*International Journal of Environment, Agriculture and Biotechnology*
*Vol-10, Issue-3; May-Jun, 2025*
*Peer-Reviewed International Journal*
*Journal Home Page Available: https://ijeab.com/*
*Journal DOI: 10.22161/ijeab*

# Effect of Nitrogen Sources and Plant Spacing on Morphological Traits of Kalmegh (*Andrographis paniculata* Nees) under Malwa Agro-Climatic Conditions of Madhya Pradesh

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Received: 07 Apr 2025; Received in revised form: 04 May 2025; Accepted: 11 May 2025; Available online: 17 May 2025


***Abstract*— *The field experiment trial titled "Effect of nitrogen sources and plant geometry on herbage yield and nutrient uptake in Kalmegh (Andrographis paniculata Nees.)" under Malwa Plateau of Madhya Pradesh" was carried out in at Herbal Garden Department of Plantation, Spices, Medicinal and Aromatic Crops, KNK College of Horticulture, Mandsaur (M.P.) during the Kharif season 2024-25. The experimental Observations on morphological parameters were recorded using standard methods. The study assessed key morphological parameters, including plant height (cm), number of leaves per plant, and number of branches per plant. Observations were recorded from five randomly selected plants at intervals of 30, 60, 90, and 120 days after transplanting (DAT), as well as at harvest. The results indicated that the nitrogen treatment $N_1$ (40 kg N applied through vermicompost combined with 40 kg N through urea) resulted in the highest values for plant height, number of branches, and number of leaves. Among the spacing treatments, $S_1$ (20 × 10 cm) was found to be the most effective, also producing the maximum plant height, number of branches, and number of leaves. Furthermore, the combined treatment of $S_1 \times N_1$ consistently recorded the highest values for all morphological traits across all growth stages, including 30, 60, 90 DAT, and at harvest.*

***Keywords*— Kalmegh, nitrogen sources, plant geometry, herbage yield, nutrient uptake.**

## I. INTRODUCTION

Kalmegh (*Andrographis paniculata* Nees.), commonly known as the "King of Bitters," is a medicinal herb belonging to the Acanthaceae family. Native to South Asia, particularly India and Sri Lanka, it is now cultivated in various tropical regions worldwide. Kalmegh has been utilized in traditional medicine systems such as Ayurveda, Siddha, and Chinese medicine for centuries. Its applications include treating fevers, liver disorders, respiratory infections, and digestive issues (Shende *et al*., 2025). The plant's therapeutic properties are attributed to its rich phytochemical profile, notably andrographolide, a diterpenoid lactone. Other bioactive compounds include flavonoids (quercetin, kaempferol), polyphenols, steroidal saponins, tannins, and alkaloids, contributing to its antioxidant, anti-inflammatory, and antidiabetic effects. (Banerjee *et al*., 2021). Kalmegh exhibits a broad spectrum of pharmacological activities: Andrographolide enhances insulin secretion, improves glucose tolerance, and exhibits anti-inflammatory and antioxidant activities, contributing to blood glucose regulation. Antiviral and Immunomodulatory Properties: Studies have shown that Kalmegh can modulate immune responses and inhibit viral replication, making it a candidate for managing viral infections (Bhaisare *et al*., 2023). Antimicrobial and Antioxidant Activities: The plant demonstrates significant antimicrobial properties against various pathogens and exhibits strong antioxidant effects, supporting its use in treating infections and oxidative stress-related conditions. Recent studies have highlighted the importance of nutrient management in Kalmegh cultivation. Applying foliar sprays of zinc and iron has been shown to enhance plant growth, chlorophyll content, and overall biomass, suggesting that micronutrient supplementation can improve yield and quality (Basak *et al*., 2020). Kalmegh (*Andrographis paniculata*) is a valuable herb with a diverse range of therapeutic applications, supported by a robust phytochemical profile and pharmacological evidence. Ongoing research continues to explore its potential in modern medicine, emphasizing the importance of sustainable cultivation practices to meet growing demand (Bhatnagar *et al*., 2023).

