Journal of Advances in Biology & Biotechnology

Volume 27, Issue 8, Page 387-398, 2024; Article no.JABB.119573
ISSN: 2394-1081

Standardization of Spacing and Fertilizer Levels for Growth, Yield and Flower Quality of French Marigold (*Tagetes patula* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i81151

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc. are available here: https://www.sdiarticle5.com/review-history/119573

Original Research Article

Received: 04/05/2024
Accepted: 09/07/2024
Published: 22/07/2024

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Cite as: *C.T., Pratheeksha, Balaji S. Kulkarni, Pavankumar P., Shirol A. M., Thammaih N., Satish D., and Sandyarani Nishani. 2024. "Standardization of Spacing and Fertilizer Levels for Growth, Yield and Flower Quality of French Marigold (Tagetes Patula L.)". Journal of Advances in Biology & Biotechnology 27 (8):387-98. https://doi.org/10.9734/jabb/2024/v27i81151.*

ABSTRACT

This study investigated the standardization of spacing and fertilizer requirements for optimizing the growth and flower quality of French Marigold (Tagetes patula L.). The primary objective was to identify the most effective treatment combination for maximizing farmer profitability and yield. The experiment utilized three fertilizer levels (F1: 225:60:60 NPK kg/ha, F2: 168.75:45:45 NPK kg/ha, F3: 112.5:30:30 NPK kg/ha) and three spacing levels (S1: 30 cm x 30 cm, S2: 45 cm x 30 cm, S3: 45 cm x 45 cm) in a factorial randomized block design with three replications. Results indicated that plant height increased with a decrease in spacing and an increase in fertilizer levels. The S1F1 treatment combination (30 x 30 cm spacing and 225:60:60 NPK kg/ha) exhibited higher plant height, plant spread, and the number of primary and secondary branches. Flower production was significantly influenced by a spacing of 30 x 30 cm and a fertilizer level of 225:60:60 NPK kg/ha. Higher levels of spacing and fertilizer, i.e., 45 x 45 cm spacing and a fertilizer level of 225:60:60 NPK kg/ha yielded superior results in terms of flowering duration, flower diameter, flower weight, and shelf life of the flowers on the plant.

Keywords: French marigold; plant spacing; NPK levels; flower yield; flower quality; flower shelf life.

1. INTRODUCTION

The marigold is a year-round commercial flower cultivated primarily for loose flower production, contributing significantly to its prominence in the domestic flower market. The diverse agroclimatic zones offer numerous natural advantages, including ample sunlight, optimal temperatures, and soil characteristics conducive to healthy plant growth. These zones are particularly promising for the cultivation of various marigold genotypes due to their unique climates and rich biodiversity. Marigold oil, known for its distinct aroma, serves as an effective repellent against flies [1]. Additionally, marigolds are recognized for their insect-repellent properties, reducing insect and nematode activity when grown in fields, which subsequently benefits subsequent crops. The cultivation of marigolds also provides economic opportunities, thereby partially alleviating unemployment issues in both public and private sectors.

The genus *Tagetes* comprises 33 species, but only two are cultivated commercially: *Tagetes erecta* L., known as the African marigold, and *Tagetes patula* L., known as the French marigold. Due to their diverse blossom heights and colors, these species are utilized in landscape architecture and for loose flower supply [2].

French marigolds are particularly valuable in landscaping for their vibrant colors, ranging from deep orange and red to bright yellow, and their natural insect-repellent properties, which enhance the health and vitality of neighboring plants. Their compact size and abundant blooming make them ideal for creating striking borders, filling gaps in garden beds, and adding pops of color to container gardens [3]. In addition to their aesthetic appeal, French marigolds repel harmful insects and attract beneficial pollinators, contributing to an ecologically balanced environment.

