic nutrients

The pooled data on development (Days to fifty per cent flowering and maturity) of the crop as affected by various spacings and levels of organic nutrients is presented in Table 1. The data revealed that spacing did not show any significant influence on days to fifty per cent flowering and maturity of Chia; however, spacing of 90 cm × 30 cm took 63 days and 81 days to attain fifty per cent flowering and maturity, respectively, which were 2 days and 6 days higher than the other treatments. The results corroborate the results of Sarala *et al*. (2020). The data also signified that the organic nutrient levels showed a significant influence on the development of the crop. Addition of 100 kg N equivalent ha^{-1} led to significantly more number of days to attain fifty per cent flowering and maturity (62 and 81 days, respectively), which was on par with N_2 and the number of days to development was recorded as fewer with N_1. These results are in line with the research analysis of Swathi *et al*. (2020). The interaction between various spacing and organic nutrient levels on the development of the crop

Table 1 : Influence of different spacings and organic nutrient levels on development and yield of Chia (Pooled data of two seasons).

Spacings	Days to fifty per cent flowering				Days to maturity				Seed yield (Kg ha^{-1})				Haulm yield (Kg ha^{-1})			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
S_1	56.23	61.02	61.12	**59.46**	73.87	80.92	81.90	**78.90**	804	1011	1026	**947**	1541	1745	1747	**1678**
S_2	53.63	58.90	58.98	**57.17**	70.90	78.08	79.20	**76.06**	885	1069	1083	**1012**	1659	1828	1835	**1774**
S_3	56.63	63.17	64.06	**61.29**	77.18	81.74	82.98	**80.63**	794	974	980	**916**	1539	1698	1724	**1654**
S_4	55.45	60.65	60.94	**59.01**	73.87	79.15	80.29	**77.77**	831	1088	1377	**1099**	1579	1853	2132	**1855**
S_5	58.26	64.27	66.65	**63.06**	78.13	82.98	84.38	**81.83**	712	899	927	**846**	1486	1671	1685	**1614**
Mean	**56.04**	**61.60**	**62.35**		**74.79**	**80.57**	**81.75**		**805**	**1008**	**1078**		**1561**	**1759**	**1825**	
	S. Em ±		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**	
Spacing (S)	2.03		**NS**		2.23		**NS**		32.34		93.69		57.34		166.11	
Nutrient level (N)	1.57		4.55		1.73		5.01		25.05		72.57		44.42		128.67	
Interaction (S×N)	3.51		**NS**		3.86		**NS**		56.01		**NS**		99.32		**NS**	

Note : S_1: 60 cm × 30 cm, S_2: 75 cm × 15 cm, S_3: 75 cm × 30 cm, S_4: 90 cm × 15 cm, S_5: 90 cm × 30 cm
N_1: 60 kg N equivalent ha^{-1}, N_2: 80 kg N equivalent ha^{-1}, N_3: 100 kg N equivalent ha^{-1}, **DAS** = Days after sowing.

was reported to be non-significant. Lesser competition for resources, especially N, in wider spacing compared to closer spacing might have prolonged the days to attain fifty per cent flowering and maturity (Bhaskaran *et al.*, 2020). Higher N application provides more opportunity for photosynthesis to occur in the plant; besides, it might have a prolonged number of calendar days for vegetative growth and time to complete the life cycle (Dar *et al.*, 2024).

Analysis of the yield based on spacing and organic nutrients

Yield attributes and yield were significantly influenced by spacing and organic nutrient levels (Table 2). Significantly higher numbers of spikes plant^{-1} (29.26), spike length (22.04 cm) and seed yield plant^{-1} (25.77 g) were observed in S_5, which was found on par with S_3 and 10 to 26 per cent more than S_1. The results are in accordance with the findings of Joshi and Patel (2021). The pooled data also signified that spacing had no significant influence on test weight, but numerically higher values were recorded with S_5 (1.75 g), followed by S_3, and lower test weight was recorded with S_1. Higher seed yield (1099 kg ha^{-1}) and haulm yield (1855 kg ha^{-1}) were observed in spacing of 90 cm × 15 cm, which was on par with S_2 because of a greater number of plants in a unit area. Similar reports were made by Ganvit *et al*. (2019). Significantly higher number of spikes plant^{-1} (29.05), spike length (21.46 cm), the seed yield plant^{-1} (24.47 g), test weight (1.69 g), seed yield (1078 kg ha^{-1}) and haulm yield (1825 kg ha^{-1}) were with N_3, which was found on par with N_2. Lesser yield attributes were obtained in N_1. The Interaction between spacing and organic nutrient levels on attributes and yield of Chia was found to be non-significant. More yield attributes in 90 cm × 30 cm might be due to a greater number of branches plant^{-1}and leaves plant^{-1}, besides lesser competition among the individual plants, which had an edge in production of more reproductive parts compared to closer spacing (Sahoo *et al.*, 2024). The organic acids and plant growth promoting factors by beneficial microbes in FYM and VC might have improved the root activity and enhanced the absorbed ions to release slowly during entire growth period coinciding the physiological needs of crop which might have effectively established good source and sink relationship by effective translocation of photosynthates to reproductive parts leading to more yield attributes as well as higher seed yield (Toor *et al*., 2021).