## II. MATERIALS AND METHODS

**Experimental site and soil:** The field experiment was carried out at the Herbal Garden, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Mandsaur (M.P.) Crops, College of Horticulture, Mandsaur, under Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior (M.P.) during kharif season of 2024-2025. The College of Horticulture, Mandsaur is situated in Malwa plateau in Western part of Madhya Pradesh at 23.45° to 24.13° North latitude, 74.44° to 75.18° East longitudes and at an altitude of 435 meters above mean sea level. This region falls under agro climatic zone No.9 of the State. Soil samples were collected from a depth of 10–15 cm at multiple locations across the experimental field, following standard sampling protocols prior to fertilizer application. A representative composite sample was prepared by thoroughly mixing the individual samples. Upon analysis, the soil was found to be light black and loamy in texture, characterized by low levels of available nitrogen and phosphorus, but a high potassium content.

**Experimental design and treatments:** The experiment was designed using Factorial Randomized Block Design (FRBD) and conducted in triplicate, with each plot covering an area of 4.32 $m^2$ (3.60 x 1.20 m) and Total experimental Area was 399.43 $m^2$ (14.96 × 26.70 m). The treatments are Main plots (04) Geometry: $S_1$ – 20 X 10, $S_2$ – 20 X 15, $S_3$ – 20 X 20, $S_4$ – 30 X 10 and Sub plots (04) N Sources: $N_1$- 40 kg N through Vermicompost + 40 kg N through Urea, $N_2$- 60 kg N through Vermicompost + 20 kg N through Urea, $N_3$- 80 kg N through Vermicompost, $N_4$- RDF (80 kg/ha N: 30 kg/ha P: 50 kg/ha K) NPK (80 kg/ha: 30 kg/ha: 50 kg/ha) and their 16 interactions are been observed..

**Observations recorded:** Observations on flowering parameters were recorded using standard methods. Key parameters included the morphological parameters such as Plant height (cm) at 30, 60, 90, 120 DAT and at harvest, Number of leaves ($Plant^{-1}$), Number of branches ($Plant^{-1}$), Five plants were randomly selected. They were measured at 30, 60, 90 and 120 DAT and at harvest. The plant height was measured from the ground level to the tip of the main shoot. The average was taken out and expressed as plant height in cm. The total number of leaves per plant was recorded at 30, 60, 90 and 120 DAT and at harvest and at harvest from the tagged plants and the average was worked out. The total number of primary branches per plant was recorded at 30, 60, 90 and 120 DAT and at harvest and at harvest from the tagged plants and the average was worked out. These measurements were taken from the net plot area of each treatment. The data for various parameters were analyzed using the analysis of variance method as outlined by (Panse and Sukhatme 1985).

**Statistical analysis:** The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique for a randomized block design. The results are presented at 5% level of significance (P=0.05).

## III. RESULTS AND DISCUSSION

**Morphological parameters**

**Plant height (cm) at 30, 60, 90, 120 DAT and at harvest**

The effects of nitrogen sources, planting geometries, and their interactions on plant height at different growth stages (30, 60, 90, 120 days after transplanting, and at harvest) were found to be significant. These results are summarized in Table 1 and illustrated in Figure 1.

