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Influence of Crop Geometry and Different Sources of Fertilizers on the Morphology and Yield Attributes of Spring Maize (*Zea mays* L.)

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ABSTRACT

Background: The rapid increase in population, urbanization and climate change have severely impacted global food production. Currently, global agriculture is facing a major threat due to erratic weather conditions, a decline in natural resources and deteriorating soil fertility. The efficient management and utilization of natural resources along with the applied fertilizers is essential at this point.

Methods: Considering the nature of situation, the field experiment was conducted in the spring season of 2022 and 2023 to evaluate the influence of crop geometry and various sources of fertilizers on the morphology and yield of spring maize. The field trial was carried out in the split-plot design with three types of crop geometry *i.e.*, 40 × 40 cm; 50 × 50 cm and 60 × 20 cm; and four different sources of fertilizers *i.e.*, nano fertilizers, ferti-capsule, customized fertilizers and normal fertilizers.

Result: The results revealed that the growth parameters like plant height (cm) and number of leaves were significantly affected under the treatment 6 (50 × 50 cm + nano fertilizers), while the grain yield and stover yield (kg/ha), were impacted by the treatment 10 *i.e.*, 60 × 20 cm + nano fertilizers. The employment of treatment 6 aided in enhancing the productivity per plant, while the former assisted in achieving the highest production per hectare.

Key words: Crop geometry, Customized, Ferti-capsule, Morphology, Nano fertilizers, Nutrients.

INTRODUCTION

Maize (*Zea mays* L.) is one of the crucial crops with a high range of adaptability, versatility and high yield potential that play a key role in ensuring global food security (Shiferaw *et al.,* 2011; Thejesh *et al*., 2024). With the depleting resources in the agriculture sector, utilizing resources effectively is vital. Crop geometry is one of the most effective methods because it enables plants to make better use of resources like sunlight, water and nutrients from the soil to achieve enhanced plant performance in terms of the growth, productivity as well as crop quality (Thakur *et al.,* 2020). Ensuring an optimal crop geometry implies that each plant receives enough light and helps to ensure that light is distributed uniformly (Mohan *et al.,* 2021). Wider planting allows for efficient resource utilization. Better sunlight interception and moisture aid in superior photosynthetic activity (Uphoff *et al.,* 2011), good plant-water relations and ultimately superior photoassimilates translocation from source to sink (Waghmare *et al.,* 2018; Aliveni *et al.*, 2025).

Fertilizers play a crucial role in providing essential nutrients to crop plants, enhancing their growth and yield. However, different types of fertilizers can have varying effects on plant performance (Balasubramanian *et al.,* 2023). Conventional fertilizers are most widely used. The fertilizer has less nutrient use efficiency (Alemayehu *et al.,* 2015) and most of the applied nutrients are lost in the form of various losses such as runoff, leaching, volatilization *etc*. They negatively impact the soil, degrade and lead to soil acidification, nutrient imbalances and fertility (Ju *et al.*, 2009). Nano fertilizers utilize nanoparticles to deliver nutrients to plants. These nanoparticles with a unit size of 1-100 nm are significantly smaller than conventional fertilizer particles, allowing for more efficient absorption by plant roots (Badawi *et al.,* 2022) and plant cells (Perez-de-Luque, 2017). Nutrients are released slowly, minimizing losses and environmental impact (Rathnayaka *et al.,* 2018) and improve plant resistance to stress and diseases. Due to the unique features like high surface-to-volume ratio and nanoscale regime, nano fertilizers are engrossing the attention (Kumar *et al.,* 2021).

Customized fertilizers are formulated to meet the specific nutrient needs of a particular crop or soil type by mixing two or more fertilizers which consist of all kinds of

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nutrient sources (including both macro and micro with or without inert material) (Rakshit *et al.,* 2012). Less fertilizer is used, reducing costs and environmental impact (Majumdar *et al*., 2018). Ferticapsule is a new technology in which the recommended dose of fertilizers is filled in the empty gelatin capsule. These prepared gelatin capsules are placed near the plant root zone similar to the band placement of fertilizers which acts as the powerhouse for nutrients by creating a microenvironment. Nutrients are more readily accessible to plant roots. So, the current research has been implemented with the objective to evaluate the influence of crop geometry and different sources of fertilizers on the morphology, yield and quality attributes of spring maize (*Zea mays* L.).