Nitrogen (N), phosphorus (P), and potassium (K) fertilizers are essential for optimal crop production, each serving distinct functions that collectively enhance plant growth and yield. Nitrogen is crucial for photosynthesis and protein synthesis, promoting vigorous vegetative growth and vibrant green foliage. Phosphorus is vital for energy transfer, root development, and the formation of flowers and seeds, ensuring robust early plant development and successful reproduction. Potassium regulates water and nutrient movement, strengthens stems, and enhances resistance to diseases and environmental stress, contributing to overall plant health and quality [4]. Together, these macronutrients support balanced nutrition, leading to higher crop yields and improved quality, making them fundamental components of agricultural productivity. Therefore, enhancing soil fertility through the judicious application of NPK fertilizers can substantially increase flower yield. Spacing also plays a critical role in achieving healthy vegetative growth and producing high-quality flowers. Wider spacing enhances the photosynthetic area and reduces nutrient competition, whereas closer spacing increases flower yield but can negatively affect vegetative growth. The interaction between fertilizers and plant spacing can significantly influence the growth and flowering behavior of marigold plants. Keeping this in view an experiment was carried out to study the effect of plant spacing and fertilizers levels on the productivity, nutrient accumulation (N and P) and k use efficiencies in French marigold.

2. MATERIALS AND METHODS

The experiment was laid out in the field during 2021-2022 by following recommended package of practices for spacing and fertilization [5].

List 1. Nutrients used in the study

Type of Application	Source of Nutrients	Nutrient Content
Soil Application	Urea	46% N
	SSP	16% P_2O_5
	MOP	60% K_2O

Crop : French marigold

Genotype : UHSFm 10

Design: Factorial RCBD

Treatments: 09

Replications: 03

Plot size: 3 x 4 m

Number of factors: Two

List 2. Treatment details

Factor 1: Spacing	Factor 2: Fertilizer levels
S_1: 30 x 30 cm	F_1: 100% RDF (225:60:60 NPK kg ha^{-1})
S_2: 45 x 30 cm	F_2: 75% RDF (168.75:45:45 kg NPK ha^{-1})
S_3: 45 x 45 cm	F_3: 50% RDF (112.5:30:30 kg NPK ha^{-1})

The treatment combinations are as follows:

T_1: S_1F_1 (30 x 30 cm + 100% RDF 225:60:60 NPK kg/ha)

T_2: S_1F_2 (30 x 30 cm + 75% RDF NPK kg/ha)

T_3: S_1F_3 (30 x 30 cm + 50% RDF NPK kg/ha)

T_4: S_2F_1 (45 x 30 cm + 100% RDF 225:60:60 NPK kg/ha)

T_5: S_2F_2 (45 x 30 cm + 75% RDF NPK kg/ha)

T_6: S_2F_3 (45 x 30 cm + 50% RDF 187.5:100:75 NPK kg/ha)

T_7: S_3F_1 (45 x 45 cm + 100% RDF 225:60:60 NPK kg/ha)

T_8: S_3F_2 (45 x 45 cm + 75% RDF NPK kg/ha)

T_9: S_3F_3 (45 x 45cm + 50% RDF 187.5:100:75 NPK kg/ha)

Seeds were sown in pro-trays, and one month later, the seedlings were transplanted into the main field with three spacing levels: S1 (30 cm x 30 cm), S2 (45 cm x 30 cm), and S3 (45 cm x 45 cm) according to the treatment plan. The experimental plots were enriched with well-decomposed FYM, half of the nitrogen dose, and the full doses of phosphorus and potassium as a basal application. The remaining half of the nitrogen dose was applied 30 days after transplanting. All cultural practices were performed uniformly.

Available nitrogen in the soil was determined using the alkaline permanganate method outlined by Subbiah and Asija [6]. Available phosphorus was estimated by the colorimetric method outlined by Olsen et al. [7], and available potassium was extracted with neutral normal ammonium acetate and quantified using a flame photometer, as suggested by Stanford and English [8], expressed in kg per hectare. Data on various growth and yield parameters were recorded from five tagged plants and analyzed statistically.

2.1 Growth Parameters

2.1.1 Plant height (cm)

Plant height was measured from the base to the tip of the main stem for all five tagged plants in each plot using a meter scale. The average plant height was then calculated in centimeters.