**(30 DAT)** Among the planting geometry, $S_1$-20 X 10 cm produced the tallest plants (10.34 cm), followed by $S_3$-20 X 20 cm (9.63 cm) and $S_2$-20 X 15 cm (9.61 cm). The shortest plants were observed in $S_4$-30 X 10 cm (8.71 cm). Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea exhibited the highest plant height (10.00 cm), followed by N3-80 kg N through vermicompost (9.99 cm). The shortest plant height (8.76 cm) was observed in $N_2$-60 kg N through vermicompost + 20 kg N through Urea. In the interaction, plant height ranged from 6.77 cm to 11.58 cm. The combination $S_1 \times N_1$ produced the tallest plants (11.58 cm), followed by $S_3 \times N_1$ (11.20 cm). On the other hand, the shortest plants (6.77 cm) were observed with $S_3 \times N_2$. **(AT 60 DAT)** Among the main factors planting geometry, the tallest plants were recorded in $S_1$-20 X 10 cm (23.18 cm), followed by $S_3$-20 X 20 cm (22.28 cm) and $S_2$-20 X 15 cm (21.69 cm). The shortest plants were observed in $S_4$-30 X 10 cm (20.40 cm). Under sub factors nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea accumulated the maximum plant height (22.87 cm), followed closely by $N_3$-80 kg N through vermicompost (22.59 cm). The shortest height was observed with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (19.83 cm). During the interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (26.43 cm), followed by $S_3 \times N_1$ (23.57 cm) and $S_1 \times N_3$ (23.77 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (19.40 cm). **(AT 90 DAT)** Among the planting geometry, the tallest plants were recorded in $S_1$-20 X 10 cm (39.35 cm), followed by $S_3$-20 X 20 cm (37.91 cm) and $S_2$-20 X 15 cm (37.80 cm). The shortest plants were observed in $S_4$-30 X 10 cm (36.37 cm). Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (38.84 cm), followed closely by $N_3$-80 kg N through vermicompost (38.63 cm). The shortest height was observed with N2-60 kg N through vermicompost + 20 kg N through Urea (36.09 cm). The interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (42.26 cm), followed by $S_1 \times N_3$ (40.69 cm) and $S_3 \times N_4$ (40.77 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (34.26 cm). **(AT 120)** In the planting geometry, the tallest plants were recorded in S1-20 X 10 cm (45.95 cm), followed by $S_3$-20 X 20 cm (45.24 cm) and $S_2$-20 X 15 cm (45.10 cm). The shortest plants were observed in $S_4$-30 X 10 cm (44.92 cm). Though, in the nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (45.88 cm), followed by $N_3$-80 kg N through vermicompost (45.85 cm). The shortest height was observed with $N_2$- 60 kg N through vermicompost + 20 kg N through Urea (44.59 cm). The interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (47.87 cm), followed by $S_3 \times N_3$ (46.33 cm) and $S_1 \times N_3$ (46.30 cm). On the other hand, the shortest plants were recorded in $S_3 \times N_2$ (42.62 cm). **(At harvest)** During the planting geometry, tallest plants were recorded in $S_1$-20 X 10 cm (50.37 cm), followed by $S_3$-20 X 20 cm (48.55 cm) and $S_2$-20 X 15 cm (48.39 cm). The shortest plants were observed in $S_4$-30 X 10 cm (47.48 cm). The sub plots as nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea exhibited the maximum plant height (49.36 cm), followed closely by $N_3$-80 kg N through vermicompost (49.29 cm). The shortest height was observed with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (47.31 cm). Regarding the interaction effects (S × N) showed a significant variation in plant height. The combination $S_1 \times N_1$ produced the tallest plants (53.25 cm), followed by $S_1 \times N_3$ (51.27 cm) and $S_3 \times N_4$ (51.02 cm). On the other hand, the shortest plants were recorded in $S_4 \times N_4$ (45.99 cm).

Plant height, a crucial morphological trait, was significantly affected by planting geometry, nitrogen sources, and their interaction across various growth stages. Among the planting geometries, $S_1$ (20 × 10 cm spacing) consistently resulted in the tallest plants, recording heights of 10.34, 23.18, 39.25, 45.95, and 50.37 cm at 30, 60, 90, 120 days after transplanting, and at harvest, respectively. This can be attributed to more efficient resource utilization and the close spacing, which encourages vertical growth by minimizing lateral competition. Conversely, the $S_4$ spacing (30 × 10 cm) produced the shortest plants, with corresponding heights of 8.71, 20.40, 36.37, 44.92, and 47.48 cm, likely due to reduced plant density and less competition, resulting in slower vertical development. Nitrogen source also played a significant role, with the highest plant height observed under the $N_1$ treatment (40 kg N from vermicompost + 40 kg N from urea), achieving 10.00, 22.87, 38.94, 45.88, and 49.36 cm at successive stages. In contrast, the lowest plant height was recorded with $N_2$ (60 kg N from vermicompost + 20 kg N from urea), measuring 8.76, 19.83, 36.09, 44.59, and 47.31 cm. The enhanced vegetative growth under $N_1$ can be attributed to the synergistic effect of combining organic and inorganic nitrogen sources, which improves nutrient availability and uptake. The interaction between spacing and nitrogen source further emphasized these trends. The combination $S_1 \times N_1$ produced the tallest plants—11.58, 26.43, 42.26, 47.87, and 53.25 cm—across the observed stages. In contrast, the $S_3 \times N_2$ combination resulted in the shortest plants, with heights of 6.77, 19.40, 34.26, 45.43, and 46.57 cm. These findings highlight the beneficial effects of closer spacing paired with balanced nutrient application on enhancing plant height. These results align with the findings of (Kumar *et al*., 2020), who reported that integrated nutrient management and optimized plant spacing significantly improve plant height in medicinal crops. Similar findings were also reported by (Cheena *et al*., 2020), (Mishra and Jain 2014), (Onsa *et al*., 2022) and (Shakywa *et al*., 2022).