MATERIALS AND METHODS

Experimental details

The research trial was carried out at research farm, of the School of Agriculture, Lovely Professional University, Punjab, India during the spring season of the year 2022 and 2023. The soil of the research site was sandy loam texture with slightly alkaline in nature (7.8 pH); low level of available nitrogen (N) (210.74 kg/ha); high level of phosphorous (23.71 kg/ha) and moderate in potassium (171.26 kg/ha). The field trial was executed in split-plot design with the three main plots *viz*. S_1- 40 × 40 cm^2, S_2- 50 × 50 cm^2, S_3- 60 × 20 cm^2 and four sub-plots *viz*. F_1- Normal Fertilizer, F_2- Nano fertilizer, F_3- Ferti-capsules, F_4-Customized fertilizer in three replications after the randomization of treatments. Table 1 present detail of factors and treatment combinations applied during the experiment. Initially, with the help of a cultivator, the field was thoroughly ploughed to break the large clods followed by planking to ensure proper land levelling. Each replication divided into three main plots which were further divided into four sub-plots with a net plot size of 25 m^2. The variety (PMH-10) was selected for the experiment at a seed rate of 25 kg/ha. Recommended dose of N: P: K (120:60:40 kg/ha) was applied uniformly in all the plots given throughout the field trial period. Four representative plants were designated for sampling throughout the experiment from the center of each plot. The selected plants were tagged with indicative labels and used for recording the various observations related to morphological attributes *viz*. plant height (cm) and number of leaves were recorded separately. As the crop attained harvesting maturity, the crop was harvested from 3 m^2 of each plot. After being completely sun-dried, the cobs were threshed to separate the grains and, the stover was bundled and further weighed. The grain and yield were converted to tonnes per hectare (t/ha) after recorded for uniform analysis. Harvest index was computed with the formula mentioned below and expressed in per cent (%).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

The obtained data was subjected to analysis of variance (ANOVA) by using R studio statistical computing

Table 1: Description of the experimental factors and treatment combination.

	Treatment combination
T_1	40 × 40 cm + Normal fertilizers
T_2	40 × 40 cm + Nano fertilizers
T_3	40 × 40 cm + Ferti-capsule
T_4	40 × 40 cm + Customized fertilizers
T_5	50 × 50 cm + Normal fertilizers
T_6	50 × 50 cm + Nano fertilizers
T_7	50 × 50 cm + Ferti-capsule
T_8	50 × 50 cm + Customized fertilizers
T_9	60 × 20 cm + Normal fertilizers
T_{10}	60 × 20 cm + Nano fertilizers
T_{11}	60 × 20 cm + Ferti-capsule
T_{12}	60 × 20 cm + Customized fertilizers
Fertilizer	**Mode of application**
Normal fertilizers	Half of the dose of N and the full dose of P and K was applied as basal dose, while the rest of the dose of N was applied a 3 split doses at 45, 60 and 75 DAS
Nano fertilizers	Half of the dose of N, P and K was given along with the 1st irrigation, while the rest of the P and K dose was given as foliar spray at 30 DAS. The rest of N was given as a split dose foliar application at 30, 45 and 60 DAS.
Ferti-capsule	The recommended dose of N, P and K was filled to prepare N, P, K mix capsules that are applied as basal dose, while the neem-coated urea-filled capsules were applied at 45 DAS
Customized fertilizers	Normal doses of customized fertilizers are applied at basal dose while the rest of the dose of N was applied as splits as urea broadcasting at 45, 60 and 75 DAS.

software. The obtained results of treatments were tested by Duncan's multiple range test (DMRT) at the 5% level of significance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Morphological attributes

Plant height (cm)

The effect of crop geometry was found significant at all the growth stages (Table 2). The maximum plant height of 19.4, 77.2, 157.7 and 189.0 cm was recorded under S_2 while the minimum plant height of 15.7, 66.7, 145.4 and 176.7 cm was recorded under S_1 at 25, 50, 75 and 100 DAS respectively. Similarly, the different sources of fertilizers have shown their impact on plant height. The maximum plant height of 19.6, 77.6, 158.2 and 189.1 cm was recorded under nano fertilizers and minimum plant height of 15.4, 66.5, 144.4 and 176.1 cm was recorded under F_1 at 25, 50, 75 and 100 DAS respectively. The interaction effect of both factors on plant height was found to be statistically significant at 25 DAS (Fig 1). The maximum plant height of 20.7 cm was recorded under T_6, where T_7 and T_2 shared statistical parity with T_6. However, at other growth stages the data was found to be non-significant. An increase in plant height of 32.3%, 23.7%, 13.6% and 10.7% was recorded at 25, 50, 75 and 100 DAS respectively under T_6 over the T_9.

