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RESEARCH ARTICLE

Integrated organic nutrient management enhances chrysanthemum production and soil health in the sub-Himalayan plains

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Abstract

Chrysanthemum (*Chrysanthemum morifolium* Ramat.) or autumn queen, a member of the *Asteraceae* family, is widely cultivated and ranks second to rose among cut and loose flowers in the global floriculture market. However, concerns regarding residual chemical fertilisers in cut flowers pose significant challenges for export, especially as international markets increasingly favour organically cultivated produce. The present study aimed to evaluate the influence of various organic nutrient sources on the yield and quality parameters of spray chrysanthemum. The experiment was conducted using a factorial randomised block design (FRBD) with two factors: chrysanthemum variety (two levels) and organic nutrient sources (thirteen levels), replicated three times. Among the treatments, T_{12} (vermicompost at 5 t/ha + *Azotobacter* at 2 g/plant + PSB at 2 g/plant) resulted in superior performance across varieties, significantly enhancing vegetative growth, floral characteristics and soil nutrient status. The $V_1 \times T_{12}$ combination significantly enhanced vegetative growth, floral quality, phenological development and recorded the highest soil nitrogen (294.28 kg/ha), phosphorus (50.71 kg/ha) and potassium (273.26 kg/ha). In contrast, the control treatment (T_1) consistently exhibited the lowest values across the measured parameters. Implementing this integrated organic nutrient management protocol offers a sustainable, cost-effective approach to producing export-quality flowers while improving soil health and reducing reliance on synthetic fertilisers in the sub-Himalayan plains.

Keywords: *Azotobacter*; chrysanthemum; organic nutrient sources; vermicompost

Introduction

Chrysanthemum (*Chrysanthemum morifolium* Ramat.), commonly referred to as guldaudi in Hindi, is a widely cultivated ornamental plant of global significance, often referred to as the queen of the east and the autumn queen (1). The term Chrysanthemum is derived from the Greek words chrysos (gold) and anthos (flower), indicative of the hue of its early cultivars. Native to particularly Asia and parts of Europe, chrysanthemum holds considerable cultural and economic importance (2). It is the national flower and an imperial emblem of Japan, as well as the birth flower for November. Internationally, chrysanthemum ranks second only to the rose in the cut and loose flower trade and it is classified within the family *Asteraceae* (3, 4). Rising global demand has intensified concerns over the environmental impacts of excessive chemical fertiliser use in floriculture. The presence of residual agrochemicals in export-quality flowers, along with evolving consumer preferences towards organically cultivated products, has heightened the necessity for sustainable production practices. While chemical fertilisers contribute to yield enhancement, their indiscriminate and prolonged application has led to the degradation of soil health, diminished biological activity and environmental imbalances (5, 6). Organic cultivation enhances soil structure and fertility by ensuring gradual and consistent nutrient release to the soil. Thus, it improves flower quality, including colour intensity, stem strength and post-harvest longevity while remaining cost-effective and environmentally sustainable (7).

Regions with limited use of organic inputs alongside chemical fertilisers offer opportunities for transitioning to fully organic production systems. Nevertheless, the absence of region-specific organic cultivation protocols for chrysanthemum poses a limitation to this transition. Organic and biofertilisers such as *Azotobacter*, phosphate-solubilising bacteria (PSB), vermicompost, farmyard manure (FYM), poultry manure and bone meal present promising alternatives, enhancing both nutrient availability and crop quality while reducing reliance on synthetic inputs (8, 9). Manures like FYM at 25 t/ha, vermicompost and poultry manure at 5 t/ha enriched with bio-fertilisers like *Azotobacter* and PSB at 2 g/ha significantly improved plants' vegetative and yield attributes (6, 7). A proper organic cultivation schedule of chrysanthemum cultivars for this region by using beneficial microorganisms has not been standardised till now. Therefore, this study aimed to evaluate the effects of different organic nutrient sources, applied individually and in combination, on the yield and quality of spray chrysanthemum, intending to develop an optimised nutrient management protocol for the Terai region of West Bengal.

Materials and Methods

Experimental site

The experiment was conducted during 2018-19 and 2019-20 at the Instructional Farm of the Department of Floriculture, Medicinal and Aromatic Plants, Faculty of Horticulture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal. The site is situated in the Terai region of the sub-Himalayan plains at an elevation of 43 m above mean sea level, located at 26°19′ N latitude and 89°23′ E longitude, having sandy loam soil, slightly acidic in pH, ranging from 5.5-6.5.

Experimental materials

The experiment was laid out in a factorial randomised block design (FRBD) with two factors: varieties (two levels) and nutrient treatments (thirteen levels), replicated three times. The chrysanthemum varieties were Marigold (V_1) and Winter Queen (V_2). Thirteen nutrient management treatments (T_1-T_{13}) comprising farmyard manure (FYM), poultry manure, vermicompost, bone meal, biofertilizers (*Azotobacter* and PSB) and their combinations were evaluated (Table 1). Synergistic effects of the treatment were found in different horticultural crops, but a proper schedule in chrysanthemum has not yet been standardised, thus these treatments were selected.

Methodology

Raised beds measuring 2.1 x 1.2 m were prepared and rooted cuttings were transplanted at a spacing of 30 x 30 cm, accommodating 28 plants per bed. Chemical fertilisers (N, P and K) were applied as per treatment specifications, with phosphorus and potassium given as a basal dose. Nitrogen was applied in two splits 50 % as a basal dose during land preparation and the remaining 50 % as a top dressing 45 days after transplanting. Bio-fertilisers (*Azotobacter* and PSB) were applied to the soil directly at 2 g/plant as a basal treatment seven days before transplanting for better multiplication of micro-organisms and readily available macronutrients. Irrigation was done weekly or to the needs of the plant and weeding was done twice a month.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SPSS software (version 27). Treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 5 % probability level ($p \leq 0.05$).

Results and Discussion

Vegetative parameters

The vegetative parameters of the studied treatments showed significant variation across years and pooled data. Maximum plant height, spread (E-W and N-S), branch number (Table 2) and leaves per branch were recorded in V_2 under T_{12}, while minimum values were observed in $V_1 \times T_1$. Leaf area was highest in $V_1 \times T_{12}$ and lowest in $V_2 \times T_1$. Chlorophyll content varied across treatments, peaking in $V_2 \times T_2$ (Y_1), $V_2 \times T_5$ (Y_2) and $V_1 \times T_2$ (pooled), whereas the lowest values occurred in $V_2 \times T_{13}$ (Y_2, pooled) and $V_1 \times T_4$ (Y_1) (Table 3). The enhanced vegetative growth under T_{12} can be attributed to improved nutrient absorption mediated by *Azotobacter* and PSB and to the enrichment of vermicompost with macronutrients, growth-promoting hormones and beneficial microbes (10-17). Vermicompost also improved soil porosity, aeration and water-holding capacity, thereby facilitating nutrient uptake. Research has demonstrated the similar findings in tuberose (19), marigold (20), chrysanthemum (21-23), gladiolus (18), china aster (24) and carnation (15).

Floral parameters

Among the floral parameters maximum number of flowers per plant, flower diameter, flowering duration and field life were found best in $V_2 \times T_{12}$ during Y_1, Y_2 and pooled, while $V_1 \times T_1$ exerted the least (Table 3 and Fig. 1-3). Fresh and dry weight of five flowers found maximum in $V_1 \times T_{11}$ during Y_1, Y_2 and pooled, while $V_2 \times T_4$ recorded the minimum fresh weight of five flowers and $V_2 \times T_1$ recorded the minimum dry weight of five flowers (Table 4). Vase life was maximised in $V_1 \times T_{13}$, $V_2 \times T_7$ and $V_2 \times T_{12}$ during Y_1, Y_2 and pooled results, while the shortest vase life was recorded in $V_2 \times T_3$ in Y_1, $V_2 \times T_6$ in Y_2 and $V_1 \times T_1$ in pooled results (Fig. 2). The superiority of integrated nutrient management treatments (T_{12}, T_{11}, T_{13}) for floral traits suggests that balanced nutrient supply, coupled with enhanced microbial activity, improved assimilate partitioning to reproductive organs.

