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Irrigation and intercropping affects the seed yield, WUE and economics of chia based intercropping with vegetables in semi-arid regions

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Abstract
Intercropping systems provide vast opportunities for farmers to get additional yield and income from component crops and are contingent against crop loss. This cropping system also enables efficient use of resources even under scarce conditions. Therefore, the study aimed to determine the effect of irrigation and intercropping on yield, water use efficiency, and economic viability of chia based cropping system. The field experiment was conducted with full (I_{100}) and deficit irrigation (I_{50}) and six intercrops in split plot design with 3 replications. Results demonstrated that deficit irrigation of 50% significantly reduced the chia seed yield (525 kg/ha) by 16% and vegetable yield by 24% compared to full irrigation (I_{100}). Among intercropping, chia + fenugreek resulted in higher chia equivalent yield (959 kg/ha) than other intercrops with high water use efficiency (3.61 kg ha mm^{-1}), net returns (0.91 lakhs/ha) and BC ratio (2.67) compared to chia monocrop. Therefore, it is concluded that the chia + fenugreek intercropping system is best for both sufficient and deficit irrigation for higher yield and income in semi-arid regions.

Keywords: Chia, deficit irrigation, intercropping and water use efficiency

Introduction
Chia (*Salvia hispanica* L.) is an emerging super food and medicinal plant of Lamiaceae family. The plant is native to Mexico and Guatemala and cultivated in several parts of the world for its seeds. The seeds are rich in medicinal properties, mainly for cardiovascular diseases, diabetes, constipation etc. the seeds are the richest source of omega-3 fatty acids, protein, and dietary fibre (Ayerza and Coates, 2011) [2]. The fibre on the seed coat forms a mucilaginous substance that is highly viscous, hygroscopic and adhesive and offers wide applicability in industries and medicine. Seeds also contain 20-36 per cent oil, rich in omega-3 content and unsaturated fatty acids (Ixtaina *et al*., 2011) [8].

Agronomic practices of chia in India are very less known, and its suitability was not studied for Indian conditions. Due to the increasing demand for chia in India and the international market, chia can be a potential crop for Indian soil and climatic condition. As a new crop to India, economic feasibility and suitability in semi-arid regions with limited irrigation needs to be addressed. In India, most of the land holdings are small and marginal in nature, and farmers depend on small holdings for their livelihood. Therefore, intercropping benefits chia growers in achieving economic befit with sustainable production. Chia is a wide-spaced crop (60 cm x 30cm) that offers potential scope for intercropping with very short-duration leafy vegetables by efficiently utilizing the initial soil moisture. This could bring additional income to farmers and be contingent on crop failures. Therefore it is hypothesized that chia can be used for growing short-duration leafy vegetables as intercrops, thereby maximizing economic benefit and water use efficiency. The objective of the study was to identify suitable and economical intercrop for chia under various irrigation regimes.

Material and Methods
A two years field experiment was conducted from November to February of 2020–21 and 2021–22 at ICAR-National Institute of Abiotic Stress Management, Pune, Maharashtra, India located at 18°09′30.62″N latitude and 74°30′30.08″E longitude situated at an altitude of 570 m above mean sea level. The experimental location falls under the water scarcity zone of Maharashtra in Deccan Plateau, hot and semi-arid climate (AER-6) and agro-climatic zone (AZ-95) in Western Maharashtra.

The experimental site has a semi-arid climatic condition with an annual average rainfall of 560 mm distributed over four months from June to September. The soil properties of the experimental field were medium black (sand, silt and clay, 54.2, 8.7, 37.1%, respectively) had pH 8.19; EC 0.24 dS m^{-1}; organic carbon 6.5 g kg^{-1}; available N, P_2O_5 and K_2O 175.0, 7.9 and 180 kg ha^{-1}, respectively.

The experiment was conducted using a split-plot design with two irrigation levels (50% CPE and 100% CPE) in main plots. In subplots, intercrops and their sloe propertions were included. The entire set of treatments was replicated three times. The chia is grown as the main crop, and in between chia, six intercrops like amaranthus, coriander, dill, spinach, radish and fenugreek were grown as intercrops. A subplot size of 3 m × 3 m was made, and a drip irrigation system raised the crop. A one-meter band was prepared to separate main plot and replication to enable easy movement and avoid water movement. Nutrient dose of 90:60:70 kg ha^{-1} N: P_2O_5: K_2O was applied through Urea DAP and MOP. During field preparation, a basal dose of nitrogen, entire P_2O_5 and K_2O was applied to the soil. The remaining dose of N for vegetables was applied 20 days after sowing as a top dressing. Main crop (chia) seeds were sown at 60cm x 30 cm spacing, whereas intercrops were sown in lines in between the main crop. Two lines of intercrops were sown in between two lines of the main crop. Irrigation was given through drip irrigation in which inline laterals of 16mm size were with drippers spaced at 30cm apart with a discharge rate of 4 liter hr^{-1}. The crop was irrigated based on cumulative pan evaporation at two levels of 50 and 100 per cent CPE. One common irrigation of 50 mm was given at the time of sowing for uniform seed germination and later irrigations were given as per the CPE recorded. The data collected on various morphological and yield parameters for two years were pooled for statistical analysis. Mean values were derived for each observation during both years and data were subjected to analysis of variance (ANOVA) and treatment means were compared using the least significant difference (LSD) at $P \leq 0.05$.