2.1.2 Plant spread (cm)

Plant spread was assessed from East-West and North-South directions by using a measuring scale and the mean plant spread was worked out for both East-West and North-South direction of plant spread**.**

2.1.3 Number of primary branches

Every branch which emerged from the main stem of the plant were counted manually and recorded. The observations were noted down from all the five tagged plants and then the mean number of primary branches were counted.

2.1.4 Number of secondary branches

The branches which were developed from primary branches were manually counted and then the average number of secondary branches were calculated by observing all five tagged plants in the plot.

2.2 Yield Parameters

2.2.1 Number of flowers per plant

The number of flowers per plant was counted from the five tagged plants from each replication till the final harvest and average was calculated.

2.2.2 Flower yield (g/plant)

After recording the number of flowers per plant, all the flowers were weighed separately at every harvest from each plant till the final harvest and the average flower yield per plant was calculated and expressed in grams per plant.

2.2.3 Flower yield (kg/plot)

Flower yield per plot was worked out by totaling the weight of flowers per plot, recorded and expressed in kilograms.

2.3 Quality Characters

2.3.1 Flower diameter (cm)

Diameter of the flower was measured at the point of maximum breadth at full bloom stage, this was measured by vernier caliper and average diameter was expressed in centimeter.

2.3.2 Shelf life (days)

Fully opened flowers were harvested from each plot and kept in paper plates in laboratory condition. Number of days was counted until the flowers lost their marketable quality.

2.3.3 Individual flower weight (g)

After recording the number of flowers per plant, the weight of individual flower was recorded in grams from the tagged plants and averages were worked out for individual flower weight.

2.4 Statistical Analysis

The recorded data were statistically analyzed (ANOVA analysis) using the software OPSTAT, (developed at O.P. Sheoran, Computer Section, CCS HAU, Hisar, India). Sources of variation were fertilizer treatments. Mean comparisons were performed using LSD test to determine whether the difference between the variables were significant at $P < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Growth parameters

Significant treatment differences were observed for plant height, plant spread, and number of branches due to varying levels of spacing and fertilizer application (Table 1).

At 90 days after transplanting (DAT), except for plant height, plant spread in both directions (E-W and N-S) was highest in S3 (45 × 45 cm spacing) at 32.95 cm and 29.68 cm, respectively, which was significantly greater than S2 (28.20 cm and 26.44 cm) and S1 (18.13 cm and 18.02 cm). Similarly, the number of primary and secondary branches was highest in S3 (14.03 and 29.79), significantly exceeding S2 (12.37 and 23.87). Plant height was highest in S1 at 40.71 cm (Table 1).

Regarding fertilizer doses, at 90 days after transplanting (DAT), maximum plant height (39.10 cm), plant spread in both directions (E-W: 32.03 cm, N-S: 30.01 cm), and number of primary and secondary branches (13.67 and 29.07) were recorded with F1, while the minimum values were observed with F3.

In terms of interactions, the combination of wider spacing with higher fertilizer dose (S3F1) showed plant spread in both directions (E-W: 34.93 cm, N-S: 31.74 cm) and a higher number of primary (14.80) and secondary branches (31.10).

Among the treatment combinations, maximum plant height (18.52 cm, 32.85 cm, and 43.82 cm) was recorded in S1F1 (30 × 30 cm + 225:60:60 kg NPK/ha) at 30, 60, and 90 DAT, respectively. The minimum plant height (13.60 cm, 20.19 cm, and 30.29 cm) was observed in S3F3 (45 × 45 cm + 50% RDF) at all stages.

The increase in plant height at closer spacing may be attributed to intense competition among plants for light, which encourages the elongation