Table 1. Treatment details of the experimental trial

First Factor	Notation	Varieties (Two levels)
	V_1	Marigold
	V_2	Winter Queen
Second Factor	**Notation**	**Organic sources of nutrients (Thirteen levels)**
	T_1	Control - without any organic and inorganic fertiliser
	T_2	Recommended doses of NPK (N:P:K at 150:75:135 kg/ha)
	T_3	Farm yard manure at 50 t/ha
	T_4	Poultry manure at 5t/ha
	T_5	Vermicompost at 5 t/ha (500 g/m$^{2)}$
	T_6	Bone meal at 5 t/ha (500 g/m^2)
	T_7	*Azotobacter* at 2 g/plant
	T_8	Phosphate-solubilising bacteria (PSB) at 2 g/plant
	T_9	*Azotobacter* at 2 g/plant + PSB at 2 g/plant
	T_{10}	FYM at 50 t/ha + *Azotobacter* at 2 g/plant + PSB at 2 g/plant
	T_{11}	Poultry Manure at 5t/ha + *Azotobacter* at 2 g/plant + PSB at 2 g/plant
	T_{12}	Vermicompost at 5 t/ha (500 g /m^2) + *Azotobacter* at 2 g/plant + PSB at 2 g/plant
	T_{13}	Bone meal at 5 t/ha + *Azotobacter* at 2 g/plant + PSB at 2 g/plant

Table 2. Effect of organic sources of nutrients on plant height, plant spread, plant spread and number of branches per plant

Treatment	Plant height (cm)			Plant spread (E-W) (cm)			Plant spread (N-S) (cm)			Number of branches per plant		
1st Factor (Varieties)												
	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled
V_1	33.97^{b}	37.12^{b}	35.55^{b}	25.30^{a}	26.86^{a}	26.08^{a}	24.75^{a}	26.00^{b}	25.38^{b}	5.31^{a}	6.18^{b}	5.74^{b}
V_2	52.67a	57.65^{a}	55.16^{a}	25.45^{a}	27.01^{a}	26.23^{a}	24.62^{a}	27.00^{a}	25.81^{a}	10.71^{ab}	12.39^{a}	11.55^{a}
SE(m)±	0.12	0.21	0.13	0.133	0.153	0.11	0.14	0.136	0.105	0.092	0.132	0.075
CD at 5 %	0.33	0.59	0.36	0.38	0.44	0.31	0.4	0.39	0.3	0.26	0.38	0.21
2nd Factor (Treatments)												
T_1	38.24^{h}	41.22^{h}	39.73i	23.80^{f}	25.45^{e}	24.63^{d}	22.39^{i}	25.73^{cd}	24.06^{f}	6.42^{f}	7.13^{f}	6.77^{f}
T_2	45.49^{bc}	50.94^{c}	48.21c	25.72^{bc}	28.64^{ab}	27.18^{b}	25.07^{cd}	26.91^{b}	25.99^{b}	8.57^{c}	10.25^{c}	9.41^{c}
T_3	41.26^{g}	44.02^{g}	42.64h	24.72^{def}	25.68^{e}	25.20^{cd}	22.81^{hi}	25.47^{cd}	24.14^{ef}	6.90^{ef}	7.76^{ef}	7.33^{e}
T_4	42.45^{f}	45.42^{fg}	43.93fg	24.71^{def}	26.52^{de}	25.62^{c}	23.23^{ghi}	25.40^{d}	24.31^{def}	7.62^{d}	8.59^{de}	8.11^{d}
T_5	41.39^{g}	45.12^{fg}	43.25gh	24.40^{ef}	25.84^{e}	25.12^{cd}	23.82^{efg}	25.40^{d}	24.61^{cdef}	7.04^{def}	8.10^{de}	7.57^{de}
T_6	42.32^{f}	45.46^{fg}	43.89fg	24.60^{def}	25.80^{e}	25.20^{cd}	24.59^{def}	25.10^{d}	24.85^{cde}	7.05^{def}	8.20^{de}	7.63^{de}
T_7	43.64^{e}	47.28^{e}	45.46e	24.32^{ef}	26.43^{de}	25.37^{cd}	23.62^{fgh}	25.56^{cd}	24.59^{cdef}	7.26^{de}	8.76^{d}	8.01^{d}
T_8	42.54^{f}	45.58^{f}	44.06fg	25.10^{cde}	26.14^{e}	25.62^{c}	24.77^{cde}	25.47^{cd}	25.12^{c}	7.51^{de}	8.61^{de}	8.06^{d}
T_9	43.71^{e}	45.69^{f}	44.70ef	25.37^{cd}	26.15^{e}	25.76^{c}	24.20^{defg}	25.91^{cd}	25.05^{cd}	7.01^{def}	8.59^{de}	7.80^{de}
T_{10}	44.38de	49.08^{d}	46.73d	25.89^{bc}	27.47^{cd}	26.68^{b}	25.76^{bc}	26.39^{bc}	26.07^{b}	9.31^{b}	10.63^{bc}	9.97^{b}
T_{11}	44.67^{cd}	49.58^{cd}	47.13d	26.42^{b}	28.00^{bc}	27.21^{b}	26.70^{ab}	28.66^{a}	27.68^{a}	9.80^{b}	11.16^{abc}	10.48^{b}
T_{12}	46.82^{a}	54.11^{a}	50.47a	27.44^{a}	28.77^{ab}	28.11^{a}	27.27^{a}	29.34^{a}	28.31^{a}	10.48^{a}	11.70^{a}	11.09^{a}
T_{13}	46.23^{ab}	52.50^{b}	49.37b	27.40^{a}	29.24^{a}	28.32^{a}	26.70^{ab}	29.16^{a}	27.93^{a}	9.13^{c}	11.24^{ab}	10.19^{b}
SE(m)±	0.30	0.53	0.32	0.339	0.391	0.28	0.356	0.346	0.268	0.235	0.338	0.19
CD at 5 %	0.85	1.51	0.91	0.96	1.11	0.80	1.01	0.98	0.76	0.67	0.96	0.54
Variety × Interaction												
$V_1 \times T_1$	31.80^{n}	34.51^{kl}	33.15^{o}	23.82^{i}	25.45^{ghi}	24.63^{jk}	23.41^{ijkl}	26.20^{defg}	24.81^{fghi}	3.75^{k}	4.14^{j}	3.95^{j}
$V_1 \times T_2$	35.69^{hi}	40.84^{i}	38.27^{l}	25.34^{defgh}	28.95^{ab}	27.14^{cd}	24.34^{fghi}	26.44^{cdef}	25.39^{efg}	6.38^{h}	7.74^{g}	7.06^{fg}
