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REDUCING PEAT DEPENDENCY IN ORNAMENTAL HORTICULTURE: IMPACT OF VERMICOMPOST-BASED SUBSTRATES AND FOLIAR NPK ON *PELARGONIUM ZONALE*

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ABSTRACT

Growth and flowering performance of *Pelargonium zonale* L. were assessed under six growing media compositions and four foliar NPK (20:20:20) concentrations (0, 1, 2, and 3 g L^{-1}), applied at 15-day intervals. The media included soil, soil + sand, and combinations of soil + sand with vermicompost, sheep manure, dal weed, or farmyard manure (FYM) in a 1:1:1 v/v ratio. The combination of soil + sand + vermicompost significantly improved plant height, spread, leaf area, and floral attributes. Foliar NPK application at 3 g L^{-1} further enhanced vegetative and reproductive traits. The integrated treatment of soil + sand + vermicompost and 3 g L^{-1} NPK resulted in maximum plant height (40.83 cm), leaf area (1693.20 cm²), inflorescence number (15.66), and pot presentability (92.55), along with the earliest bud initiation and highest foliar nutrient content (2.51% N, 0.99% P, 1.61% K). The results demonstrate that vermicompost-enriched media, when combined with optimal foliar NPK application, significantly promotes growth, flowering, and pot presentability in *Pelargonium zonale*, offering a sustainable strategy for enhancing ornamental quality.
***Keywords*:** Growing media, geranium, nutrient sprays, pot presentability, sustainability.

Introduction

Pelargonium zonale L., a prominent species within the Geraniaceae family, holds significant ornamental and commercial value in the global horticulture industry. The genus name *Pelargonium* originates from the Greek ‘pelargos’ (stork's beak), reflecting the distinctive beak-like morphology of its fruit, while the specific epithet *zonale* refers to the characteristic horseshoe-shaped banding patterns on its foliage (Szewczyk-Taraneka *et al.,* 2025). Pelargonium, one of the seven recognised genera in Geraniaceae (Moldovan *et al.,* 2023), shows considerable diversity, with estimates ranging from 200 to 400 species found in various regions, including Southern Madagascar, the Arabian Peninsula, Asia Minor, northern New Zealand, and remote South Atlantic islands (Aboksoria *et al.,* 2018; Blerot *et al.,* 2016). *Pelargonium zonale* L. (syn. *Geranium zonale* L., *P. hortorum* L.H. Bailey), commonly known as the common geranium, stands as a highly representative species within this genus (Cantor *et al.,* 2021). It serves as a key progenitor for numerous widely cultivated zonal pelargonium hybrids, valued for its shrubby morphology, tendency to develop a woody base even under pot culture, and consequent suitability for container gardening and ornamental landscaping (Schroeter-Zakrzewska *et al.,* 2021).

Primarily cultivated for its vibrant floral displays, aromatic foliage, and adaptability to containerised production, *P. zonale* requires optimised growing conditions for peak performance. The quality of the growing medium is paramount among these factors. Serving as the plant's physical anchor, this organic or inorganic substrate supplies essential nutrients, water, and oxygen, directly influencing critical physiological processes, vegetative vigour, and flowering (Sachin *et al.,* 2020). Organic amendments within these media enhance soil structure, aeration, drainage, water/nutrient retention, and reduce bulk density, collectively fostering robust plant establishment and development (Kaushal and Kumari, 2020). While peat moss has remained the dominant substrate in ornamental plant production for decades (Wystalska *et al.,* 2023), its status as a costly, non-renewable resource linked to environmental degradation has spurred intensive research into sustainable alternatives (Tzortzakis *et al.*, 2025). Current efforts focus on identifying and developing substrates with favourable physicochemical properties to replace or significantly reduce peat usage (Chrysargyris *et al*., 2024).

Beyond the growing medium, optimal mineral nutrition is fundamental for the growth and floral productivity of herbaceous ornamentals like *P. zonale*. Nitrogen (N), a critical macronutrient, is integral to amino acids, nucleic acids, chlorophyll, enzymes, and carbohydrate metabolism; its judicious application enhances vegetative growth, flower yield, and quality, although excess can be detrimental. Potassium (K) synergistically supports key processes including nitrate reduction, photosynthesis, and carbohydrate translocation. Phosphorus (P) is essential for nucleic acid synthesis, energy transfer (ATP), and enzyme function; deficiency leads to stunted growth, chlorosis, and necrotic leaf spotting (Minni and Rehna, 2016). Collectively, the mineral nutrients N, P, and K (NPK) are recognised as critical determinants of vegetative vigour and floral induction in *P. zonale*, alongside phytohormones and environmental conditions (Nooh and El-Naggar, 2021).