*Table 1: Effect of N sources, planting geometries, and their interactions on plant height (cm) at various growth stages in Kalmegh.*

| Treatments | | 30 DAT | 60 DAT | 90 DAT | 120 DAT | At harvest |
|---|---|---|---|---|---|---|
| **N Sources** | | | | | | |
| $N_1$ | **40kg N by vermi +40 kg N by Urea** | 10.00 | 22.87 | 38.84 | 45.88 | 49.36 |
| $N_2$ | **60kg N by vermi +20 kg N by Urea** | 8.76 | 19.83 | 36.09 | 44.59 | 47.31 |
| $N_3$ | **80 kg N by Vermicompost** | 9.99 | 22.59 | 38.63 | 45.85 | 49.29 |
| $N_4$ | **RDF** | 9.55 | 22.25 | 37.87 | 44.89 | 48.82 |
| **S.Em ±** | | **0.16** | **0.24** | **0.50** | **0.18** | **0.34** |
| **CD at 5%** | | **0.46** | **0.69** | **1.43** | **0.53** | **0.97** |
| **Geometry** | | | | | | |
| $S_1$ | **20 X 10 cm** | 10.34 | 23.18 | 39.35 | 45.95 | 50.37 |
| $S_2$ | **20 X 15 cm** | 9.61 | 21.69 | 37.80 | 45.10 | 48.39 |
| $S_3$ | **20 X 20 cm** | 9.63 | 22.28 | 37.91 | 45.24 | 48.55 |
| $S_4$ | **30 X 10 cm** | 8.71 | 20.40 | 36.37 | 44.92 | 47.48 |
| **S.Em ±** | | **0.16** | **0.24** | **0.50** | **0.18** | **0.34** |
| **CD at 5%** | | **0.46** | **0.69** | **1.43** | **0.53** | **0.97** |
| **Interaction S (Geometry) x N (Sources)** | | | | | | |
| $S_1 \times N_1$ | | 11.58 | 26.43 | 42.26 | 47.87 | 53.25 |
| $S_2 \times N_1$ | | 9.17 | 21.84 | 38.71 | 45.45 | 48.41 |
| $S_3 \times N_1$ | | 11.20 | 23.57 | 39.17 | 46.25 | 49.27 |
| $S_4 \times N_1$ | | 8.03 | 19.63 | 35.23 | 43.95 | 46.52 |
| $S_1 \times N_2$ | | 8.98 | 20.10 | 36.18 | 45.43 | 46.81 |
| $S_2 \times N_2$ | | 8.93 | 20.33 | 36.29 | 45.43 | 46.57 |
| $S_3 \times N_2$ | | 6.77 | 19.40 | 34.26 | 42.62 | 46.30 |
| $S_4 \times N_2$ | | 10.36 | 19.49 | 37.61 | 44.87 | 49.55 |
| $S_1 \times N_3$ | | 10.86 | 23.77 | 40.69 | 46.30 | 51.27 |
| $S_2 \times N_3$ | | 9.93 | 22.43 | 39.51 | 45.03 | 50.47 |
| $S_3 \times N_3$ | | 9.83 | 22.80 | 37.43 | 45.73 | 47.59 |
| $S_4 \times N_3$ | | 9.32 | 21.36 | 36.90 | 46.33 | 47.84 |
| $S_1 \times N_4$ | | 9.93 | 22.40 | 38.27 | 44.20 | 50.16 |
| $S_2 \times N_4$ | | 10.39 | 22.17 | 36.69 | 44.47 | 48.11 |
| $S_3 \times N_4$ | | 10.72 | 23.33 | 40.77 | 46.37 | 51.02 |
| $S_4 \times N_4$ | | 7.14 | 21.10 | 35.73 | 44.53 | 45.99 |
| **S.Em ±** | | **0.32** | **0.48** | **0.99** | **0.37** | **0.67** |
| **CD at 5%** | | **0.92** | **1.39** | **2.87** | **1.07** | **1.94** |