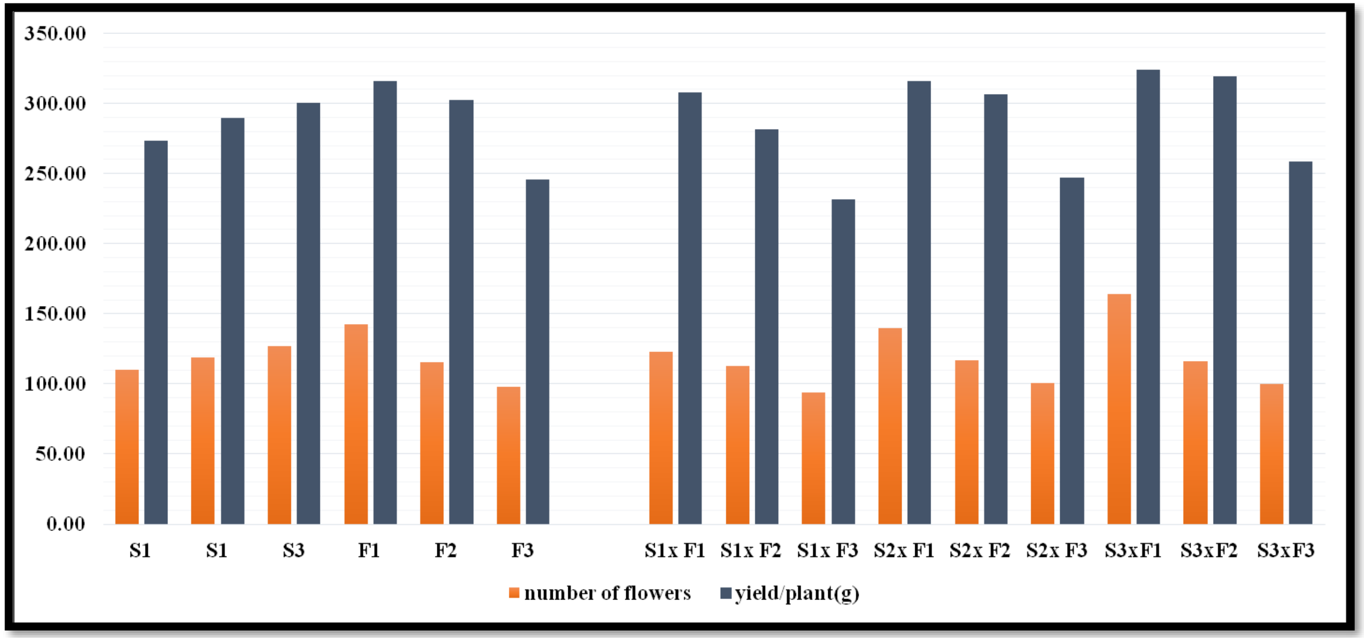

Fig. 1. Yield parameters as influenced by different levels of spacing and fertilizers in French marigold

S1 = 30 × 30 cm	*F1 = 225:60:60 kg NPK/ha*
S2 = 45 × 30 cm	*F2 = 168.75:45:45 kg NPK/ha*
S3 = 45 × 45 cm	*F3 = 112.5:30:30 kg NPK/ha*

Table 1. Effect of spacing and varied levels of NPK on plant height (cm) and plant spread (cm) in French marigold

	Plant Height (cm)				Plant Spread E-W (cm)				Plant Spread N-S (cm)			
	90 DAT				90 DAT				90 DAT			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
S_1	43.82	41.16	37.16	**40.71**	29.42	27.72	25.68	**27.61**	28.63	26.64	24.95	**26.74**
S_2	40.12	38.42	35.50	**38.01**	31.73	30.35	27.70	**29.95**	29.67	27.72	26.61	**28.00**
S_3	33.36	31.67	30.29	**31.77**	34.93	32.82	31.11	**32.95**	31.74	29.58	27.73	**29.68**
Mean	**39.10**	**37.08**	**34.32**		**32.03**	**30.30**	**28.19**		**30.01**	**27.98**	**26.43**	
	S. Em.±		**CD at 5%**		**S. Em.±**		**CD at 5%**		**S. Em.±**		**CD at 5%**	
Spacing (S)	1.05		3.14		0.89		2.69		0.77		2.32	
Fertilizer(F)	1.05		3.14		0.89		2.69		0.77		2.32	
S×F	1.81		5.43		1.55		4.65		1.34		4.02	

DAT-Days After Transplanting, NS- Non-Significant, F=NPK Levels, S=Spacing, SxF = Spacing x NPK Levels