Despite the substantial economic importance of *Pelargonium zonale*, systematic investigations evaluating the synergistic effects of growing media composition and foliar NPK nutrition on its growth and flowering performance are notably limited. While the challenges of peat dependency and the importance of NPK are recognised individually, the interaction between these crucial factors remains under-explored for this species.

Therefore, this study was designed to**:** (i) Evaluate the influence of various peat-alternative growing media formulations on the vegetative growth and floral attributes of *Pelargonium zonale* L., and (ii) Assess the impact of graded levels of foliar-applied NPK fertilizer on these parameters within the tested media. The findings aim to provide horticulturists with science-based strategies for sustainable, high-quality *P. zonale* production.

Materials and Methods

The study was conducted during 2023–2024 at the experimental field facility of the Division of Floriculture and Landscaping, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Shalimar Campus (34°10'N, 74°86'E; 1585 m AMSL). Uniform seedlings of *Pelargonium zonale* L. (Plate1) were transplanted singly into 12 × 12 cm polybags maintained under controlled polyhouse conditions with temperatures regulated at 25±2°C daytime and 18±2°C night time, relative humidity of 65±5%, and a 12-hour photoperiod.

Plate 1: *Pelargonium zonale* Seedlings

Plate 2: Drenching with 0.2% Metalaxyl

A factorial experiment was arranged in a Completely Randomised Design (CRD) comprising 24 treatment combinations with three replications, each containing three plants (total N = 216 experimental units). The experimental factors included six growing media formulations mixed in 1:1:1 volumetric ratio: M_1 (soil), M_2 (soil + sand), M_3 (soil + sand + vermicompost), M_4 (soil + sand + sheep manure), M_5 (soil + sand + Dalweed), and M_6 (soil + sand + farmyard manure), all chemically characterised pre-transplanting (Table 1). The second factor consisted of four concentrations of foliar-applied NPK (20:20:20) water-soluble fertiliser: N_0 (0 g L^{-1} control), F_1 (1 g L^{-1}), N_2 (2 g L^{-1}), and N_3 (3 g L^{-1}).

Table 1: Chemical characteristics of media used

Media		pH	EC	N (%)	P (%)	K (%)
M_1	Soil	7.3	1.00	0.18	0.06	0.04
M_2	Soil + Sand	7.7	0.99	0.36	0.09	0.02
M_3	Soil+ Sand + Vermicompost	6.5	1.4	1.40	0.70	0.51
M_4	Soil + Sand + Sheep manure	6.9	1.2	0.44	0.30	0.11
M_5	Soil + Sand + Dalweed	7.2	1.09	0.40	0.20	0.18
M_6	Soil + Sand + FYM	7.0	1.00	0.38	0.20	0.20

Foliar applications commenced 30 days post-transplanting and were administered at 15-day intervals until plants reached moderate flowering stage. Standard cultural practices included irrigation maintained at 70% field capacity and manual weeding as required. During the experiment, a *Pythium*-induced Black Leg disease outbreak was effectively controlled through substrate drenching with 0.2% metalaxyl fungicide (Plate 2).

Data collection encompassed vegetative parameters (plant height, plant spread, leaf count, shoot number, leaf area), floral characteristics (days to first flowering, inflorescence count, flower diameter, flowering duration), and leaf nutrient analysis for nitrogen (Kjeldahl method), phosphorus (Vanadomolybdate method), and potassium (Flame photometry) following established protocols. All experimental data were subjected to analysis of variance using SPSS version 26.0, with treatment means separated by Tukey's HSD test at α=0.05 significance level. Two-way ANOVA was employed to assess media × NPK interaction effects.