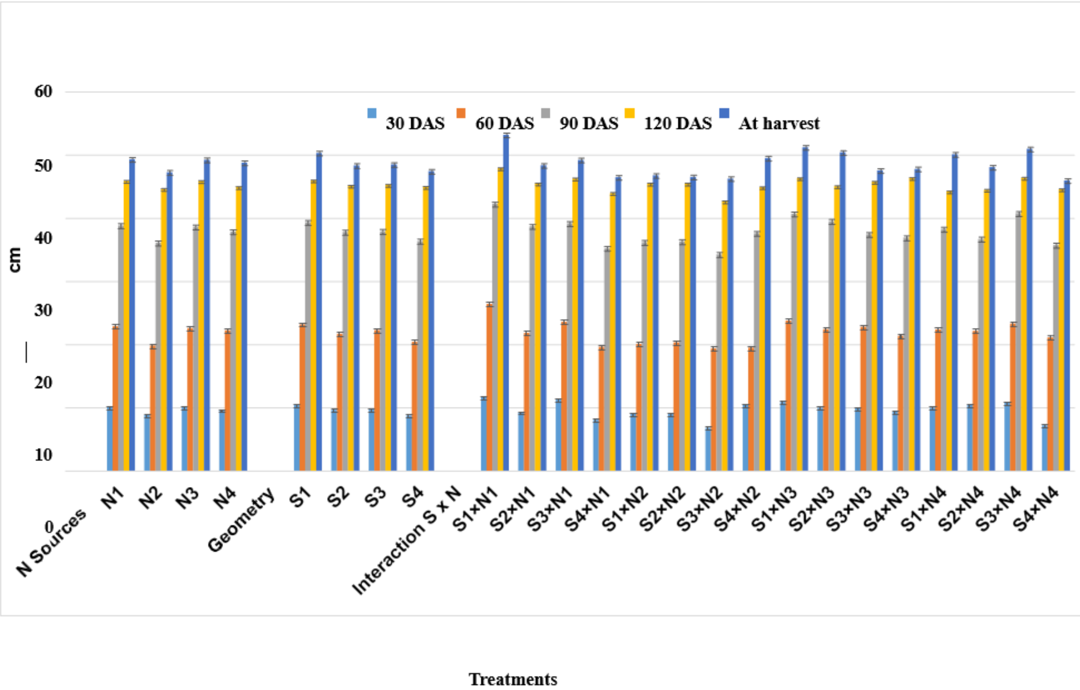


*Fig.- 1 Effect of nitrogen sources, planting geometries, and their interactions on plant height (cm) at various growth stages in Kalmegh*

**Number of branches (plant$^{1}$) at 30, 60, 90, 120 DAT and at harvest**

The number of branches was significantly affected by the application of different nitrogen sources and planting geometries across various growth stages (30, 60, 90, 120 days after transplanting, and at harvest). These results are presented in Table 2 and illustrated graphically in Figure 2.