$V_1 \times T_3$	32.94^{lmn}	35.21^{kl}	34.08^{no}	24.69^{fghi}	26.11^{fghi}	25.40^{efghijk}	23.31^{ijkl}	25.34^{fgh}	24.32^{ghij}	3.80^{k}	4.09^{j}	3.95^{j}
$V_1 \times T_4$	32.13^{n}	34.56^{kl}	33.34^{o}	25.20^{defgh}	26.69^{efgh}	25.94^{efghi}	24.43^{efghi}	25.20^{fgh}	24.81^{fghi}	4.99^{ij}	5.15^{ij}	5.07^{hi}
$V_1 \times T_5$	32.55^{lm}	35.66^{kl}	34.10^{no}	25.08^{defghi}	26.59^{fghi}	25.84^{efghi}	25.66^{cdef}	26.31^{defg}	25.98^{cde}	4.04^{k}	5.12^{ij}	4.58^{ij}
$V_1 \times T_6$	32.72^{lmn}	35.92^{kl}	34.32^{no}	24.62^{fghi}	26.06^{fghi}	25.34^{fghijk}	23.85^{ghi}	25.09^{fgh}	24.47^{fghi}	4.46^{ijk}	5.14^{ij}	4.80^{i}
$V_1 \times T_7$	33.78^{jkl}	36.49^{jk}	35.14^{n}	24.52^{ghi}	26.58^{fghi}	25.55^{efghij}	23.80^{ghi}	25.14^{fgh}	24.47^{fghi}	4.99^{ij}	5.08^{ij}	5.04^{hi}
$V_1 \times T_8$	32.94^{lmn}	34.22^{l}	33.58^{o}	24.48^{ghi}	25.51^{ghi}	24.99^{ijk}	24.85^{cdefgh}	25.22^{fgh}	25.03^{efg}	5.19^{i}	6.13^{hi}	5.66^{h}
$V_1 \times T_9$	33.66^{klm}	34.81^{kl}	34.24^{no}	24.83^{defghi}	25.39^{ghi}	25.11^{hijk}	24.92^{cdefg}	25.41^{fgh}	25.17^{efg}	4.11^{jk}	6.05^{hi}	5.08^{hi}
$V_1 \times T_{10}$	34.95^{ij}	38.54^{j}	36.75^{m}	25.63^{defg}	26.71^{efgh}	26.17^{defgh}	26.00^{bcd}	25.05^{gh}	25.52^{def}	6.45^{h}	7.15^{gh}	6.80^{g}
$V_1 \times T_{11}$	34.78^{ijk}	38.12^{j}	36.45^{m}	25.83^{bcdefg}	27.15^{cdef}	26.49^{de}	24.96^{cdefg}	26.87^{bcde}	25.91^{cde}	6.93^{h}	8.04^{g}	7.48^{fg}
$V_1 \times T_{12}$	36.87^{h}	42.66^{i}	39.76^{k}	27.09^{ab}	28.21^{bcde}	27.65^{bc}	26.18^{bc}	27.72^{bc}	26.95^{bc}	7.19^{h}	8.12^{g}	7.66^{f}
$V_1 \times T_{13}$	36.79^{h}	41.06^{i}	38.93^{kl}	27.79^{a}	29.80^{a}	28.79^{a}	26.09^{bcd}	28.07^{b}	27.08^{b}	6.69^{h}	8.40^{g}	7.54^{fg}
$V_2 \times T_1$	44.68^{g}	47.92^{h}	46.30^{j}	23.79^{i}	25.46^{ghi}	24.62^{jk}	21.36^{m}	25.26^{fgh}	23.31^{jk}	9.08^{g}	10.11^{f}	9.60^{e}
$V_2 \times T_2$	55.29^{b}	61.04^{b}	58.16^{c}	26.11^{bcde}	28.33^{abcd}	27.22^{cd}	25.81^{cde}	27.38^{bcd}	26.59^{bcd}	10.75^{de}	12.77^{bc}	11.76^{c}
$V_2 \times T_3$	49.58^{f}	52.83^{g}	51.21^{j}	24.75^{efghi}	25.26^{hi}	25.01^{ijk}	22.32^{jklm}	25.59^{efgh}	23.95^{hijk}	10.00^{efg}	11.43^{cdef}	10.72^{d}
$V_2 \times T_4$	52.77^{de}	56.28^{def}	54.52^{fg}	24.23^{hi}	26.36^{fghi}	25.29^{fghijk}	22.02^{klm}	25.61^{efgh}	23.82^{ijk}	10.25^{ef}	12.04^{cde}	11.14^{cd}
$V_2 \times T_5$	50.22^{fe}	54.58^{fg}	52.40^{hi}	23.72^{i}	25.08^{i}	24.40^{k}	21.99^{lm}	24.50^{h}	23.25^{k}	10.03^{ef}	11.09^{def}	10.56^{d}
$V_2 \times T_6$	51.92^{e}	55.00^{ef}	53.46^{gh}	24.59^{fghi}	25.54^{ghi}	25.07^{hijk}	25.32^{cdef}	25.11^{fgh}	25.22^{efg}	9.64^{fg}	11.26^{def}	10.45^{d}
$V_2 \times T_7$	53.49^{cd}	58.08^{cd}	55.78^{ef}	24.12^{hi}	26.28^{fghi}	25.20^{ghijk}	23.43^{hijk}	25.98^{efg}	24.71^{fghi}	9.53^{fg}	12.44^{cd}	10.99^{d}
$V_2 \times T_8$	52.13^{e}	56.95^{de}	54.54^{fg}	25.71^{cdefg}	26.78^{defgh}	26.25^{defg}	24.69^{defghi}	25.71^{efgh}	25.20^{efg}	9.83^{efg}	11.08^{ef}	10.46^{d}
$V_2 \times T_9$	53.76^{cd}	56.57^{def}	55.17^{f}	25.91^{bcdef}	26.90^{defg}	26.41^{def}	23.47^{hij}	26.41^{cdefg}	24.94^{efgh}	9.92^{efg}	11.12^{def}	10.52^{d}
$V_2 \times T_{10}$	53.80^{cd}	59.61^{bc}	56.71^{de}	26.16^{bcd}	28.22^{bcde}	27.19^{cd}	25.51^{cdef}	27.73^{bc}	26.62^{bc}	12.17^{bc}	14.10^{ab}	13.13^{b}
$V_2 \times T_{11}$	54.57^{bc}	61.04^{b}	57.80^{cd}	27.01^{abc}	28.86^{ab}	27.94^{abc}	28.43^{a}	30.45^{a}	29.44^{a}	12.67^{b}	14.27^{a}	13.47^{b}
$V_2 \times T_{12}$	56.76^{a}	65.57^{a}	61.17^{a}	27.80^{a}	29.34^{ab}	28.57^{ab}	28.36^{a}	30.97^{a}	29.67^{a}	13.77^{a}	15.28^{a}	14.53^{a}
$V_2 \times T_{13}$	55.67^{ab}	63.93^{a}	59.80^{b}	27.00^{abc}	28.68^{abc}	27.84^{abc}	27.31^{ab}	30.26^{a}	28.79^{a}	11.58^{cd}	14.08^{ab}	12.83^{b}
SE(m)±	0.43	0.75	0.45	0.479	0.553	0.396	0.504	0.489	0.379	0.332	0.477	0.269
CD at 5 %	1.21	2.13	1.28	1.36	1.57	1.13	1.43	1.39	1.08	0.94	1.36	0.76
CV %	1.70	2.75	1.72	3.27	3.20	5.39	3.54	3.20	2.56	7.18	8.91	5.39