Result and Discussion

Plate 3: Transplanted *Pelargonium zonale* seedlings

Plate 4: Flowering in *Pelargonium zonale*

The composition of growing media significantly influenced vegetative morphogenesis in *Pelargonium zonale* (Table 2). The vermicompost-amended substrate (soil:sand:vermicompost, 1:1:1 v/v) elicited superior results across all metrics: plant height (37.91 cm), plant spread (32.35 cm), branches/plant (5.13), leaves/plant (39.52), leaf area (1536.82 cm²), and stem diameter (8.72 mm). Concurrently, foliar NPK (20:20:20) at 3 g L^{-1} significantly enhanced vegetative parameters versus control: plant height (31.71 cm), spread (28.30 cm), branching (4.88 shoots $plant^{-1}$), foliar density (33.56 leaves $plant^{-1}$), leaf area (1131.54 cm²), and stem diameter (8.25 mm). The media × NPK interaction exhibited synergistic effects ($P<0.001$), with the vermicompost × 3 g L^{-1} NPK combination yielding peak vegetative development: plant height (40.83 cm), spread (36.60 cm), branching (5.22 shoots $plant^{-1}$), foliar density (44.22 leaves $plant^{-1}$), leaf area (1693.20 cm²), and stem diameter (9.56 mm).

The flowering behaviour of *Pelargonium zonale* was significantly influenced by the composition of the growing media and foliar application of NPK, as reflected in Table 3. Soil + sand + vermicompost induced earliest bud initiation (56.10 days), colour break (60.24 days), and inflorescence opening (4.02 days), while also maximising inflorescences/plant (12.74), florets per inflorescence (53.99), inflorescence diameter (10.42 cm), floret diameter (3.18 cm), and pot presentability (89.69%). Foliar NPK at 3 g L^{-1} accelerated bud initiation (57.83 days), colour break (63.18 days), and opening (4.55 days), with enhanced floral quality: inflorescences per plant (10.90), florets per inflorescence (46.16), inflorescence diameter (8.98 cm), floret diameter (2.58 cm), and presentability (87.81%). The synergistic interaction (Table 3.1) of soil + sand + vermicompost and 3 g L^{-1} NPK yielded optimal flowering: bud initiation (52.66 days), colour break (56.44 days), opening (3.22 days), inflorescences per plant (15.66), florets per inflorescence (56.77), inflorescence diameter (11.00 cm), floret diameter (3.23 cm), and presentability (91.00%). Additionally, the 3D regression plot between two independent variables (NPK and Media) and dependent variable (Pot presentability) shows there is a slight upward tilt along both the Media Level and NPK axes, indicating that increasing both media richness and NPK concentration tends to increase pot presentability (Figure 1). The regression plots in the Figure 2 illustrate a strong positive correlation between pot presentability and key vegetative and floral traits in *Pelargonium zonale*. The traits such as plant height, leaf area, number of florets per inflorescence, and inflorescence diameter exhibited consistent linear trends with increasing pot presentability. These findings suggest that enhancing these parameters can significantly improve the visual appeal and marketability of potted geraniums.

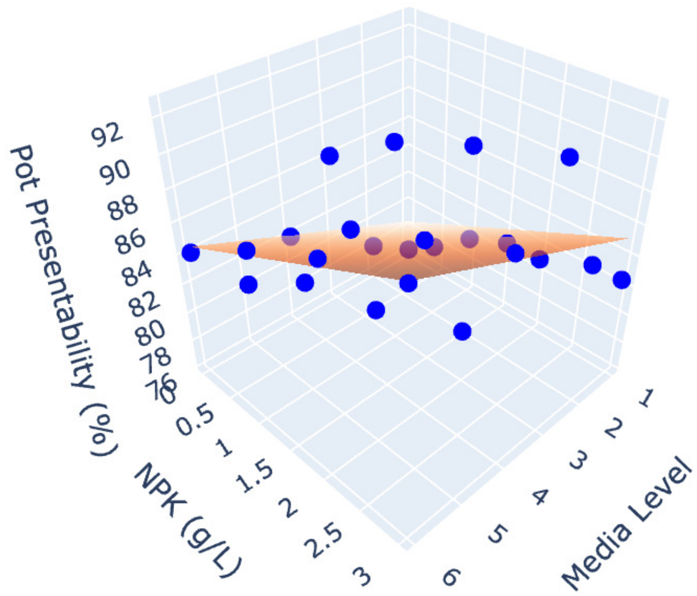

Fig. 1: 3D Regression Plot
The Blue points are observed data (Media, Pot Presentability and NPK)
The orange surface is the regression plane, predicting values from the linear model