The application of nano fertilizers through irrigation *i.e.*, fertigation during the initial growth stages might have positively affected the plant height (Reddy *et al.,* 2022). More precision of foliar application of nano fertilizers at later stages has aided in efficient absorption and nutrient use efficiency (Maheta *et al.,* 2023). The improved and continuous nutrient availability through nano sources at diverse physiological stages could have perhaps amplified the metabolic processes (cell division, cell respiration, cell elongation) (Meena *et al.,* 2023). They might have provided balanced crop nutrition and promoted auxin synthesis in maize, which resulted in superior plant height (Rashmi *et al.*, 2023). There was a lesser impact of spacing at 25 DAS when compared to the other growth intervals at which the good foliage cover was recorded. The wider plant spacing might have promoted the plant height by reducing the competition among plants for essential resources like light, water nutrients and space *etc.* Increased light interception enhanced photosynthesis activity and growth hormone production that promoted cell elongation (Meena *et al.,* 2022). Improved nutrient and water absorption by roots resulted in improved nutrient content and better plant-water relations. Lower ethylene accumulation due to wider spacing, perhaps permitted the plant to focus on vertical growth which helped in attaining a virtuous plant height. Similar outcomes were obtained by (Akpan *et al.,* 2021).

Number of leaves

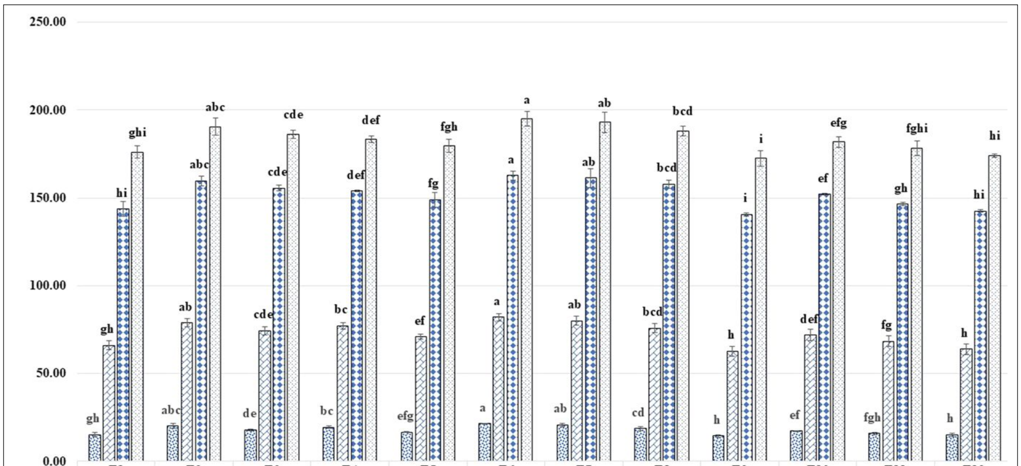
The different crop geometries were effective in amplifying the leaf number at all the growth stages (Table 2). The maximum number of leaves (6.6, 9.9, 14.5 and 13.8) were recorded under S_2, while the minimum (6.7, 9.9, 14.5 and 13.8) were

Table 2: Impact of crop geometry and different fertilizer sources on the plant height (cm), number of leaves, grain yield, stover yield and harvest index of spring maize at 25, 50, 75 and 100 DAS.

Factors	Plant height (cm)				Number of leaves				Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
Crop geometry	25 DAS	50 DAS	75 DAS	100 DAS	25 DAS	50 DAS	75 DAS	100 DAS			
S_1 40 × 40	18.19	74.06	153.18	184.06	5.81	9.41	13.96	13.21	8.85	14.84	37.33
S_2 50 × 50	19.37	77.24	157.71	188.99	6.60	9.90	14.51	13.78	8.00	13.74	36.67
S_3 60 × 20	15.68	66.68	145.40	176.70	4.54	8.12	13.26	12.27	9.70	15.80	37.90
CD (at p≤0.05)	0.638	3.325	2.812	6.068	0.162	0.668	0.425	0.712	0.594	0.289	NS
SEm (±)	0.158	0.825	0.697	1.505	0.040	0.166	0.106	0.177	0.147	0.072	0.406
Fertilizer sources											
F_1 Normal fertilizer	15.43	66.53	144.38	176.07	4.00	7.89	13.24	12.24	7.92	13.60	36.76
F_2 Nano fertilizer	19.60	77.64	158.18	189.12	6.75	9.92	14.52	13.83	9.74	15.83	37.91
F_3 Ferti-capsules	18.20	74.20	154.49	185.93	6.11	9.48	14.11	13.37	9.25	15.46	37.37
F_4 Customized fertilizer	17.75	72.28	151.34	181.87	5.74	9.29	13.78	12.91	8.49	14.29	37.16
CD (at p≤0.05)	0.856	2.487	2.848	3.497	0.676	0.520	0.449	0.584	0.363	0.307	NS
SEm (±)	0.286	0.830	0.951	1.168	0.226	0.174	0.150	0.195	0.121	0.102	0.395
A × B	1.425	NS	NS	NS	1.025	1.017	NS	NS	NS	0.539	NS