The means with different letters as superscripts are significant ($p < 0.05$). The means with the same letters or having common letter(s) are not significantly different.

Table 3. Effect of organic sources of nutrients on the number of leaves per branch, leaf area and chlorophyll content of leaves (SPAD 502)

Treatment	Number of leaves per branch			Leaf area (cm²)			Chlorophyll content of leaves (SPAD502)		
	1st Factor (Varieties)								
	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled
V_1	11.59^{b}	13.83^{b}	12.71^{b}	16.96^{a}	17.31^{a}	17.14^{a}	165.51^{a}	166.48^{a}	165.99^{a}
V_2	23.78^{a}	28.13^{a}	25.96^{a}	7.28^{b}	7.27^{b}	7.27^{b}	144.13^{b}	146.42^{b}	145.28^{b}
SE(m)±	0.191	0.193	0.123	0.09	0.10	0.06	0.65	1.912	1.106
CD at 5 %	0.54	0.55	0.35	0.25	0.28	0.17	1.85	5.43	3.14
	2nd Factor (Treatments)								
T_1	13.67^{e}	18.32^{g}	15.99^{g}	10.80^{g}	11.25^{f}	11.03^{h}	134.92^{g}	145.98^{d}	140.45^{ef}
T_2	19.86^{ab}	18.25^{g}	19.05^{cde}	13.08^{ab}	13.07^{ab}	13.07^{b}	257.36^{a}	189.67^{b}	223.51^{a}
T_3	15.99^{cd}	21.77^{bcd}	18.88^{cdef}	11.18^{fg}	11.77^{ef}	11.47^{g}	120.66^{i}	118.57^{f}	119.62^{i}
T_4	15.80^{d}	20.73^{cde}	18.27^{def}	12.05^{cde}	12.16^{cde}	12.10^{def}	110.87^{j}	134.67^{de}	122.77^{hi}
T_5	19.10^{b}	17.57^{g}	18.33^{def}	12.46^{bc}	12.03^{e}	12.25^{cde}	137.90^{g}	238.78^{a}	188.34^{b}
T_6	15.85^{d}	20.41^{de}	18.13^{f}	12.15^{cde}	12.02^{e}	12.09^{def}	122.50^{hi}	133.22^{de}	127.86^{gh}
T_7	16.47^{cd}	19.97^{ef}	18.22^{ef}	11.81^{def}	12.02^{e}	11.91^{ef}	126.08^{h}	138.82^{de}	132.45^{fg}
T_8	17.34^{c}	18.87^{fg}	18.10^{f}	11.60^{ef}	11.95^{ef}	11.77^{fg}	120.29^{i}	172.38^{c}	146.33^{e}
T_9	16.83^{cd}	21.88^{bc}	19.35^{c}	11.52^{ef}	12.07^{de}	11.79^{fg}	168.96^{d}	189.68^{b}	179.31^{c}
T_{10}	17.01^{cd}	21.23^{bcde}	19.12^{cd}	12.47^{bc}	12.77^{bcd}	12.62^{c}	148.64^{f}	129.97^{ef}	139.30^{ef}
T_{11}	20.82^{a}	22.22^{b}	21.52^{b}	12.47^{bc}	12.24^{cde}	12.35^{cd}	154.22^{e}	133.13^{de}	143.67^{e}
T_{12}	20.88^{a}	25.37^{a}	23.12^{a}	13.62^{a}	13.55^{a}	13.58^{a}	233.93^{b}	146.94^{d}	190.43^{b}
T_{13}	20.34^{ab}	26.15^{a}	23.24^{a}	12.38^{cd}	12.85^{abc}	12.62^{c}	176.32^{c}	162.07^{c}	169.19^{d}
SE(m)±	0.486	0.491	0.315	0.23	0.25	0.15	1.656	4.876	2.819
CD at 5 %	1.38	1.39	0.89	0.65	0.70	0.42	4.70	13.85	8.01
	Variety × Interaction								
$V_1 \times T_1$	8.32^{k}	11.34^{jk}	9.83^{l}	15.38^{g}	16.35^{e}	15.87^{h}	144.84^{g}	150.23^{e}	147.53^{gh}
$V_1 \times T_2$	10.93^{ij}	13.25^{hij}	12.09^{jk}	18.15^{b}	18.58^{ab}	18.37^{b}	257.05^{a}	250.04^{a}	253.54^{a}
$V_1 \times T_3$	11.20^{ij}	14.11^{h}	12.66^{jk}	16.00^{fg}	16.43^{e}	16.22^{gh}	111.84^{no}	118.79^{ij}	115.31^{kl}
$V_1 \times T_4$	10.21^{jk}	13.50^{hi}	11.85^{jk}	16.51^{def}	16.86^{e}	16.69^{efg}	105.56^{o}	126.71^{hij}	116.13^{kl}
$V_1 \times T_5$	10.62^{ij}	13.33^{hi}	11.98^{jk}	17.35^{bcde}	16.69^{e}	17.02^{def}	146.40^{g}	208.15^{bc}	177.27^{e}
$V_1 \times T_6$	10.50^{ij}	14.04^{hi}	12.27^{jk}	17.08^{cde}	16.51^{e}	16.80^{efg}	125.1^{3kl}	130.35^{fghij}	127.73^{j}
$V_1 \times T_7$	10.75^{ij}	12.13^{ijk}	11.44^{k}	16.49^{def}	17.16^{cde}	16.83^{ef}	133.53^{ij}	148.45^{efg}	140.98^{hi}
$V_1 \times T_8$	13.54^{gh}	10.92^{k}	$12.23j^{k}$	16.48^{ef}	17.15^{cde}	16.82^{ef}	122.08^{lm}	201.48^{c}	161.77^{f}
$V_1 \times T_9$	10.40^{ij}	14.31^{h}	$12.35j^{k}$	15.99^{fg}	16.97^{e}	16.48^{fg}	200.82^{d}	153.01^{e}	176.91^{e}
$V_1 \times T_{10}$	11.64^{hij}	14.07^{hi}	12.86^{j}	17.40^{bcd}	18.01^{bcd}	17.71^{c}	153.55^{f}	140.37^{efgh}	146.96^{gh}
$V_1 \times T_{11}$	16.27^{f}	13.00^{hij}	14.63^{i}	17.49^{bc}	17.07^{de}	17.28^{cde}	165.45^{e}	149.88^{ef}	157.66^{fg}
$V_1 \times T_{12}$	14.00^{g}	18.03^{g}	16.02^{h}	19.19^{a}	19.08^{a}	19.14^{a}	240.85^{b}	173.95^{d}	207.39^{c}
$V_1 \times T_{13}$	12.33^{ghi}	17.77^{g}	15.05^{ji}	17.03^{cde}	18.13^{abc}	17.58^{cd}	244.50^{b}	212.89^{bc}	228.69^{b}
$V_2 \times T_1$	19.02^{e}	25.29^{e}	22.16^{g}	6.22^{m}	6.15^{h}	6.19^{n}	125.01^{kl}	141.73^{efgh}	133.37^{ij}
$V_2 \times T_2$	28.78^{a}	23.25^{f}	26.02^{cd}	8.00^{hi}	7.56^{fg}	7.78^{ij}	257.67^{a}	129.30^{ghij}	193.48^{d}
$V_2 X T_3$	20.79^{de}	29.42^{c}	25.10^{cdef}	6.36^{lm}	7.10^{fgh}	6.73^{mn}	129.49^{jk}	118.36^{ij}	123.92^{jk}
$V_2 \times T_4$	21.39^{cd}	27.96^{cd}	24.68^{ef}	7.59^{hijk}	7.46^{fg}	7.52^{ijkl}	116.19^{mn}	142.64^{efgh}	129.41^{j}
$V_2 \times T_5$	27.57^{a}	21.81^{f}	24.69^{ef}	7.57^{hijk}	7.37^{fg}	7.47^{ijkl}	129.40^{jk}	269.41^{a}	199.40^{cd}
$V_2 \times T_6$	21.20^{d}	26.78^{de}	23.99^{f}	7.22^{hijkl}	7.53^{fg}	7.38^{jkl}	119.86^{lm}	136.11^{efghi}	127.98^{j}
$V_2 \times T_7$	22.18^{cd}	27.81^{cd}	25.00^{def}	7.12^{ijklm}	6.88^{gh}	7.00^{lm}	118.64^{lm}	129.19^{ghij}	123.91^{jk}
$V_2 \times T_8$	21.13^{d}	26.83^{de}	23.98^{f}	6.72^{klm}	6.74^{gh}	6.73^{mn}	118.51^{lm}	143.29^{efgh}	130.89^{ij}
$V_2 \times T_9$	23.25^{c}	29.46^{c}	26.35^{c}	7.05^{jklm}	7.17^{fg}	7.11^{klm}	137.10^{hi}	226.36^{b}	181.72^{e}
$V_2 \times T_{10}$	22.38^{cd}	28.40^{cd}	25.39^{cde}	7.55^{hijk}	7.52^{fg}	7.53^{ijkl}	143.72^{gh}	119.58^{ij}	131.65^{ij}
$V_2 \times T_{11}$	25.37^{b}	31.45^{b}	28.41^{b}	7.45^{hijk}	7.40^{fg}	7.43^{jkl}	142.99^{gh}	116.40^{j}	129.69^{ij}
$V_2 \times T_{12}$	27.75^{a}	32.70^{ab}	30.23^{a}	8.04^{h}	8.01^{f}	8.03^{i}	227.01^{c}	119.93^{ij}	173.47^{e}
$V_2 \times T_{13}$	28.34^{a}	34.53^{a}	31.44^{a}	7.73^{hij}	7.57^{fg}	7.65^{ijk}	108.14^{o}	111.26^{j}	109.70^{l}
SE(m)±	0.687	0.694	0.445	0.32	0.35	0.21	2.342	6.895	3.987
CD at 5 %	1.95	1.97	1.26	0.92	0.99	0.60	6.65	19.59	11.32
CV %	4.62	5.73	4.18	4.92	4.92	2.98	2.62	7.63	4.44

The means with different letters as superscripts are significant ($p < 0.05$). The means with the same letters or having common letter(s) are not significantly different.

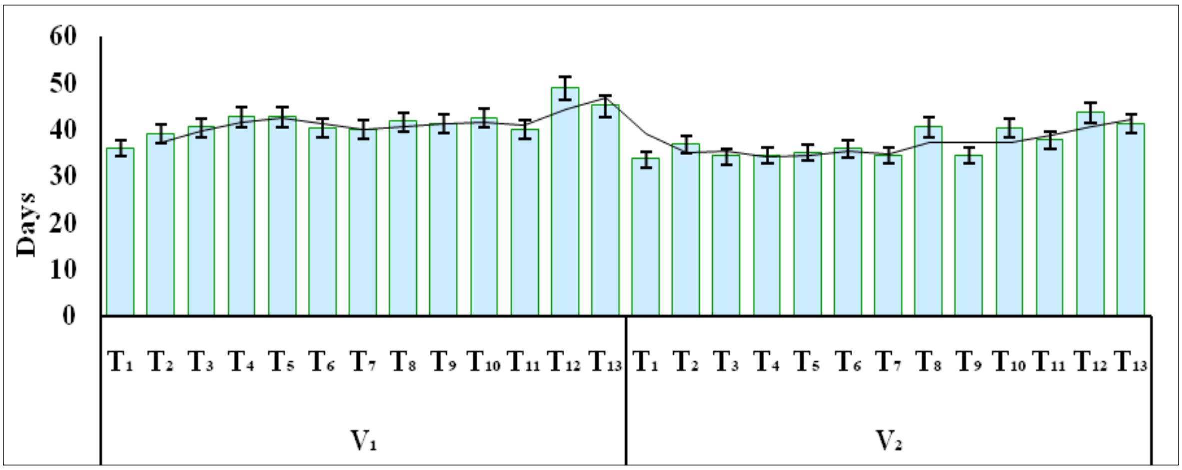

Fig. 1. Effect of organic nutrient sources on duration of flowering.