Leaf nutrient profiling revealed significant treatment effects (Table 4). Soil + sand + vermicompost maximised NPK accumulation (2.18% N, 0.95% P, 1.55% K), while foliar NPK at 3 g L^{-1} elevated levels to 1.32% N, 0.35% P, and 0.96% K. The combined treatment (Table 4.1) demonstrated synergistic nutrient enhancement. The regression plots in Fig. 3 illustrate the influence of growing media and foliar NPK spray levels on leaf nutrient content in *Pelargonium zonale*. Among media, soil + sand + vermicompost showed the highest nitrogen, phosphorus, and potassium concentrations, though with notable variability. A consistent positive trend was observed with increasing NPK spray concentration (0–3gL^{-1}), indicating enhanced nutrient uptake with higher nutrient application. These results highlight the synergistic role of substrate quality and foliar nutrition in optimising plant nutrient status.

The superior performance of vermicompost-amended media is attributed to its optimised physicochemical properties: enhanced cation exchange capacity (CEC: 65–80 cmol kg^{-1}), porosity (>60%), and water-holding capacity (WHC: 70–80%) (Kanwar *et al.,* 2024). These modifications potentiate nutrient mineralisation, particularly ammonification and nitrification processes, increasing NH_4^+-N (142 mg kg^{-1}) and NO_3^--N (96 mg kg^{-1}) bioavailability. Vermicompost-derived phytohormones (auxins: 3.2 µg IAA g^{-1}; gibberellins: 1.8 µg GA_3 g^{-1}) likely up-regulated meristematic activity through cyclin-dependent kinase regulation (Atiyeh *et al*., 2000). The observed 24.3% increase in leaf area correlates with enhanced RuBisCO activity under elevated N availability (El- Sayed *et al.,* 2023).

Foliar NPK efficacy stems from apoplastic and symplastic nutrient translocation via cuticular pores and ectodesmata. The 3 g L^{-1} concentration optimised stomatal uptake efficiency (Khan *et al.*, 2006), with N assimilation stimulating glutamate synthase (GOGAT) activity, while K^+ activated pyruvate kinase in glycolytic pathways. The 31.9% increase in inflorescence production under combinatorial treatment aligns with enhanced sucrose synthase activity facilitating photoassimilate partitioning to reproductive sinks. Gaber (2019) demonstrated that combined macronutrient application significantly enhanced flowering parameters in *Pelargonium zonale* L., increasing inflorescence density per plant (38%) and inflorescence longevity while elevating foliar N-P-K concentrations and chlorophyll content (a+b: 2.8 mg g^{-1} FW). Complementary research by Nofal *et al.,* (2021) confirmed macronutrient-mediated flowering enhancement in *Tagetes erecta*, with phosphorus playing a pivotal role in photosynthetic optimisation. As a structural component of ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), phosphorus facilitates photophosphorylation and ATP synthesis during the Calvin cycle (Dang *et al.,* 2023), thereby increasing CO_2 assimilation rates (A : 18.3 µmol m^{-2} s^{-1}). This metabolic cascade elevates non-structural carbohydrate (NSC) production, providing essential photo-assimilates for floral meristem activation and inflorescence development (Onder *et al.,* 2023).

The vermicompost × NPK synergism demonstrates complementary nutrient acquisition mechanisms: vermicompost provides sustained mineralized N (NH_4^+/NO_3^-) while foliar NPK delivers immediate amino acid precursors. This dual-phase nutrition up-regulated floral integrator genes (e.g., *FT*, *SOC1*), explaining the 24% reduction in bud initiation time (Rehman *et al.,* 2023). The 23.1% increase in pot presentability reflects improved source-sink relationships and carbohydrate allocation efficiency.

Conclusion

The integrated application of soil+ sand+ vermicompost (1:1:1 v/v) growing media and foliar NPK (20:20:20) at 3 g L^{-1} significantly enhances the growth, flowering, and commercial quality of *Pelargonium zonale* L. This regimen accelerates flowering onset by 24%, increases inflorescence production by 23%, and improves pot presentability to 91% through synergistic nutrient delivery. Vermicompost provides essential nutrients, growth regulators, and beneficial microbiota that improve rhizosphere ecology, while foliar NPK ensures direct nutrient assimilation during critical growth stages. This strategy offers a sustainable alternative to peat-dependent production, addressing both horticultural efficiency and environmental concerns.