Results and discussion

Growth attributes

Irrigation levels and intercrops significantly ($p < 0.05$) influenced the growth attributes of chia such as plant height and leaf area per plant (LA) of chia (Table 1). Irrigation at 100 per cent CPE (I_{100}) produced the highest plant height (69.7 cm) and LA (703.4 cm^2) compared to deficit irrigation at 50 per cent CPE (62.0 cm and 598.7 cm^2, respectively). Previous researchers' findings supported the present results that the chia crop is susceptible to deficit moisture. Herman *et al*., (2016) [7] reported that 30-60 per cent deficit irrigation affected the transpiration and photosynthesis of chia, which might have reduced the chia growth. Similar observations were made in nigella (Ghamarnia *et al*. 2010) [4] and coriander (Harisha *et al*., 2019) [6].

Similarly, intercropping systems reduced the growth of chia compared to chia in sole cropping (Table 1). The plant (72.2cm) and leaf are per plant in sole chia crop was highest among cropping systems. However, the chia fenugreek system showed higher chia plant height and leaf area than other intercrops. Furthermore, the interaction of irrigation I_{100} + chia sole cropping achieved higher plant height (74.3 cm), LA (759.0 cm^2). It was also observed that chia + spinach (60.3cm) and chia + radish (59.6 cm) intercropping reduced the plant height of chia drastically due to strict competition. Our findings corroborate the results of Yildirim and Guvenc (2005) [16] and Ghawade *et al*. (2019) [5] that intercropping of radish affected the growth and biomass accumulation when intercropped with cabbage, fennel, and fenugreek, respectively. Besides the short duration (30-35 days) and leguminous nature of fenugreek, the chia's growth was supplemented due to the lesser competition. This benefit was also due to atmospheric nitrogen fixation and enhanced availability. Growth and biomass accumulation in fennel crops was reported when intercropped with leguminous species, such as fenugreek, on loamy sand soils (Verma *et al*., 2021) [14].

Seed yield and chia equivalent yield

Irrigation at I_{100} recorded higher chia seed yield (627 kg/ha) and chia equivalent yield (CEY) compared to deficit irrigation (Table 1). The chia sole crop (706 kg/ha) produced the highest seed yield. Among intercrops, the higher seed yield (628 kg/ha) and CEY (1663 kg/ha) was obtained in chia + fenugreek, followed by chia + coriander. Furthermore, the interaction of irrigation I_{100} + sole chia cropping achieved a higher seed yield (794 kg ha^{-1}). However, I_{100} - chia + fenugreek system was the next best in seed yield (693 kg ha^{-1}) compared to I_{100}-chia sole crop. Higher seed yield in the sole crop may be due to better plant growth and more photosynthetic surface area improved the yield traits resulting in higher seed yield. The higher production in chia monoculture may be due to the homogeneous growing condition and lesser interspecific competition (Xie and Kristensen, 2017). Another reason for less intercropping yield could be the competition for nutrients and water not faced by the sole crop. Radish and spinach intercropping drastically reduced the seed yield of chia due to stringent competition for nutrients and water. Better yield and yield traits were reported when intercropped with legumes in chilli + ground nut (Meundimath *et al*., 2019) [12] and fennel + fenugreek (Ghaderimokrim *et al*., 2022) [3]. Irrigation significantly affected the yield of vegetables and it was highest in I100. The reduction in vegetable yield due to deficit irrigation was 24% compared to I_{100}. The vegetable yield was higher in radish (11885 kg/ha), followed by spinach, dill, fenugreek, coriander, and amaranthus. The yield of all vegetables was found to be higher in I_{100}. Reduction in yield under I_{50} may be due to poor water availability and competition for space, water, and nutrients.

Table 1: Plant growth, yield and water use efficiency as influenced by irrigation and intercropping practices in chia