F_1-225 :60:60 kg NPK ha^{-1} F_2-168.75:45:45 kg NPK ha^{-1} F_3- 112.5:30:30 kg NPK ha^{-1}

S_1- 30 X 30 cm S_2 – 45 X 30 cm S_3 - 45 X 45

Table 2. Effect of spacing and varied levels of NPK on number of branches in French marigold

	Number of Primary Branches				Number of Secondary Branches			
	90 DAT				90 DAT			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
S_1	12.50	11.70	**11.20**	**11.80**	26.70	25.30	24.90	**25.64**
S_2	13.70	12.90	12.10	**12.90**	29.30	28.00	26.20	**27.86**
S_3	**14.80**	13.90	13.40	**14.03**	**31.10**	30.06	28.20	**29.79**
Mean	**13.67**	**12.83**	**12.23**		**29.07**	**27.79**	**26.43**	
	S. Em.±		**CD at 5%**		**S. Em.±**		**CD at 5%**	
Spacing (S)	0.36		1.07		0.68		2.05	
Fertilizer(F)	0.36		1.07		0.68		2.05	
S×F	0.62		NS		1.18		3.54	

DAT-Days After Transplanting, NS- Non-Significant, F=NPK Levels, S=Spacing, SxF = Spacing x NPK levels

F_1-225 :60:60 kg NPK ha^{-1} F_2-168.75:45:45 kg NPK ha^{-1} F_3- 112.5:30:30 kg NPK ha^{-1}

S_1- 30 X 30 cm S_2 – 45 X 30 cm S_3 - 45 X 45 cm

Table 3. Effect of spacing and NPK levels on number of flowers/ plant and flower yield per plant (g) in French marigold

Spacing/ Fertilizer	Number of Flowers/Plant				Yield Per Plant(g/Plant)				Yield Per Plot(kg/Plant)			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
S_1	123.10	112.90	**93.60**	**109.87**	308.10	281.55	**231.30**	**273.65**	10.78	9.55	**7.87**	**9.40**
S_2	139.50	116.80	100.30	**118.72**	315.99	306.78	246.92	**289.90**	17.35	16.21	13.36	**15.64**
S_3	**164.10**	119.60	105.20	**129.63**	**323.84**	319.56	258.54	**300.70**	**27.05**	25.81	21.18	**24.68**
Mean	**142.08**	**116.43**	**99.70**		**316.03**	**302.63**	**245.59**		**18.39**	**17.19**	**14.14**	
	S. Em.±		**CD at 5%**		**S. Em.±**		**CD at 5%**		**S. Em.±**		**CD at 5%**	
Spacing (S)	3.51		10.55		6.44		19.35		0.54		1.63	
Fertilizer(F)	3.51		10.55		6.44		19.35		0.54		1.63	
S×F	6.01		18.06		11.17		33.49		0.93		2.81	

DAT-Days After Transplanting, NS- Non-Significant, F=NPK levels, S=Spacing, SxF = Spacing x NPK levels
F_1-225 :60:60 kg NPK ha^{-1} F_2-168.75:45:45 kg NPK ha^{-1} F_3- 112.5:30:30 kg NPK ha^{-1}
S_1- 30 X 30 cm S_2 – 45 X 30 cm S_3 - 45 X 45 cm

Table 4. Effect of spacing and NPK levels on quality parameters in French marigold

Spacing/ Fertilizer	Individual Flowers Weight (g)				Flower Diameter(cm)				Shelf Life(days)			
	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean	F_1	F_2	F_3	Mean
S_1	1.03	0.93	**0.85**	**0.94**	4.02	3.95	**3.61**	**3.86**	2.85	2.75	**2.30**	**2.63**
S_2	1.09	0.99	0.91	**1.00**	4.27	4.11	3.89	**4.09**	3.80	3.25	2.95	**3.33**
S_3	**1.15**	1.05	0.98	**1.06**	**4.52**	4.34	4.19	**4.35**	**3.95**	3.75	3.05	**3.58**
Mean	**1.09**	**0.99**	**0.91**		**4.27**	**4.13**	**3.90**		**3.53**	**3.25**	**2.77**	
	S. Em.±		**CD at 5%**		**S. Em.±**		**CD at 5%**		**S. Em.±**		**CD at 5%**	
Spacing (S)	0.02		0.08		0.11		0.37		0.08		0.27	
Fertilizer(F)	0.02		0.08		0.11		0.37		0.08		0.27	
S×F	0.04		0.14		0.19		0.58		0.16		0.47	