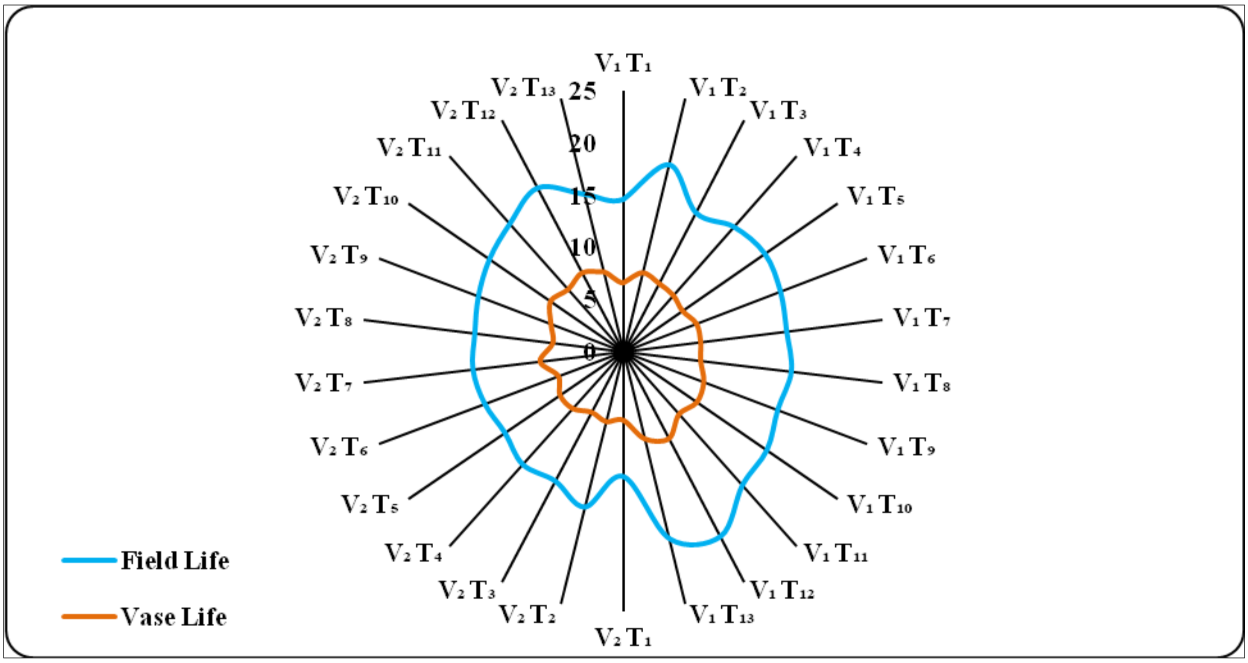

Fig. 2. Effect of organic nutrient sources on field life and vase life (days).

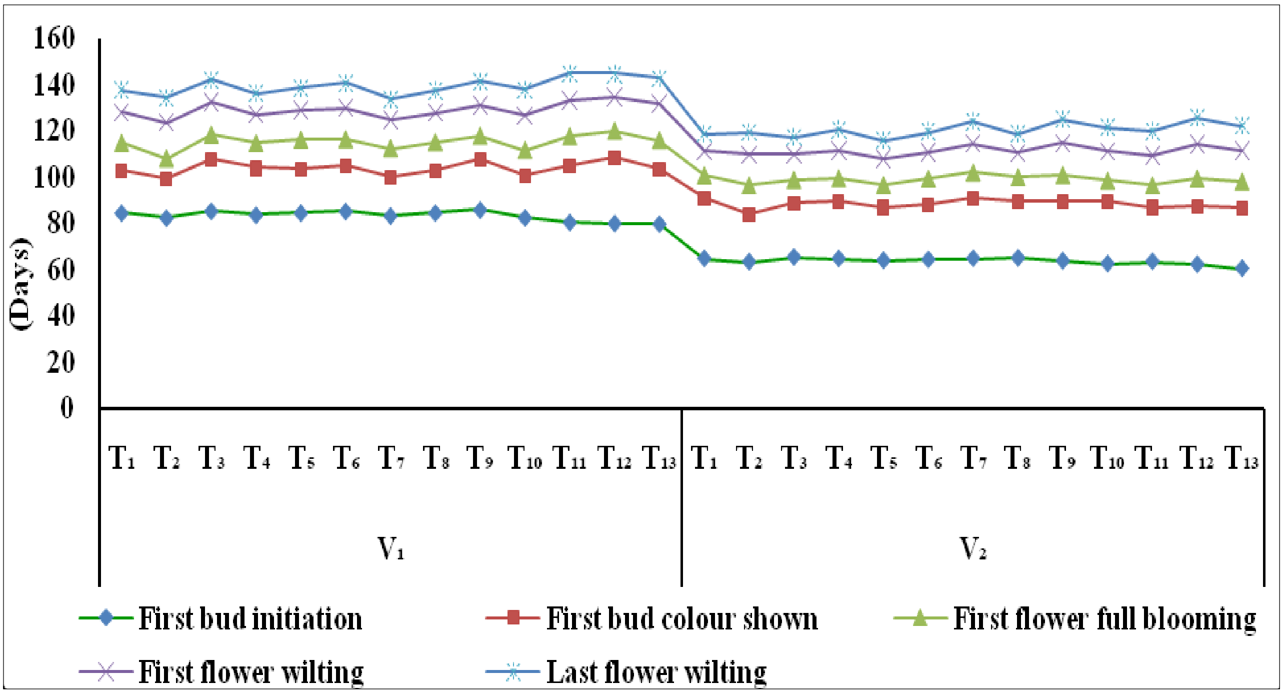

Fig. 3. Effect of organic nutrient sources on first flower bud initiation, first flower bud colour shown, first flower full bloom, first flower wilting and last flower wilting.

Table 4. Effect of organic sources of nutrients on the total number of flowers per plant, flower diameter, fresh weight of 5 flowers and dry weight of 5 flowers