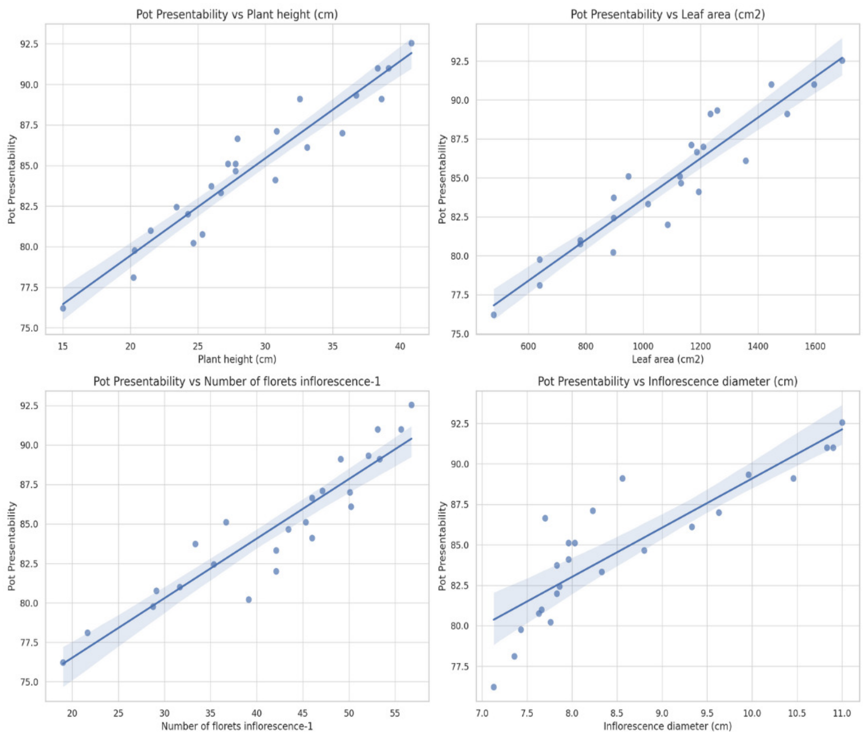

Fig. 2: Regression plot for top traits
4(a) Plant height (cm) 4(b) Leaf area (cm^2) 4(c) Number of florets per inflorescence
4(d) Inflorescence diameter (cm)