**(30 DAT)** Among the planting geometry, the highest number of branches was recorded in $S_1$-20 X 10 cm (5.91), followed by $S_3$-20 X 20 cm (5.41) and $S_2$-20 X 15 cm (5.32). The lowest number of branches was recorded in $S_4$-30 X 10 cm (4.82), indicating that closer spacing in S1 promoted better branching. Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea produced the highest number of branches (5.90), followed by $N_3$- 80 kg N through vermicompost (5.43). The lowest number of branches was recorded with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (4.76). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the maximum number of branches (7.33), followed by $S_3 \times N_1$ (6.43) and $S_1 \times N_3$ (6.29). Conversely, the lowest number of branches was observed in $S_3 \times N_2$ (4.03). **(60 DAT)** Among the planting geometry, the maximum number of branches was observed in $S_1$-20 X 10 cm (14.31), followed by $S_3$-20 X 20 cm (13.33) and $S_2$- 20 X 15 cm (13.27). The lowest number of branches was recorded in $S_4$-30 X 10 cm (13.24), indicating that closer spacing in $S_1$ enhanced branching. Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (14.45), followed by $N_3$- 80 kg N through vermicompost (13.73). The lowest number of branches was observed with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (12.87). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the highest number of branches (17.13), followed by $S_3 \times N_1$ (15.08) and $S_4 \times N_3$ (14.25). Conversely, the lowest number of branches was observed in $S_3 \times N_2$ (11.47). **(90 DAT)** During the planting geometry, the maximum number of branches was observed in $S_1$-20 X 10 cm (16.63), followed by $S_3$-20 X 20 cm (16.09) and $S_2$- 20 X 15 cm (16.07) while, $S_4$-30 X 10 cm (15.99) was showed lowest for the same treatment. Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (16.58), lagged behind the former closely by $N_3$-80 kg N through vermicompost (16.46) while, the lowest number of branches was observed with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (15.76). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1 \times N_1$ produced the highest number of branches (18.40), followed by $S_4 \times N_2$ (16.73) and $S_4 \times N_3$ (16.63). Conversely, the lowest number of branches was observed in S3 × N2 (15.00). **(At 120 DAT)** Among the planting geometry, the highest number of branches was observed in $S_1$-20 X 10 cm (17.65), followed by $S_3$-20 X 20 cm (16.73) and $S_2$- 20 X 15 cm (16.70). The lowest number of branches was recorded in $S_4$-30 X 10 cm (16.44). Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the highest number of branches (17.58), second highest $N_3$-80 kg N through vermicompost (17.21). The lowest number of branches was accumulated with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (16.13). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1$ × $N_1$ produced the highest number of branches (20.00), followed by $S_1$ × $N_3$ (18.90) and $S_3$ × $N_4$ (18.13). Conversely, the lowest number of branches was observed in $S_3$ × $N_2$ (14.50). **(At harvest)** Among the planting geometry, the maximum number of branches was observed in $S_1$-20 X 10 cm (19.18), followed by $S_3$-20 X 20 cm (18.31) and $S_2$- 20 X 15 cm (18.27). The lowest number of branches was recorded in $S_4$-30 X 10 cm (18.23). Regarding nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the greater number of branches (19.23), came after the highest $N_3$-80 kg N through vermicompost (18.72) while less with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (17.71). The interaction effects (S × N) showed significant variation in the number of branches. The combination $S_1$ × $N_1$ produced the highest number of branches (20.53), followed by $S_1$ × $N_3$ (19.67) and $S_3$ × $N_4$ (19.13). Conversely, the lowest number of branches was observed in $S_3$ × $N_2$ (16.47).

The number of branches per plant serves as a key indicator of vegetative growth and overall plant health. This trait was significantly influenced by planting geometry, nitrogen sources, and their interaction across all growth stages. Among the planting geometries, $S_1$ (20 × 10 cm spacing) consistently recorded the highest number of branches—5.91, 14.31, 16.63, 17.65, and 19.18 at 30, 60, 90, 120 days after transplanting, and at harvest, respectively. This increased branching is likely a result of greater inter-plant competition for light under closer spacing, which promotes lateral growth. On the other hand, $S_4$ (30 × 10 cm) produced fewer branches—4.82, 13.24, 15.99, 16.44, and 18.23 at the corresponding growth stages—possibly due to lower plant density and reduced competition. Regarding nitrogen treatments, $N_1$ (40 kg N through vermicompost + 40 kg N through urea) led to the highest number of branches—5.90, 14.45, 16.58, 17.58, and 19.23—highlighting the importance of a balanced nitrogen supply for optimal vegetative development. In contrast, $N_2$ (60 kg N through vermicompost + 20 kg N through urea) recorded the lowest values—4.76, 12.87, 15.76, 16.13, and 17.71—indicating comparatively weaker vegetative performance. The interaction between planting geometry and nitrogen source further reinforced these findings. The $S_1$ × $N_1$ combination yielded the highest number of branches across all stages—7.33, 17.13, 18.40, 20.00, and 20.53—demonstrating the positive effect of close spacing combined with a well-balanced nitrogen regimen. Conversely, the $S_3$ × $N_2$ treatment produced the fewest branches—4.03, 11.47, 15.00, 14.50, and 16.47—across the respective stages. These results underscore the synergistic influence of optimal spacing and nutrient management on enhancing branching and overall vegetative vigor. These findings corroborate those of (Patel *et al.* 2019), (Cheena *et al.*, 2020), (Mishra and Jain 2014), (Semwal *et al.*, 2016) and (Chouhan *et al.*, 2023) who noted similar trends in other medicinal crops under integrated nutrient management systems.