Treatment	Total number of flowers per plant			Flower diameter (cm)			Fresh weight of 5 flowers (g)			Dry weight of 5 flowers (g)		
1st Factor (Varieties)												
	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled	Y_1	Y_2	pooled	Y_1	Y_2	pooled
V_1	10.48^{b}	12.48^{b}	11.48^{b}	6.09^{b}	6.03^{b}	6.01^{b}	16.04^{a}	16.08^{a}	16.06^{a}	4.24^{a}	4.22^{a}	4.23^{a}
V_2	50.82^{a}	56.29^{a}	53.56^{a}	7.17^{a}	7.22^{a}	7.19^{a}	6.77^{b}	6.79^{b}	6.78^{b}	1.08^{b}	1.10^{b}	1.09^{b}
SE(m)±	0.187	0.257	0.166	0.088	0.08	0.064	0.05	0.05	0.042	0.017	0.018	0.012
CD at 5 %	0.53	0.73	0.47	0.25	0.23	0.18	0.143	0.142	0.119	0.047	0.05	0.04
2nd Factor (Treatments)												
T_1	24.04^{g}	27.23^{g}	25.63^{j}	5.65^{e}	5.54^{f}	5.23^{e}	10.44^{ef}	10.28^{f}	10.36^{fg}	2.38^{f}	2.37^{ef}	2.37^{ef}
T_2	27.77^{g}	34.20^{g}	30.99^{ef}	7.08^{ab}	7.01^{bcd}	7.05^{b}	12.68^{c}	12.61^{c}	12.65^{c}	2.81^{b}	2.73^{b}	2.77^{b}
T_3	26.05^{e}	29.50^{cd}	27.78^{i}	5.95^{de}	6.44^{de}	6.19^{d}	9.76^{g}	9.81^{g}	9.78^{h}	2.01^{g}	2.03^{h}	2.02^{h}
T_4	28.27^{f}	32.81^{f}	30.54^{efg}	6.57^{bcd}	6.21^{e}	6.39^{d}	10.42^{ef}	10.46^{f}	10.44^{fg}	2.51^{de}	2.47^{de}	2.49^{d}
T_5	28.08^{e}	32.16^{de}	30.12^{fgh}	6.40^{cd}	6.57^{cde}	6.49^{cd}	10.19^{f}	10.32^{f}	10.25^{g}	2.12^{g}	2.19^{g}	2.15^{g}
T_6	28.08^{e}	30.25^{e}	29.16^{h}	6.53^{bcd}	6.23^{e}	6.38^{d}	11.27^{d}	11.55^{d}	11.41^{d}	2.38^{f}	2.31^{fg}	2.35^{f}
T_7	30.40^{e}	28.99^{f}	29.70^{gh}	6.52^{bcd}	6.24^{e}	6.38^{d}	10.69^{e}	10.45^{f}	10.57^{f}	2.48^{def}	2.49^{de}	2.49^{d}
T_8	29.91^{d}	34.55^{fg}	32.23^{d}	6.22^{de}	6.46^{de}	6.34^{d}	10.37^{ef}	$10.58e^{f}$	10.47^{fg}	2.45^{ef}	2.47^{de}	2.46^{de}
T_9	28.53^{d}	34.82^{cd}	31.68^{de}	6.26^{de}	6.45^{de}	6.35^{d}	11.36^{d}	11.30^{d}	11.33^{d}	2.70^{bc}	2.53^{cd}	2.62^{c}
T_{10}	34.08^{e}	39.06^{c}	36.57^{c}	7.01^{abc}	6.85^{bcd}	6.93^{bc}	11.12^{d}	10.87^{e}	11.00^{e}	2.59^{cd}	2.65^{bc}	2.62^{c}
T_{11}	37.19^{c}	41.74^{b}	39.46^{b}	7.25^{a}	7.07^{bc}	7.16^{ab}	13.91^{a}	13.92^{a}	13.92^{a}	3.43^{a}	3.40^{a}	3.41^{a}
T_{12}	40.07^{b}	42.23^{a}	41.15^{a}	7.47^{a}	7.68^{a}	7.57^{a}	13.18^{b}	13.29^{b}	13.23^{b}	3.41^{a}	3.53^{a}	3.47^{a}
T_{13}	36.00^{a}	39.45^{a}	37.73^{c}	7.28^{a}	7.38^{ab}	7.33^{ab}	$12.89b^{c}$	13.18^{b}	13.03^{b}	3.38^{a}	3.41^{a}	3.40^{a}
SE(m)±	0.478	0.656	0.424	0.225	0.203	0.164	0.128	0.137	0.107	0.042	0.047	0.031
CD at 5 %	1.36	1.86	1.20	0.64	0.58	0.47	0.364	0.389	0.304	0.12	0.13	0.09
Variety × Interaction												
$V_1 \times T_1$	6.61^{o}	8.08^{m}	7.34^{o}	4.97^{g}	5.17^{d}	4.33^{g}	14.40^{ef}	14.12^{fg}	14.26^{f}	3.78^{e}	3.71^{e}	3.74^{f}
$V_1 \times T_2$	12.26^{jk}	14.02^{hijk}	13.14^{jkl}	6.64^{bcde}	5.96^{defg}	6.30^{bcdef}	18.18^{c}	18.08^{c}	18.13^{c}	4.44^{b}	4.27^{b}	4.36^{c}
$V_1 \times T_3$	6.51^{o}	8.25^{m}	7.38^{o}	5.69^{fg}	5.86^{efg}	5.78^{f}	13.01^{h}	12.97^{h}	12.99^{h}	3.01^{g}	3.05^{g}	3.03^{h}
$V_1 \times T_4$	9.50^{mn}	11.13^{l}	10.31^{mn}	6.13^{def}	5.69^{fg}	5.91^{ef}	14.35^{ef}	14.33^{fg}	14.34^{f}	4.01^{d}	3.94^{cd}	3.97^{e}
$V_1 \times T_5$	7.62^{no}	12.06^{jkl}	9.84^{n}	5.98^{ef}	6.10^{def}	6.04^{def}	13.68^{g}	13.93^{g}	13.80^{g}	3.21^{f}	3.32^{f}	3.27^{g}
$V_1 \times T_6$	8.98^{mn}	11.42^{kl}	10.20^{mn}	6.00^{ef}	5.83^{efg}	5.92^{ef}	15.93^{d}	16.38^{d}	16.15^{d}	3.74^{e}	3.59^{e}	3.67^{f}
$V_1 \times T_7$	9.15^{mn}	12.03^{jkl}	10.59^{mn}	6.04^{ef}	5.91^{defg}	5.97^{def}	14.67^{e}	14.24^{fg}	14.46^{f}	3.96^{d}	3.92^{d}	3.94^{e}
$V_1 \times T_8$	11.15^{kl}	12.47^{jkl}	11.81^{lm}	6.08^{ef}	5.85^{efg}	5.97^{def}	14.10^{fg}	14.45^{f}	14.28^{f}	3.88^{de}	3.92^{d}	3.90^{e}
$V_1 \times T_9$	9.55^{lm}	13.38^{ijkl}	11.47^{lmn}	6.05^{ef}	5.87^{efg}	5.96^{def}	15.76^{d}	15.64^{e}	15.70^{e}	4.29^{bc}	3.97^{cd}	4.13^{d}
$V_1 \times T_{10}$	12.42^{ijk}	13.37^{ijkl}	12.89^{kl}	5.97^{ef}	6.09^{def}	6.03^{def}	15.65^{d}	15.18^{e}	15.42^{e}	4.18^{c}	4.13^{bc}	4.16^{d}
$V_1 \times T_{11}$	14.54^{h}	16.40^{h}	15.47^{i}	6.47^{cdef}	6.41^{cdef}	6.44^{bcde}	20.82^{a}	20.95^{a}	20.89^{b}	5.66^{a}	5.73^{a}	5.70^{a}
$V_1 \times T_{12}$	14.18^{hi}	15.32^{hi}	14.75^{ij}	6.68^{bcde}	7.02^{bc}	6.85^{b}	19.10^{b}	19.30^{b}	19.20^{b}	5.50^{a}	5.73^{a}	5.61^{ab}
$V_1 \times T_{13}$	13.75^{hij}	14.30^{hij}	14.03^{ijk}	6.47^{cdef}	6.70^{cd}	6.58^{bcd}	18.90^{b}	19.42^{b}	19.16^{k}	5.51^{a}	5.60^{a}	5.56^{b}
$V_2 \times T_1$	41.47^{g}	46.37^{g}	43.92^{h}	6.33^{cdef}	5.91^{defg}	6.12^{cdef}	6.47^{i}	6.43^{l}	6.45^{i}	0.98^{i}	1.03^{j}	1.00^{l}
$V_2 \times T_2$	43.28^{g}	54.38^{cd}	48.83^{fg}	7.53^{ab}	8.06^{a}	7.80^{a}	7.18^{ij}	7.14^{ij}	7.16^{jk}	1.17^{hijk}	1.19^{hij}	1.18^{jk}
$V_2 \times T_3$	45.60^{f}	50.75^{ef}	48.17^{g}	6.20^{cdef}	7.01^{bc}	6.61^{bcd}	6.51^{kl}	6.65^{jkl}	6.58^{jk}	1.01^{kl}	1.01^{j}	1.01^{l}
$V_2 \times T_4$	47.05^{ef}	54.49^{cd}	50.77^{e}	7.01^{bcd}	6.72^{cd}	6.87^{b}	6.50^{kl}	6.60^{kl}	6.55^{jk}	1.01^{kl}	1.01^{j}	1.01^{l}
$V_2 \times T_5$	48.53^{e}	52.27^{de}	50.40^{ef}	6.82^{bcde}	7.05^{bc}	6.93^{b}	6.69^{jkl}	6.72^{jkl}	6.71^{jk}	1.02^{jkl}	1.06^{ij}	1.04^{l}
$V_2 \times T_6$	47.18^{ef}	49.08^{f}	48.13^{g}	7.05^{bc}	6.64^{cde}	6.85^{b}	6.61^{kl}	6.73^{jkl}	6.67^{jk}	1.02^{jkl}	1.03^{j}	1.03^{l}
$V_2 \times T_7$	51.67^{d}	45.94^{g}	48.80^{fg}	7.00^{bcd}	6.57^{cde}	6.78^{b}	6.71^{jkl}	6.65^{jkl}	6.68^{jk}	0.99^{i}	1.06^{ij}	1.03^{l}
$V_2 \times T_8$	48.67^{e}	56.63^{c}	52.65^{d}	6.35^{cdef}	7.06^{bc}	6.71^{bc}	6.63^{kl}	6.71^{jkl}	6.67^{ij}	1.02^{jkl}	1.01^{j}	1.02^{l}
$V_2 \times T_9$	47.50^{ef}	56.27^{c}	51.89^{de}	6.47^{cdef}	7.02^{bc}	6.74^{bc}	6.96^{ijkl}	6.96^{ijk}	6.96^{jk}	1.11^{ijkl}	1.09^{ij}	1.10^{kl}
$V_2 \times T_{10}$	55.75^{c}	64.76^{b}	60.25^{c}	8.04^{a}	7.61^{ab}	7.82^{a}	6.60^{kl}	6.57^{kl}	6.58^{ij}	1.00^{i}	1.17^{hij}	1.08^{kl}
$V_2 \times T_{11}$	59.83^{b}	67.08^{ab}	63.46^{b}	8.04^{a}	7.73^{ab}	7.89^{a}	7.01^{ijk}	6.89^{ijkl}	6.95^{ij}	1.19^{hij}	1.07^{ij}	1.13^{jkl}
$V_2 \times T_{12}$	65.96^{a}	69.14^{a}	67.55^{a}	8.26^{a}	8.35^{a}	8.30^{a}	7.26^{i}	7.27^{i}	7.26^{i}	1.31^{h}	1.32^{h}	1.32^{i}
$V_2 \times T_{13}$	58.25^{b}	64.60^{b}	61.43^{c}	8.10^{a}	8.07^{a}	8.08^{a}	6.88^{ijkl}	6.93^{ijkl}	6.91^{ij}	1.25^{hi}	1.23^{hi}	1.24^{ij}
SE(m)±	0.676	0.928	0.6	0.318	0.287	0.232	0.257	0.261	0.215	0.06	0.067	0.044
CD 5 %	1.92	2.64	1.70	0.90	0.82	0.66	0.515	0.533	0.431	0.17	0.19	0.13
CV %	3.82	4.68	3.19	8.32	7.51	6.08	2.76	2.75	2.30	3.90	4.34	2.89