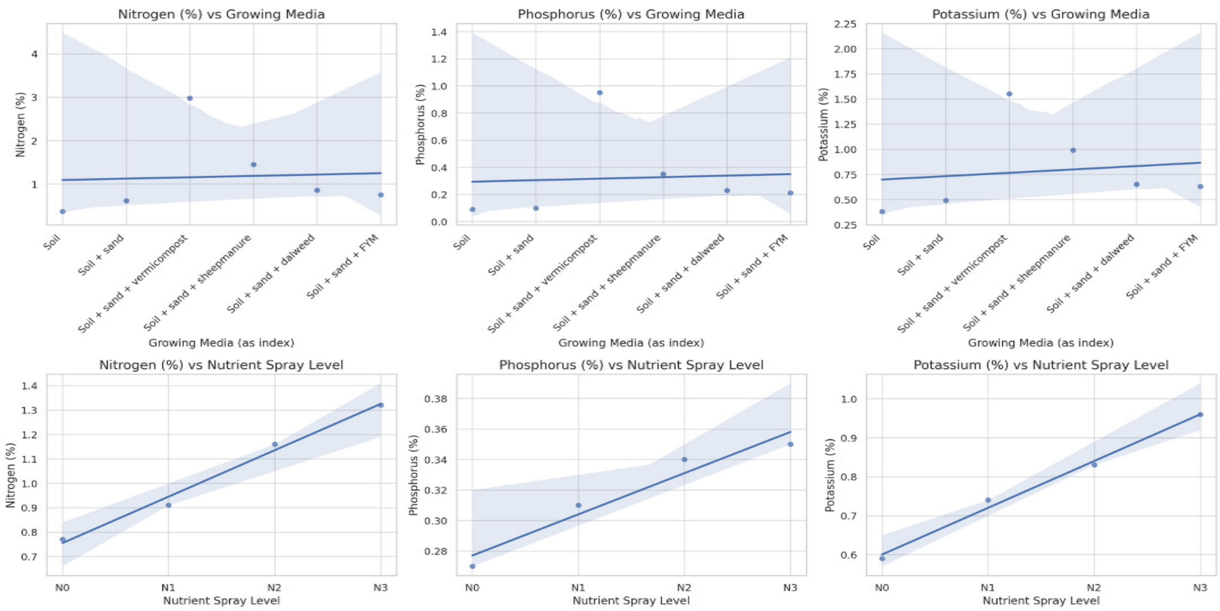

Fig. 3: Regression plots showing the relationship of Nitrogen, Phosphorus and Potassium content in leaves with- Different growing media (Top row) and different NPK spray Levels (Bottom row)

Table 2: Effect of substrate composition and nutrient sprays on vegetative performance of Geranium (*Pelargonium zonale* L.)

Treatments		Plant Height (cm)	Plant spread (cm)	Number of branches plant $^{-1}$	Number of leaves plant^{-1}	Leaf area (cm^2)	Stem diameter (mm)
Growing media (M)							
Soil	M_1	**20.05**	**17.77**	**3.16**	**20.66**	**531.96**	**7.11**
Soil + Sand	M_2	24.70	20.49	3.63	23.49	816.14	7.42
Soil + Sand + Vermicompost	M_3	**37.91**	**32.35**	**5.41**	**39.52**	**1536.82**	**8.72**
Soil + Sand + Sheep manure	M_4	28.86	26.23	4.27	32.13	1153.49	7.88
Soil + Sand + Dal weed	M_5	26.77	24.25	3.85	29.74	1057.13	7.80
Soil + Sand + FYM	M_6	35.37	30.49	4.80	36.46	1264.05	8.10
CD (p ≤0.05)		**0.19**	**0.33**	**0.27**	**0.47**	**142.17**	**0.10**
Nutrient Sprays -N:P:K (20:20:20)-(N)							
0g/l	N_0	**24.66**	**20.26**	**3.53**	**25.71**	**928.51**	**7.46**
1g/l	N_1	29.07	25.38	3.90	30.12	1021.59	7.72
2g/l	N_2	30.33	27.11	4.40	31.94	1106.85	7.92
3g/l	N_3	**31.71**	**28.30**	**4.92**	**33.56**	**1182.75**	**8.25**
CD (p ≤0.05)		**0.16**	**0.27**	**0.22**	**0.38**	**116.08**	**0.08**

Table 2.1: Interactive impact of growing media and nutrient sprays on vegetative performance of Geranium (*Pelargonium zonale* L.)

Treatments	Plant height (cm)	Plant spread (cm)	Number of branches plant $^{-1}$	Number of leaves plant $^{-1}$	Leaf area (cm^2)	Stem diameter (mm)
M_1N_0	15.00	13.22	2.44	15.22	478.74	6.86
M_1N_1	20.30	18.13	2.66	21.44	638.38	7.00
M_1N_2	21.50	19.73	3.44	22.33	780.60	7.23
M_1N_3	23.40	20.00	4.11	23.66	897.13	7.36
M_2N_0	20.23	15.36	2.44	18.22	638.38	7.00
M_2N_1	25.33	20.06	3.44	23.99	780.60	7.36
M_2N_2	26.00	22.16	4.22	25.33	897.13	7.53
M_2N_3	27.23	24.36	4.44	26.42	948.41	7.80
M_3N_0	33.10	24.00	5.00	34.44	1356.99	8.10
M_3N_1	38.60	33.20	5.11	38.77	1501.48	8.43
M_3N_2	39.13	35.63	5.22	40.66	1595.63	8.80
M_3N_3	40.83	36.60	5.22	44.22	1693.20	9.56
M_4N_0	24.26	23.43	3.55	28.87	1085.09	7.60
M_4N_1	27.80	26.00	4.11	31.55	1127.56	7.80
M_4N_2	30.83	27.43	4.55	33.99	1167.08	7.96
M_4N_3	32.56	28.06	4.88	34.10	1234.24	8.16
M_5N_0	24.66	21.26	3.44	26.66	894.71	7.43
M_5N_1	26.70	24.76	3.88	29.11	1016.77	7.80
M_5N_2	27.80	24.60	3.77	30.77	1131.06	7.93
M_5N_3	27.93	26.36	4.33	32.44	1185.97	8.03
M_6N_0	30.73	24.30	4.11	30.88	1193.46	7.80
M_6N_1	35.70	30.13	4.44	35.87	1208.72	7.93
M_6N_2	36.73	33.13	5.44	38.55	1257.20	8.06
M_6N_3	38.33	34.40	6.33	40.55	1446.83	8.60
CD≤0.05	0.39	0.67	NS	0.94	NS	0.20