DAT-Days After Transplanting, NS- Non-Significant, F=NPK Levels, S=Spacing, SxF = Spacing x NPK levels
F_1-225 :60:60 kg NPK ha^{-1} F_2-168.75:45:45 kg NPK ha^{-1} F_3- 112.5:30:30 kg NPK ha^{-1}
S_1- 30 X 30 cm S_2 – 45 X 30 cm S_3 - 45 X 45 cm

Table 5. Available nutrient status of soil after harvest as influenced by different levels of spacing and fertilizer

Spacing/ Fertilizer	**N uptake kg/ha**				**P uptake kg/ha**				**K uptake kg/ha**			
	F_1	**F_2**	**F_3**	**Mean**	**F_1**	**F_2**	**F_3**	**Mean**	**F_1**	**F_2**	**F_3**	**Mean**
S_1	182.20	180.73	**179.50**	**180.58**	44.55	44.32	**44.03**	**43.97**	246.73	241.98	**237.90**	**241.97**
S_2	184.35	181.74	183.12	**183.00**	46.54	45.13	44.05	**45.47**	253.11	250.05	249.83	**250.33**
S_3	**186.69**	185.68	185.25	**185.87**	**50.34**	49.75	49.53	**49.87**	**262.98**	262.22	260.58	**262.82**
Mean	**184.41**	**182.71**	**182.62**		**47.15**	**45.99**	**45.87**		**255.79**	**251.42**	**249.44**	
	S. Em.±		**CD at 5%**		**S. Em.±**		**CD at 5%**		**S. Em.±**		**CD at 5%**	
Spacing(S)	0.30		0.90		0.32		0.95		1.67		5.01	
Fertilizer (F)	0.30		0.90		0.32		0.95		1.67		5.01	
S×F	0.52		1.57		0.55		NS		2.90		NS	

DAT-Days after transplanting, NS- Non-significant, F=NPK levels, S=Spacing, SxF = Spacing x NPK levels
F_1-225:60:60 kg NPK ha^{-1} F_2-168.75:45:45 kg NPK ha^{-1} F_3- 112.5:30:30 kg NPK ha^{-1}
S_1- 30 X 30 cm S_2 – 45 X 30 cm S_3 - 45 X 45 cm

of the main stem. Additionally, crowded conditions can lead plants to grow vertically due to the shading effects cast by neighboring plants. Nain et al. (2017) also reported maximum plant height at a closer spacing of 30 × 30 cm in marigold. These findings align with the results of Chauhan et al. [9], Meena et al. [10] in African marigold, and Sonara et al. [11] in marigold.

Regarding branches per plant and plant spread, the treatment combination S3F1 (45 × 45 cm, 225:60:60 kg NPK/ha) produced the highest values (26.10 and 29.85 cm), on par with S3F2 (45 × 30 cm, 168.75:45:45 kg NPK/ha). The minimum values (21.31 and 24.95 cm) were observed in the S1F3 (30 × 30 cm, 112.5:30:30 kg NPK/ha) combination (Table 2). This suggests that a closer spacing of 30 × 30 cm combined with enhanced nutrition resulted in the tallest French marigold plants. Conversely, a wider spacing of 45 × 45 cm with higher nutrition positively impacted all other growth parameters except for plant height.