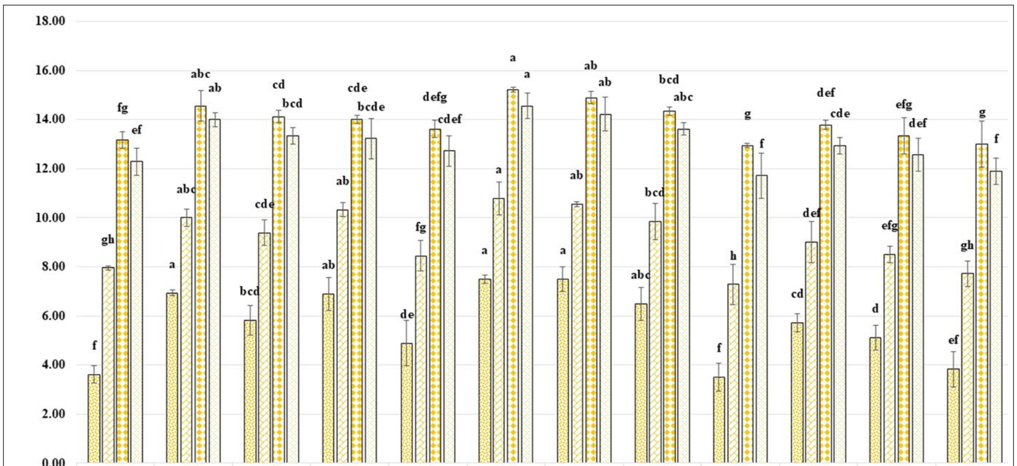
recorded under S_1 at 25, 50, 75 and 100 DAS respectively. The different sources of fertilizers have shown their effect on augmenting the leaf count. The maximum number of leaves (6.7, 9.9, 14.5 and 13.8) were obtained under F_2 and the minimum number of leaves (4.0, 7.9, 13.2 and 12.2) were obtained under F_1 at 25, 50, 75 and 100 DAS respectively. The interaction effect of both factors was found non-significant at all the growth stages except at 25 DAS (Fig 2). The maximum number of leaves (7.5) was recorded under T_6 and T_7. While the minimum number of leaves (3.5) was recorded under T_9. However, the treatments T_2 and T_8 have shared statistical parity with T_6. An increase in the leaf count of 53.3%, 32.4%, 14.9% and 19.9% was recorded at 25, 50, 75 and 100 DAS respectively under T_6 over T_9.

The residues of nano fertilizers in the soil due to the application through irrigation might have enriched the rhizosphere with nutrients which improved nutrient uptake due to targeted nutrient delivery. Especially the N that is crucial for chlorophyll synthesis and assisted in the growth of more leaves as the plant has more energy and resources to allocate for superior leaf and biomass production (Rashmi *et al.*, 2023). The nano fertilizers could have assisted plants to withstand environmental stress by enabling the effective physiological responses of a healthier plant and enhanced stress resistance that has resulted in more leaves (Reddy *et al.,* 2022; Meena *et al.,* 2023). Initially, the influence of spacing was less due to less foliage development and competition. At later growth stages, the wider spacing might have reduced competition



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
25 DAS	15.18	20.16	17.96	19.45	16.62	21.44	20.72	18.70	14.51	17.21	15.91	15.09
50 DAS	66.04	78.88	74.27	77.07	70.94	82.1	80.05	75.88	62.62	71.93	68.3	63.89
75 DAS	143.59	159.69	155.62	153.83	149.00	162.75	161.37	157.72	140.57	152.09	146.49	142.46
100 DAS	176.11	190.53	186.31	183.29	179.66	195.03	193.11	188.15	172.44	181.80	178.38	174.18

Fig 1: Impact of interaction of crop geometry and different fertilizer sources on the plant height (cm) of spring maize.