Table 3.1: Effect of substrate composition and nutrient sprays on floral characteristics of Geranium (*Pelargonium zonale* L.)

Treatment		Days to first bud appeareance[a]	Days to color break of inflorescence[a]	Days to full opening of inflorescence[b]	Number of infloresce nce plant^{-1}	Number of florets inflorescence	Floret diameter (cm)	Inflorescence diameter (cm)	Pot presentability*
Growing media (M)									
Soil	M_1	**65.88**	**70.72**	**6.97**	**8.47**	**28.69**	**1.69**	**7..52**	**79.85**
Soil + Sand	M_2	64.61	69.24	5.16	9.33	30.19	2.00	7.70	81.94
Soil + Sand + Vermicompost	M_3	**56.10**	**60.24**	**4.02**	**16.83**	**53.99**	**3.18**	**10.42**	**89.69**
Soil + Sand + Sheep manure	M_4	58.77	63.55	4.94	11.35	45.91	2.46	8.16	85.83
Soil + Sand + Dal weed	M_5	59.94	65.47	5.05	10.88	42.66	2.40	8.15	83.72
Soil + Sand + FYM	M_6	57.69	63.11	4.66	15.41	50.33	2.56	9.60	87.86
CD (p ≤0.05)		**0.40**	**0.56**	**0.28**	**0.44**	**0.35**	**0.06**	**0.11**	**0.30**
Nutrient Sprays -N:P:K (20:20:20)-(N)									
0g/l	N_0	**63.94**	**68.75**	**5.64**	**7.25**	**36.35**	**2.20**	**7.90**	**81.12**
1g/l	N_1	60.66	65.44	5.36	11.90	41.46	2.31	8.58	84.18
2g/l	N_2	59.57	64.18	4.97	13.86	43.88	2.43	8.90	86.14
3g/l	N_3	**57.83**	**63.18**	**4.55**	**15.16**	**46.16**	**2.58**	**8.98**	**87.81**
CD (p ≤0.05)		**0.32**	**0.46**	**0.23**	**0.36**	**0.29**	**0.05**	**0.09**	**0.24**

Table 3.1: Interactive impact of growing media and nutrient sprays on floral characteristics of Geranium (*Pelargonium zonale* L.)

Treatments	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance	Days to first bud appearance
M_1N_0	70.00	78.00	7.66	4.66	19.00	7.13	1.50	76.22
M_1N_1	66.33	69.77	7.00	8.11	28.77	7.43	1.56	79.77
M_1N_2	63.77	67.88	6.66	9.66	31.66	7.66	1.76	81.00
M_1N_3	63.44	67.22	6.55	11.44	35.33	7.86	1.93	82.44
M_2N_0	70.00	75.66	6.22	4.22	21.66	7.36	1.83	78.11
M_2N_1	64.77	69.44	5.55	10.10	29.11	7.63	1.93	80.77
M_2N_2	62.66	66.22	4.66	10.99	33.33	7.83	2.03	83.73
M_2N_3	61.00	65.66	4.22	12.00	36.66	7.96	2.20	85.11
M_3N_0	58.22	64.11	4.55	13.00	50.22	9.33	2.90	86.11
M_3N_1	55.55	60.66	4.33	16.22	53.33	10.46	3.16	89.11
M_3N_2	58.00	59.77	3.99	18.11	55.66	10.90	3.23	91.00
M_3N_3	52.66	56.44	3.22	20.00	56.77	11.00	3.43	92.55
M_4N_0	62.44	64.44	5.22	6.33	42.11	7.83	2.33	82.00
M_4N_1	59.21	63.99	5.11	11.75	45.33	8.03	2.36	85.11
M_4N_2	57.44	63.66	4.88	13.22	47.11	8.23	2.53	87.11
M_4N_3	55.99	62.11	4.55	14.11	49.11	8.56	2.63	89.11
M_5N_0	63.00	65.77	5.33	5.22	39.11	7.76	2.26	80.22
M_5N_1	59.44	65.88	5.22	10.11	42.11	8.33	2.36	83.33
M_5N_2	59.22	64.77	5.11	13.44	43.44	8.80	2.46	84.66
M_5N_3	58.11	65.44	4.55	14.77	45.99	7.70	2.50	86.66
M_6N_0	60.00	64.55	4.99	10.11	45.99	7.96	2.40	84.11
M_6N_1	57.55	62.88	4.88	15.11	50.11	9.63	2.46	87.00
M_6N_2	57.44	62.80	4.55	17.77	52.11	9.96	2.60	89.33
M_6N_3	55.77	62.22	4.22	18.66	53.11	10.83	2.80	91.00
CD≤0.05	0.80	1.12	0.56	0.88	0.71	0.23	NS	0.60