The means with different letters as superscripts are significant ($p < 0.05$). The means with the same letters or having common letter(s) are not significantly different.

Vermicompost provided sustained nutrient release, while biofertilizers supported nitrogen fixation and phosphorus solubilization, collectively improving flower size, weight and postharvest longevity. These outcomes corroborate earlier reports in chrysanthemum (21-23) and other ornamentals such as gladiolus (18) and carnation (15).

Phenological parameters

The earliest flower bud initiation and days taken for first flower bud colour appearance were found in $V_2 \times T_{13}$ and $V_2 \times T_2$, while delayed response was noted in $V_1 \times T_9$, $V_1 \times T_3$and $V_1 \times T_{12}$. The first full bloom was reached earliest in $V_2 \times T_{13}$ in Y_1, $V_2 \times T_{11}$ in Y_2 and $V_2 \times T_2$ in pooled, whereas the latest blooming was observed in $V_1 \times T_3$ in Y_1, $V_1 \times T_{11}$ in Y_2 and $V_1 \times T_{12}$ in pooled. Phenological parameters like first flower and last flower wilting were found earliest in $V_2 \times T_1$ and $V_2 \times T_3$, while these were delayed in $V_1 \times T_{13}$, $V_2 \times T_{12}$, $V_1 \times T_9$ and $V_1 \times T_{11}$ (Fig. 3).. Enhanced fertiliser availability and nutrient absorption, bolstered by inorganic potassium, beneficial microbes (*Azospirillum*, *Azotobacter*, PSB) and micronutrient-rich vermicompost, boosted leaf growth and photosynthate accumulation, yielding more and larger flowers (15, 18, 25). The development of auxiliary buds was facilitated by PSB and *Azotobacter*, leading to an increase in the number of branches and the size of blooms (15). Variations in the floral traits may be attributed to enhanced photosynthetic activity, improved water balance, increased moisture content, enhanced nutrient absorption by the plants, due to the biological fixation of nitrogen and phosphorus in their roots, resulting in larger flowers with higher dry matter content (26, 27).

Furthermore, *Azotobacter* contributes to the production of GA_3 and cytokinin-like compounds that promote plant development, as well as playing a role in nitrogen fixation, preventing floret senescence, which results in the accumulation of photosynthates and a more gradual emergence of flowers per plant, thereby extending the blooming period (28-31). Optimal nutrient absorption is facilitated by favourable soil physical characteristics, the solubilising effect of microorganisms and organic acids produced during the decomposition of vermicompost on native soil nutrients, leading to higher nutrient content in leaves, stems and flowers, ultimately resulting in maximum vase life (25).

The synthesis and secretion of substances such as thiamin, riboflavin, pyridoxine, nicotinic acid, pantothenic acid, indole-acetic acid (IAA) and gibberellins, in addition to the production of antifungal antibiotics by *Azotobacter*, which inhibit harmful soil fungi, may contribute to the induced initiation of flower buds (18). Early sprouting in tuberose was observed with the application of *Azotobacter* and PSB (32). These findings are consistent with similar results reported in carnation (33, 34, 35), marigold (20), china aster (16), gaillardia (36) and annual chrysanthemum (37). This suggests that integrated nutrient management not only accelerates flowering but also prolongs bloom duration, which is critical for cut flower industries.

Soil parameters

Integrated treatment T_{12} significantly enhanced soil NPK and organic carbon, while control T_1 recorded the lowest values (Fig. 4). In terms of soil organic carbon, the $V_2 \times T_{12}$ treatment achieved the maximum content at 1.11 %, whereas the $V_2 \times T_1$ treatment recorded the minimum value of 0.69 % (Fig. 5). The results indicate that T_{12} (vermicompost at 5 t/ha + *Azotobacter* at 2 g/plant + PSB at 2 g/plant) significantly improved soil macro-nutrient and organic carbon content. Vermicompost has been shown to enhance total nitrogen levels through processes of mineralisation and microbial activity, effectively converting organic nitrogen into its inorganic form (8, 38), enhancing soil physical and biological properties, increasing organic carbon content and enhancing soil aggregation and hydraulic conductivity (8, 38-40). The decomposition of organic manure increases phosphorus availability by releasing organic acids that

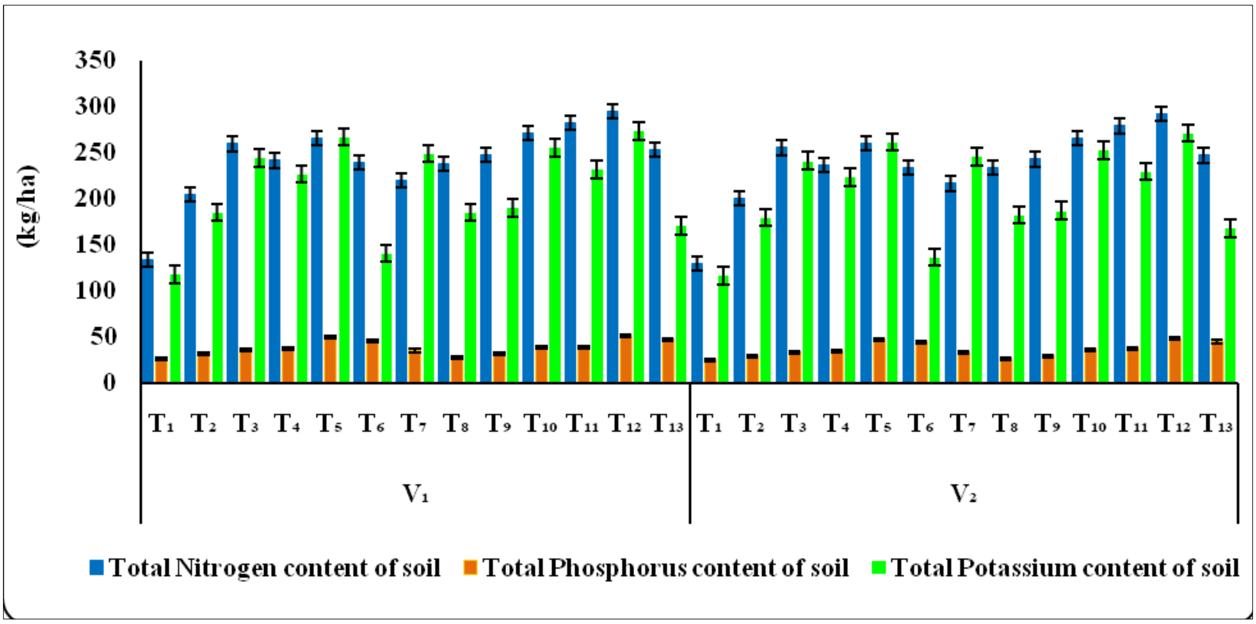

Fig. 4. Effect of organic nutrient sources on total nitrogen, phosphorus and potassium content of the soil.