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
25 DAS	3.61	6.93	5.83	6.89	4.89	7.50	7.50	6.50	3.50	5.72	5.11	3.83
50 DAS	7.95	10	9.39	10.33	8.45	10.78	10.56	9.84	7.28	9	8.5	7.72
75 DAS	13.17	14.56	14.11	14.00	13.61	15.22	14.89	14.33	12.95	13.78	13.33	13.00
100 DAS	12.28	14.00	13.34	13.22	12.72	14.56	14.22	13.61	11.72	12.94	12.56	11.89

Fig 2: Impact of interaction of crop geometry and different fertilizer sources on the number of leaves of spring maize.

that has enabled the plant to have more access to resources and good air circulation. The optimum plant growth curbed stress development and assisted the plants in prioritizing lateral growth along with vertical growth. Eventually, the effective utilization of resources might have helped in the generous foliage production by avoiding the premature die-off of leaves (Meena *et al.,* 2022).

Yield attributes

Grain yield (t/ha)

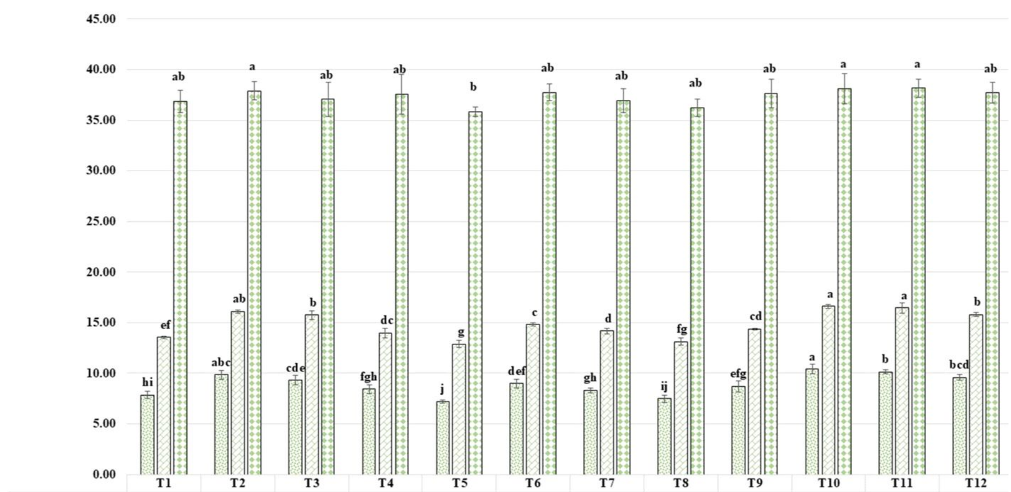
The implementation of crop geometries has shown its impact on amplifying the grain yield of spring maize (Table 2). The highest grain yield of 9.7 t/ha was recorded under S3 and lowest under S_2 (8.0 t/ha). Correspondingly, the different sources of fertilizers were effective in increasing the grain yield. The highest grain yield of 9.74 t/ha was recorded under F_2 and lowest under F_1 (7.9 t/ha). The interaction effect of both factors was found statistically non-significant (Fig 3). An increase in grain yield of 30.6% was recorded under T_{10} when compared to T_5.

Nano fertilizers are engineered to be more readily absorbed by plants due to their small size, larger surface area with controlled and slow release with targeted delivery (Rashmi *et al*., 2023). All these characteristic features might have ensured the accessibility of nutrients like N, P and K and their translocation throughout the cropping season that promoted growth and eventually yield (Maheta *et al.,* 2023). Use of conventional fertilizers often suffer from nutrient losses in the soil. In contrast, nano fertilizers might have maintained consistent growth, optimal grain filling and yield due to the slow release of nutrients in a controlled manner according to the requirement of the crop with targeted nutrient delivery (Parmeshnaik *et al.,* 2024). Plant population play a crucial role in obtaining superior grain yield. Closer spacing results in a higher number of plants per unit area, which might have potentially increased overall grain yield per hectare despite smaller ears, fewer and lighter kernels (Golla *et al.,* 2020). The 50 × 50 cm (with plant population: 40,000/ha) with 51.9% and 36% lesser plant population than 60 × 20 cm (with plant population: 83,333/ha) and 40 × 40 cm (with plant population: 62,500/ha) respectively has recorded superior growth and yield contributing attributes. Due to the smaller plant population, the overall grain yield has been impacted which ultimately led to lower grain yield (Hamid *et al.,* 2022).