Influence of agrometeorological indices on seed yield under different spacings and organic nutrient regimes

The agrometeorological indices provide a reliable index for the growth and development of the crop. The relation between GDD, HTU and seed yield was correlated for both years (Figs. 1 and 2). A good linear positive relation existed between GDD, HTU and seed yield. The seed and haulm TUE and HTUE were significantly influenced under different spacing and levels of nutrients (Table 3). Significantly higher TUE of grain and haulm (0.71 and 1.16 kg ha^{-1} ^{0}C day^{-1}, respectively) and HTUE of grain and haulm (0.097 and 0.158 kg ha^{-1}

Table 2 : Influence of different spacings and organic nutrient levels on yield attributes of Chia (Pooled data of two seasons).

Spacings	Number of spikes plant^{-1}				Spike length (cm)				Test weight (g plant^{-1})				Seed yield plant^{-1} (g)			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
S_1	20.15	24.28	26.27	**23.56**	11.34	18.73	18.81	**16.29**	1.41	1.60	1.60	**1.54**	17.44	20.64	20.85	**19.64**
S_2	20.61	26.94	27.32	**24.96**	12.26	19.43	20.07	**17.26**	1.41	1.61	1.63	**1.55**	17.53	21.49	21.64	**20.22**
S_3	23.36	29.76	29.94	**27.69**	15.12	22.45	23.18	**20.25**	1.55	1.66	1.68	**1.63**	19.60	26.82	27.51	**24.64**
S_4	21.51	29.15	29.73	**26.80**	12.78	20.01	20.21	**17.67**	1.52	1.64	1.66	**1.60**	17.83	22.27	23.41	**21.17**
S_5	23.82	31.98	31.99	**29.26**	16.98	24.10	25.03	**22.04**	1.58	1.78	1.90	**1.75**	20.17	28.18	28.95	**25.77**
Mean	**21.89**	**28.42**	**29.05**		**13.70**	**20.94**	**21.46**		**1.49**	**1.66**	**1.69**		**18.51**	**23.88**	**24.47**	
	S. Em ±		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**	
Spacing (S)	0.92		2.24		0.85		2.48		0.05		**NS**		0.75		2.17	
Nutrient level (N)	0.72		2.07		0.66		1.92		0.04		0.10		0.58		1.68	
Interaction (S×N)	1.60		**NS**		1.48		**NS**		0.08		**NS**		1.30		**NS**	

Note : S_1: 60 cm × 30 cm, S_2: 75 cm × 15 cm, S_3: 75 cm × 30 cm, S_4: 90 cm × 15 cm, S_5: 90 cm × 30 cm
N_1: 60 kg N equivalent ha^{-1}, N_2: 80 kg N equivalent ha^{-1}, N_3: 100 kg N equivalent ha^{-1}, **DAS** = Days after sowing.

Table 3 : Influence of different spacings and organic nutrient levels on agrometeorological indices of Chia (Pooled data of two seasons).

Spacings	Thermal use efficiency (grain)(Kg/ha/^{0}C day)				Thermal use efficiency (haulm)(Kg/ha/^{0}C day)				Helio thermal use efficiency (grain) (Kg/ha/ ^{0}C day hrs.)				Helio thermal use efficiency (haulm) (Kg/ha/^{0} C Day hrs.)			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
S_1	0.60	0.61	0.64	**0.62**	1.04	1.04	1.09	**1.05**	0.080	0.080	0.090	**0.083**	0.142	0.142	0.149	**0.144**
S_2	0.65	0.65	0.82	**0.71**	1.10	1.11	1.26	**1.16**	0.090	0.090	0.110	**0.097**	0.149	0.151	0.174	**0.158**
S_3	0.55	0.58	0.59	**0.57**	1.01	1.02	1.03	**1.02**	0.080	0.080	0.080	**0.080**	0.137	0.138	0.140	**0.138**
S_4	0.50	0.53	0.54	**0.52**	0.94	0.99	1.00	**0.98**	0.070	0.070	0.070	**0.070**	0.129	0.135	0.136	**0.133**
S_5	0.43	0.47	0.48	**0.46**	0.89	0.94	0.92	**0.92**	0.060	0.060	0.070	**0.063**	0.121	0.125	0.125	**0.124**
Mean	**0.55**	**0.57**	**0.61**		**0.99**	**1.02**	**1.06**		**0.076**	**0.076**	**0.084**		**0.136**	**0.138**	**0.145**	
	S. Em ±		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**		**S. Em ±**		**CD (p=0.05)**	
Spacing (S)	0.02		0.06		0.02		0.06		0.003		0.008		0.003		0.010	
Nutrient level (N)	0.02		0.04		0.02		0.05		0.002		0.006		0.003		0.007	
Interaction (S×N)	0.03		**NS**		0.04		**NS**		0.005		**NS**		0.006		**NS**	

Note: S_1: 60 cm × 30 cm, S_2: 75 cm × 15 cm, S_3: 75 cm × 30 cm, S_4: 90 cm × 15 cm, S_5: 90 cm × 30 cm
N_1: 60 kg N equivalent ha^{-1}, N_2: 80 kg N equivalent ha^{-1}, N_3: 100 kg N equivalent ha^{-1}, **DAS** = Days after sowing.