3.2 Yield Parameters

Table 3 presents the data on flower yield, highlighting the effects of spacing, fertilizer, and their interactions. Spacing significantly influenced the number of flowers per plant. The maximum number of flowers per plant (129.63) was recorded with 45 × 45 cm spacing (S3), followed by 118.72 with S2 (45 × 30 cm) spacing, and the minimum (109.87) with S1 (30 × 30 cm) spacing. Among the fertilizer treatments, the highest number of flowers per plant (142.08) was recorded with F1 (225:60:60 kg NPK/ha), followed by 116.43 with F2 (168.75:45:45 kg NPK/ha), and the lowest (99.70) with F3 (112.5:30:30 kg NPK/ha). In terms of interactions, the maximum number of flowers per plant (164.10) was recorded with the S3F1 (45 × 45 cm, 225:60:60 kg NPK/ha) combination, while the minimum (93.60) was observed with the S1F3 (30 × 30 cm, 112.5:30:30 kg NPK/ha) combination.

Similarly, the maximum flower yield per plant (300.70 g) and per plot (24.68 kg) was recorded with S3 (45 × 45 cm) spacing, which was on par with S2 (45 × 30 cm) at 289.90 g/plant. The minimum flower yield per plant (273.65 g) was recorded with S1 (30 × 30 cm) spacing.

The highest flower yield per plant (316.03 g) and per plot (18.39 kg) was recorded in F1 (225:60:60 kg NPK/ha), followed by F2 (168.75:45:45 kg NPK/ha) with 302.63 g/plant, and the lowest yield was in F3 (112.5:30:30 kg NPK/ha) with 245.59 g/plant. The treatment combination S3F1 (45 × 45 cm, 225:60:60 kg NPK/ha) resulted in the maximum flower yield per plant (323.84 g) and per plot (27.05 kg), followed by S3F2 (45 × 45 cm, 168.75:45:45 kg NPK/ha) with 302.63 g/plant and 25.81 kg/plot. The lowest yield was observed in the S1F3 (30 × 30 cm, 112.5:30:30 kg NPK/ha) treatment combination.

Flower production in French marigold was significantly influenced by increasing spacing levels (Fig. 1). The number of flowers increased gradually as spacing increased from 30 × 30 cm to 45 × 45 cm, and a similar trend was observed for flower yield (g/plant). The maximum yield per plant at wider spacing might be due to the higher number of branches per plant, which leads to a greater number of flowers and increased flower yield per plant. Divyashree et al [12]. also reported higher yield and a maximum number of flowers at wider spacing (60 × 60 cm) in gaillardia. Similar results were found by Hugar [13] in gaillardia, Sharma et al. [14] in marigold, Dorajeerao et al. [15] in annual chrysanthemum, Kour et al. [16] in marigold, and Duggani et al. [17] in gomphrena.

3.3 Quality Parameters

The maximum individual flower weight was recorded at 1.06 g with 45 × 45 cm spacing (S3), followed by 1.00 g with S2 spacing (45 × 30 cm), while the minimum individual flower weight of 0.94 g was observed with S1 spacing (30 × 30 cm) (Table 4). Among the NPK levels, the highest individual flower weight was 1.09 g in F1 (225:60:60 kg NPK/ha), followed by 0.99 g in F2 (168.75:45:45 kg NPK/ha), and the lowest was 0.91 g in F3 (112.5:30:35 kg NPK/ha).

Among the different spacing treatments, 45 × 45 cm (S3) produced flowers with the highest diameter (4.35 cm), followed by S2 (45 × 30 cm) with 4.09 cm, while the smallest flower diameter (3.86 cm) was observed in S1 (30 × 30 cm). Varied NPK levels also had a significant influence on flower diameter. The maximum diameter (4.27 cm) was recorded in F1 (225:60:60 kg NPK/ha), followed by 4.13 cm in F2 (168.75:45:45 kg NPK/ha), and the minimum (3.90 cm) in F3 (112.5:30:30 kg NPK/ha). The largest flower diameter (4.52 cm) was observed in the treatment combination S3F1 (45 × 45 cm, 225:60:60 kg NPK/ha). However, this was statistically similar (4.34 cm) to the S3F2 combination (45 × 45 cm, 168.75:45:45 kg

NPK/ha), while the smallest diameter (3.61 cm) was recorded in the S1F3 combination (30 × 30 cm, 112.5:30:30 kg NPK/ha).