Stover yield (t/ha)

The employment of different crop geometries has shown a positive impact on stover yield (Table 2). The highest stover yield of 15.8 t/ha was recorded under S_3 and lowest under S_1 (13.7 t/ha). The different sources of fertilizers have shown increment in the stover yield. The maximum stover yield of 15.83 t/ha was recorded under F_2 and minimum under F_1 (13.6 t/ha). The interaction effect of both factors was found to be statistically significant (Fig 3). An increase in the stover yield of 22.4% was recorded under T10 when compared to T_5. However, the treatment T_{11} and T_2 have shared statistical parity with T_{10}.

A similar trend of results as recorded for grain yield was found for stover yield. Nano fertilizers which show better efficiency in the use of nutrients due to their small particle size, led to better nutrient use efficiency, particularly N (Meena *et al.,* 2023). This might have supported the overall growth of a plant *i.e.*, stem elongation, leaf area *etc.* (Rashmi *et al*., 2023) that resulted in greater biomass accumulation and ultimately increased the stover yield when compared to the other fertilizer sources (Parameshnaik *et al.,* 2024). The wider plant spacing with more access to resources for each plant, might have helped to develop thicker stalks and larger leaves as the plants could have allocated more resources towards vegetative growth (Meena *et al.,* 2022). While in the closer spacing, the contrast conditions led to thinner



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Grain yield (t/ha)	7.85	9.85	9.30	8.42	7.22	8.99	8.33	7.48	8.69	10.40	10.15	9.59
Stover yield (t/ha)	13.56	16.09	15.75	13.97	12.90	14.80	14.19	13.11	14.37	16.62	16.46	15.81
Harevst index (%)	36.84	37.90	37.05	37.56	35.82	37.74	36.92	36.24	37.64	38.11	38.16	37.69

Fig 3: Impact of interaction of crop geometry and different fertilizer sources on the yield parameters of spring maize.

stalks and smaller leaves (Gaire *et al.,* 2020). Due to variation in the plant population in the three spacing patterns, the closer plant spacing with a higher plant population resulted in superior stover yield compared to wider plant spacing with a lesser population despite its good growth.

Harvest index (%)

The employment of different crop geometries has a non-significant influence on the harvest index (Table 2). The maximum harvest index of 37.90% was recorded under S3 and the minimum under S_2 (36.7%). The different sources of fertilizers have shown non-significant influence on harvest index. The highest harvest index of 37.9% was recorded under F_2, while the lowest recorded under F_4 (36.8%). The interaction effect of both factors was found to be statistically non-significant (Fig 3). However, the maximum harvest index of 38.2% was recorded under T_{11}, while the minimum stover yield of 35.8% was recorded under T_5.

The harvest index is the key parameter that defines the reproductive efficiency of plants. The application of nano fertilizers has promoted the harvest index when compared to other fertilizer sources (Parameshnaik *et al.,* 2024). This might be due to improved nutrient uptake, photosynthesis, reduced excessive vegetative growth as well as ensured efficient resource allocation towards grain production (Rashmi *et al.*, 2023). The impact of wider plant spacing was evident which resulted from the reduced competition for resources, improved photosynthetic efficiency and promoted better allocation of nutrients to grain production. This might have led to maximum grain yield per unit of biomass resulted in superior harvest index (Meena *et al.,* 2022).

CONCLUSION

The results of present experiment suggest that different crop geometries and fertilizer sources positively influenced the morphological characters and yield performance of maize. The application of nano fertilizers in combination with 50 × 50 cm and 60 × 20 cm plant spacing enhanced growth and yield attributes, respectively. The results revealed that wider spacing, when integrated with nano fertilizers, promoted efficient utilization of resources, better crop management, stress mitigation and reduced inter-plant competition. These factors collectively ensured improved nutrient translocation and plant-water relations, ultimately boosted the growth, yield and quality parameters of spring maize. Although the 50 × 50 cm spacing combined with nano fertilizers demonstrated superior productivity per plant, it is important to recognize that, from a farmer's perspective, overall yield and economic returns remain the primary considerations. Therefore, it is concluded that the treatment 60 × 20 cm + nano fertilizers was found effective in obtaining the highest grain yield of spring maize.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

NA

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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