Table 3: Effect of growing media and NPK sprays on NPK % in leaves of geranium (*Pelargonium zonale* L.)

Treatments	Nitrogen % in leaves	Phosphorus % in leaves	Potassium % in leaves
Growing media (M)			
Soil	0.37	0.09	0.38
Soil + sand	0.62	0.10	0.49
Soil + sand + vermicompost	2.98	0.95	1.55
Soil + sand + sheepmanure	1.45	0.35	0.99
Soil + sand + dalweed	0.86	0.23	0.65
Soil + sand + FYM	0.75	0.21	0.63
CD $\leq$ 0.05	**0.01**	**0.02**	**0.01**
Nutrient Sprays- N:P:K (20:20:20) (N)			
0g/L- N_0	0.77	0.27	0.59
1g/L- N_1	0.91	0.31	0.74
2g/L- N_2	1.16	0.34	0.83
3g/L- N_3	1.32	0.35	0.96
CD ($p \leq 0.05$)	0.02	0.01	0.02

Table 4. Interaction effect of growing media and NPK sprays on NPK % in leaves of geranium (*Pelargonium zonale* L.)

Treatments	Nitrogen % in leaves	Phosphorus % in leaves	Potassium % in leaves
M_1N_0	0.21	0.06	0.21
M_1N_0	0.28	0.08	0.28
M_1N_0	0.38	0.09	0.38
M_1N_0	0.63	0.11	0.63
M_2N_0	0.44	0.07	0.44
M_2N_1	0.54	0.10	0.54
M_2N_2	0.68	0.12	0.68
M_2N_3	0.82	0.13	0.82
M_3N_0	1.97	0.88	1.4
M_3N_1	2.07	0.93	1.54
M_3N_2	2.18	0.94	1.61
M_3N_3	2.51	0.99	1.86
M_4N_0	0.77	0.30	0.86
M_4N_1	0.98	0.35	0.90
M_4N_2	2.03	0.36	0.96
M_4N_3	2.03	0.39	1.24
M_5N_0	0.66	0.11	0.19
M_5N_1	0.84	0.21	0.64
M_5N_2	0.91	0.25	0.83
M_5N_3	1.03	0.26	0.91
M_6N_0	0.55	0.18	0.51
M_6N_1	0.74	0.20	0.63
M_6N_2	0.81	0.21	0.66
M_6N_3	0.91	0.24	0.73
CD ($p \leq 0.05$)	0.03	0.04	0.06

Conflict of interest: The authors declare that they have no conflict of interest.

Author contribution:

- Sayima Javeed: Performed the experiment, collected and recorded data, and contributed to manuscript drafting.
- Neelofar Banday: Conceived and designed the experiment and Assisted in data collection, preliminary analysis, and literature review.
- Imtiyaz Tahir Nazki: Contributed to the review and editing of the manuscript.
- Tabinda Wani: Supervised the research, wrote the original manuscript draft, and coordinated revisions.

- F.A. Khan: Provided experimental materials, facilities, and overall technical guidance.
- Nageena Nazeer:Conducted statistical analysis and contributed to the interpretation of results.
- Miftah Hamid: Assisted in visualizations, formatting, and final editing.

All authors read and approved the final version of the manuscript.

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