°C hr^{-1}, respectively) were recorded with S_2, whereas lower TUE and HTUE were observed with S_5. The results are in close agreement with the findings of Bharat *et al*. (2022). The data also revealed that N_3 has recorded higher TUE of grain and haulm (0.61 and 1.06 kg ha^{-1} ^{0}C day^{-1}, respectively) and was found to be on par with N_2, and lower was recorded in N_1. Application nutrients through N_3 recorded a higher HTUE of grain (0.084 kg ha^{-1} ^{0}C hr^{-1}) and lower was with N_1. Higher HTUE of haulm was observed with N_3(0.145 kg ha^{-1} ^{0}C hr^{-1}) and found on par with N_2, whereas lower HTUE was observed with N_1(0.136 kg ha^{-1} ^{0}C hr^{-1}). The results corroborate the results of Morsy *et al*. (2022). The interaction effect between spacing, organic nutrient levels and agrometeorological indices was found to be non-significant. Higher plant population of Chia crop in S_2 spacing than in S_5, prolonged phenophases with increased supply of nutrients from N_3 to N_1 might have resulted in

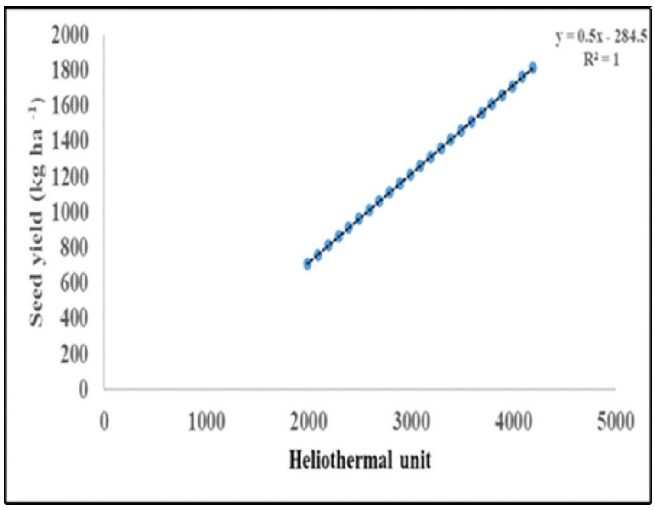


Fig. 1 : Relationship between Seed yield (Kg ha^{-1}) and growing degree of Chia crop during both seasons (*Rabi* 2020-21 and *Rabi* 2021-22).

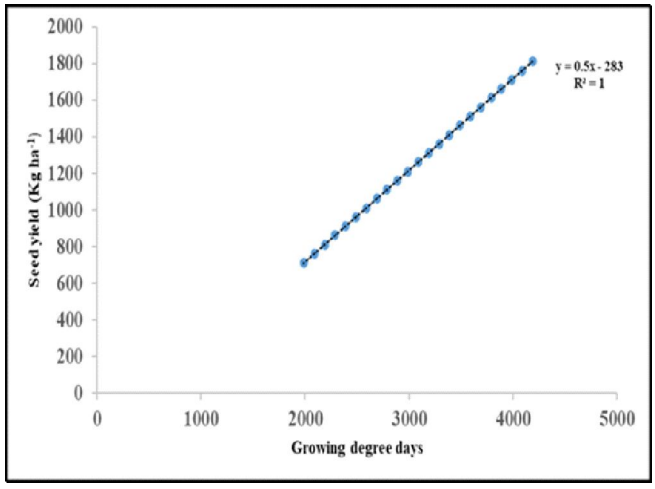


Fig. 2 : Relationship between Seed yield (Kg ha^{-1}) and heliotheral units of Chia crop during both seasons (*Rabi* 2020-21 and *Rabi* 2021-22).

higher dry matter accumulation, more accumulated GDD, grain and haulm yield, which in turn reflected in higher agrometeorological indices values (Singh *et al*., 2021; Swetasree *et al*., 2024).

Conclusion

Planting of Chia crop under wider row spacing of 90 cm × 30 cm with 100 kg N ha^{-1} has resulted in significantly higher yield attributes and a longer number of days to development compared to the crop sown under narrow row spacing and a lower nutrient regime. Higher seed yield under 90 cm × 15 cm and 75 cm × 15 cm besides application of higher nutrients, can be positively correlated with more plant population and availability of more nutrients. Temperature changes during the crop cycle not only influence crop phenophases, but also affect the economic yield. A strong positive linear correlation was observed between seed yield and agromet indices (GDD and HTU). Narrow row spacing of 75 cm × 15 cm under a higher nutrient regime of 100 kg N ha^{-1} resulted in higher grain and haulm TUE, HTUE. However, all the interaction effects were found to be non-significant. Under the present scenario of declination of soil fertility, cultivation of nutraceuticals like Chia under standard crop geometry and organic nutrient sources using the agromet indices will be indispensable for sustainable cultivation of crops.

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