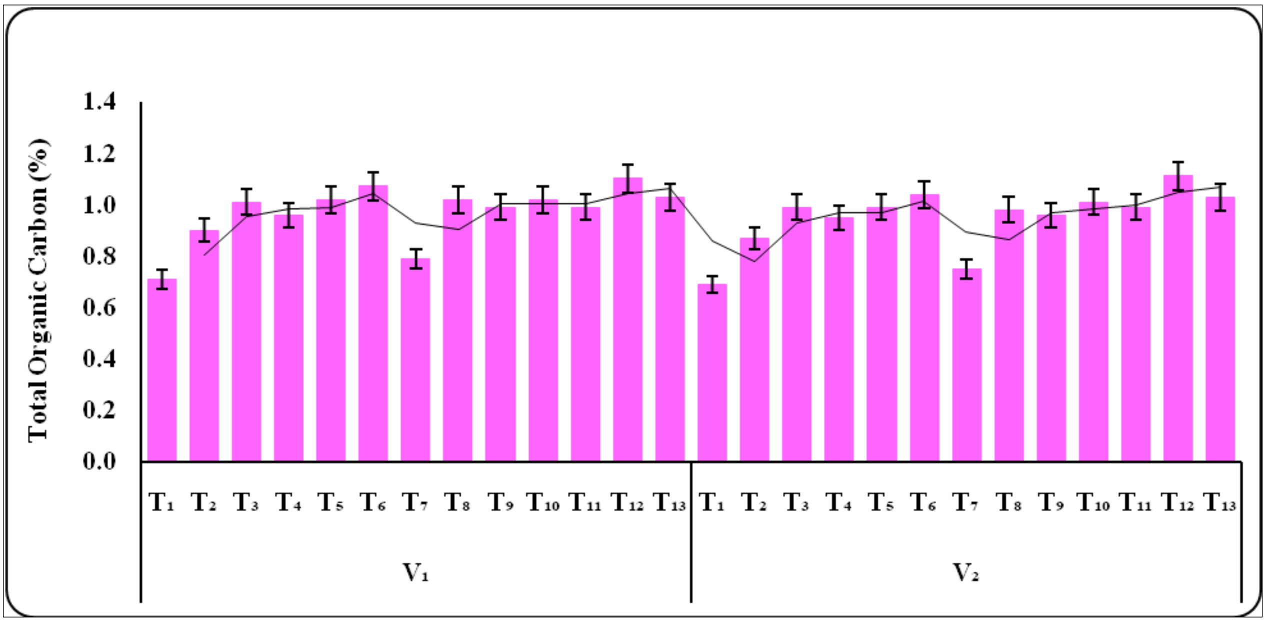

Fig. 5. Effect of organic sources of nutrients on total organic carbon (%).

solubilise native phosphorus (41). *Azotobacter* spp. have been found to improve the physicochemical and microbiological properties of soil, thereby enhancing the availability of nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) (42-44), while also contributing to organic carbon enrichment through nitrogen fixation and microbial decomposition (44, 45). Phosphate-solubilising bacteria further augment phosphorus availability, facilitating nutrient uptake (46). The combination of biofertilizers with organic fertilisers enhances microbial abundance, phosphatase activity and increases soil P and K content (47-49).

A correlation analysis conducted in the present study revealed trends consistent with these findings. Notably, potash content demonstrated moderate positive correlations with field life, vase life, total number of flowers per plant and flower diameter, signifying its role in enhancing post-harvest longevity and nutrient accumulation. Similarly, nitrogen and phosphorus content displayed positive correlations with flower diameter, field life and vase life (Fig. 6). Overall, the integration of vermicompost with biofertilizers substantially enhanced soil fertility, which directly translated into improved floral and post-harvest performance which directly addressed the critical issues of chemical residues and aligned with international trade standards specially in Europe and North American markets where preferences should be given to minimal chemical inputs. In organic cultivation, the initial input costs may be a consideration, but continuing this practice can lead to higher yields, higher net income and a better overall benefit-cost ratio of up to 3.69 compared to conventional methods. In developing countries, floriculture is a major source of export revenue. Transition to integrated organic management practices can enhance the competitiveness of the national industry on the global stage by aligning production with the demands of high-value markets.

Conclusion

The integrated application of vermicompost (5 t/ha), *Azotobacter* (2 g/plant) and phosphate-solubilising bacteria (2 g/plant) significantly improved vegetative growth, flowering performance and soil fertility in both chrysanthemum varieties. The integrated nutrient management protocol represents a sustainable approach to chrysanthemum cultivation, improving soil health and reducing reliance on synthetic fertilisers, with potential for enhancing flower quality and market value.

Authors' contributions

PS and DS carried out the whole research, performed the statistical analysis and drafted the manuscript. AS and PDT carried out the analysis and modification of original draft. IS and SM design the study and supervise the research. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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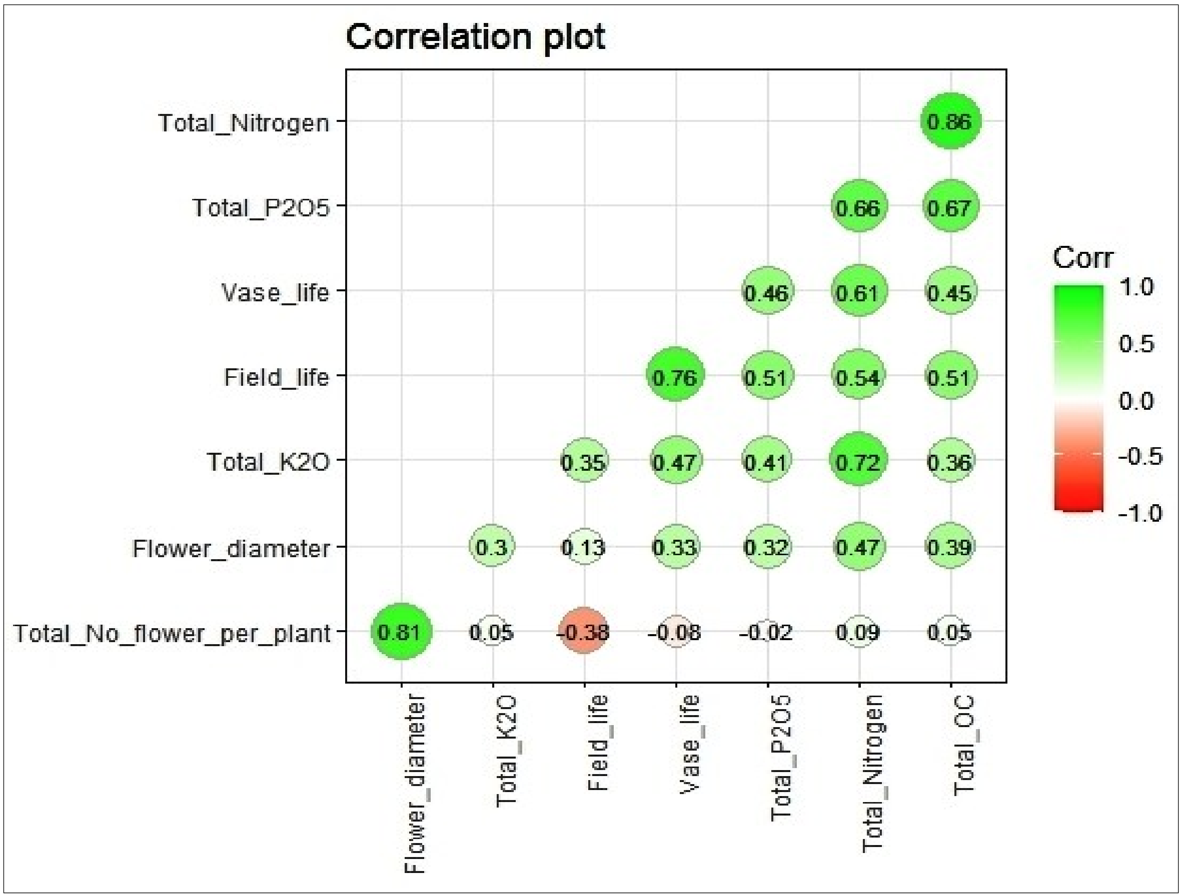

Fig. 6. Correlation between flowering attributes with soil NPK content.

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