	Plant height (cm)	Leaf area (cm^2)	Seed yield (q/ha)	Vegetable yield (kg/ha)	CEY (Q/ha)	WUE (kg ha mm^{-1})
Irrigation regimes						
I_{50}	62.0b	598.7b	525b	5700b	7.47b	3.66a
I_{100}	69.7a	703.4a	627a	7482a	9.65a	2.81b
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Intercropping systems						
Chia + amaranthus	65.6b	604.7bc	550d	2202e	6.51e	2.51e
Chia + coriander	68.5ab	666.0b	604bc	4569d	8.86c	3.39b
Chia + dill	66.0b	662.1b	567cd	4975c	8.67c	3.27c
Chia + spinach	60.3c	587.2c	498d	5663b	8.34d	3.05d
Chia + radish	59.6c	582.5c	480d	11885a	9.36b	3.60a
Chia + fenugreek	68.7ab	721.4a	628b	4685d	9.59a	3.61a
Chia sole crop	72.2a	733.5a	706a	-	-	-
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction of irrigation x intercropping						
I_{50} chia+amaranthus	61.3e-g	589.5	525fg	2013h	6.37 h	3.01e-g
I_{50}-chia+coriander	63.0d-f	631.4	548d-f	4280de	8.00 e	3.93b
I_{50}- chia+dill	61.9e-g	598.4	529f	4127e	7.46 f	3.65c
I_{50}- chia+spinach	56.3fg	485.1	455 gh	4883d	6.29 h	3.06e
I_{50}- chia+radish	55.8g	499.3	437 h	10786b	8.76 d	4.30a
I_{50}- chia+fenugreek	65.5b-e	679.0	562 d-f	3383f	8.13 e	4.00b
I_{50}- chia sole	70.1a-c	707.9	617cd	-	-	-
I_{100} chia+amaranthus	69.9a-d	619.9	575d-f	2390g	6.86g	2.01i
I_{100}-chia+coriander	74.0a	700.5	659bc	4858	9.72c	2.85h
I_{100}- chia+dill	70.2a-c	725.7	604c-e	5823cd	9.88c	2.88gh
I_{100}- chia+spinach	64.4c-e	689.3	540ef	6443c	10.39b	3.03ef
I_{100}- chia+radish	63.3c-f	665.6	524fg	12984a	9.96c	2.90f-h
I_{100}- chia+fenugreek	71.9ab	763.8	693b	5988c	11.06a	3.21d
I_{100}- chia sole	74.3a	759.0	794a	-	-	-
P value	0.027	<.0001	0.006	<.0001	<.0001	<.0001

Water use efficiency

Water use efficiency calculated on CEY basis (Table 1) showed that irrigation at I_{50} achieved the highest WUE, 3.66 kg ha mm^{-1}. Intercropping also enhanced the WUE of these systems, and among them, the chia + fenugreek system (3.61 kg ha-mm^{-1}) achieved higher WUE, followed by chia + radish (3.60 kg ha-mm^{-1}). At I_{50} the radish intercropping recorded higher WUE, followed by fenugreek and coriander. The results indicate that these crops utilize moisture more efficiently than intercropping dill, amaranthus, and spinach. However, a limited quantity of water applied resulted in higher equivalent yields, further increasing water use efficiency (Meundimath *et al.*, 2019) [12]. Therefore, it is crucial to choose suitable intercrop when limited irrigation water is available to use water efficiently and produce a good yield. These findings confirm with Pankou *et al.*, (2021) [13] in the wheat + pea system and Amanullah *et al.*, (2016) [1] in pigeon pea and mungbean intercropping under limited irrigated conditions.

Economics

The economic viability of chia based intercropping system was calculated (Table 2). Irrigation at I_{100} showed the highest gross returns (Rs.1.09 l/ha), net returns (Rs.0.60 l/ha) and BC ratio (2.24 l/ha) compared to I_{50} realized gross returns (Rs.0.84 l/ha), net returns (Rs.0.37 l/ha) and BC ratio (1.81 l/ha).

Similarly, intercropping systems recorded higher returns than chia monocrop and all vegetables in sole proportion. The highest gross returns (Rs.1.47 l/ha), net returns (Rs. 0.91 l/ha) and BC ratio (2.66) resulted from chia + fenugreek system followed by chia + dill (gross returns of Rs.1.30 l/ha, net returns of Rs.0.78 l/ha and BC ratio of 2.58) and chia + coriander system (gross returns of Rs.1.30 l/ha, net returns Rs.0.76 l/ha and BC ratio (2.44) at both irrigation systems. These results indicate the profitable intercropping system like chia + fenugreek, chia+ dill and chia + coriander compared to chia sole crop and other intercrops for higher returns and BC ratio. These results indicate the profitable intercropping system like chia + fenugreek, chia+ dill and chia + coriander compared to chia sole crop and other intercrops for higher returns and BC ratio. The results of higher returns and BRC ratio in intercropping compared to sole crop aligns with earlier findings of Kumar *et al.*, (2018) [9] in coriander + fenugreek, Mehta *et al.* (2015) [11] in fennel and onion and Mehta *et al.* (2010) [10] in coriander + onion.

Conclusion

The study concluded that deficit irrigation of 50% significantly reduced the chia seed yield by 16% and vegetable yield by 24% compared to full irrigation (100%). Among intercropping systems, chia + fenugreek resulted in higher chia equivalent yield than other intercrops with high water use efficiency and net returns compared to chia monocrop. Therefore, it is concluded that the chia + fenugreek intercropping system is best for both sufficient and deficit irrigation for higher yield and income in semi-arid regions.

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