The maximum shelf life of the flowers (3.58 days) was observed with S3 spacing (45 × 45 cm), followed by S2 spacing (45 × 30 cm) with 3.33 days, and the minimum shelf life (2.63 days) was recorded with S1 spacing (30 × 30 cm). Similarly, the longest shelf life (3.53 days) was noted at the highest level of NPK (F1: 225:60:60 kg NPK/ha), followed by F2 (168.75:45:74 kg NPK/ha) with 3.25 days, and the shortest shelf life (2.77 days) was recorded with F3 (112.5:30:30 kg NPK/ha). The treatment combination S3F4 (45 × 45 cm, 225:60:60 kg NPK/ha) resulted in the maximum shelf life (3.95 days) of the flowers, followed by S3F2 (45 × 45 cm, 187.5:100:75 kg NPK/ha) with 3.75 days, and the shortest shelf life (2.77 days) was observed in the S1F3 (30 × 30 cm, 112.5:30:30 kg NPK/ha) combination.

Spacing plays a crucial role in producing quality flowers by ensuring adequate aeration and light during the flowering period. Duggani et al. [17] also found that all quality traits were highest with a wider spacing of 60 cm x 30 cm in gomphrena. This is primarily due to better nutrient availability and reduced competition between plants, resulting in larger and heavier flowers. The application of NPK may have enhanced photosynthesis by increasing the source size (number of branches and leaf size), thus providing more photosynthates to developing flowers and leading to greater cell division and expansion in flower tissues. Similar findings were reported by Hugar [13] in gaillardia, Chaudhary et al. [18] in annual chrysanthemum, and Munikrishnappa [19] in China aster.

3.4 Available Nutrient in Soil

A considerable disparity in nitrogen, phosphorus, and potassium concentration was observed. S3 (45 × 45 cm) had the greatest accessible nitrogen, phosphorus, and potassium levels (185.87, 49.87, and 262.82 kg ha^{-1}, respectively). S1 (30 × 30 cm) had the lowest nitrogen, phosphorus, and potassium availability (180.58, 43.97, and 241.97 kg ha^{-1}, respectively) (Table 5).

However, the available soil NPK was found maximum (184.41, 47.15 and 255.79 kg ha^{-1}) in treatment F_1 (225:60:60 N, P_2O_5, K_2O kg ha^{-1}). The results are in conformity with the findings of Mohanty et al. (2000) in tuberose, Samantaray et al. [20] in marigold. Among the interaction effect, S3F1 (45 cm × 45 cm: 225:60:60 kg NPK/ha) showed maximum available soil NPK.

The current study found that varied amounts of NPK had a substantial effect on nutrient availability in soil, with greater levels of NPK having the highest accessible soil NPK (225:60:60 kg/ha). The soil's increased availability of nitrogen as well as the external application of fertilizers with higher nitrogen and potassium contents and their preferred absorption may be the cause of this. Phosphorus and potassium's synergistic impact may also be the cause of the linear increase in nitrogen, phosphorus, and potassium concentration up to F1. The outcomes agree with those of Hugar and Nalawadi [21] with gaillardia, Karuppaiah and Krishna [22] regarding marigold, Airadevi [23] and Sanas et al. [24] regarding *Chrysanthemum coronarium* [25,26].

4. CONCLUSION

Based on the study findings, it can be inferred that utilizing a closer spacing of 30 × 30 cm combined with a higher dosage of nitrogen, phosphorus, and potassium (225:60:60 kg NPK/ha) was advantageous for achieving maximum number of flowers and flower yield per hectare. This spacing and nutrient combination likely facilitated optimal plant density and nutrient availability, thereby promoting higher flower production.

Conversely, employing a wider spacing of 45 × 45 cm alongside the same nutrient application (225:60:60 kg NPK/ha) was found to be optimal for promoting robust vegetative growth and ensuring superior quality of flowers. The wider spacing provided ample room for plant expansion and reduced competition for resources among plants, while the enhanced nutrient supply supported vigorous vegetative development and the production of high-quality flowers.

In conclusion, the choice between closer and wider spacing with specific nutrient levels should be guided by the desired outcome: closer spacing for maximizing flower yield per hectare and wider spacing for promoting strong vegetative growth and superior flower quality.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119573