*Table 2: Effect of N sources, planting geometries, and their interactions on number of branches at various growth stages in Kalmegh.*

| **Treatments** | | **30 DAT** | **60 DAT** | **90 DAT** | **120 DAT** | **At harvest** |
|---|---|---|---|---|---|---|
| **N Sources** | | | | | | |
| **$N_1$** | **40kg N by vermi +40 kg N by Urea** | 5.90 | 14.45 | 16.58 | 17.58 | 19.23 |
| **$N_2$** | **60kg N by vermi +20 kg N by Urea** | 4.76 | 12.87 | 15.76 | 16.13 | 17.71 |
| **$N_3$** | **80 kg N by Vermi** | 5.43 | 13.73 | 16.46 | 17.21 | 18.72 |
| **$N_4$** | **RDF** | 5.37 | 13.11 | 15.99 | 16.60 | 18.33 |
| **S.Em ±** | | **0.14** | **0.22** | **0.15** | **0.25** | **0.27** |
| **CD at 5%** | | **0.40** | **0.64** | **0.42** | **0.71** | **0.78** |
| **Geometry** | | | | | | |
| **$S_1$** | **20 X 10 cm** | 5.91 | 14.31 | 16.63 | 17.65 | 19.18 |
| **$S_2$** | **20 X 15 cm** | 5.32 | 13.27 | 16.07 | 16.70 | 18.27 |
| **$S_3$** | **20 X 20 cm** | 5.41 | 13.33 | 16.09 | 16.73 | 18.31 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **$S_4$** | **30 X 10 cm** | 4.82 | 13.24 | 15.99 | 16.44 | 18.23 |
| **S.Em ±** | | **0.14** | **0.22** | **0.15** | **0.25** | **0.27** |
| **CD at 5%** | | **0.40** | **0.64** | **0.42** | **0.71** | **0.78** |
| **Interaction S (Geometry) x N (Sources)** | | | | | | |
| **$S_1 \times N_1$** | | 7.33 | 17.13 | 18.40 | 20.00 | 20.53 |
| **$S_2 \times N_1$** | | 5.63 | 12.92 | 15.90 | 17.20 | 19.23 |
| **$S_3 \times N_1$** | | 6.43 | 15.08 | 16.53 | 16.93 | 19.37 |
| **$S_4 \times N_1$** | | 4.21 | 12.67 | 15.47 | 16.20 | 17.77 |
| **$S_1 \times N_2$** | | 4.73 | 12.80 | 15.63 | 16.30 | 17.83 |
| **$S_2 \times N_2$** | | 4.97 | 13.06 | 15.67 | 16.37 | 17.87 |
| **$S_3 \times N_2$** | | 4.03 | 11.47 | 15.00 | 14.50 | 16.47 |
| **$S_4 \times N_2$** | | 5.30 | 14.16 | 16.73 | 17.33 | 18.67 |
| **$S_1 \times N_3$** | | 6.29 | 13.97 | 16.57 | 18.90 | 19.67 |
| **$S_2 \times N_3$** | | 5.47 | 13.59 | 16.20 | 15.17 | 18.47 |
| **$S_3 \times N_3$** | | 5.30 | 13.12 | 16.43 | 17.33 | 18.27 |
| **$S_4 \times N_3$** | | 4.67 | 14.25 | 16.63 | 17.43 | 18.47 |
| **$S_1 \times N_4$** | | 5.30 | 13.37 | 15.93 | 15.40 | 18.67 |
| **$S_2 \times N_4$** | | 5.20 | 13.50 | 16.50 | 18.07 | 17.50 |
| **$S_3 \times N_4$** | | 5.87 | 13.67 | 16.40 | 18.13 | 19.13 |
| **$S_4 \times N_4$** | | 5.10 | 11.90 | 15.13 | 14.80 | 18.00 |
| **S.Em ±** | | **0.28** | **0.45** | **0.29** | **0.49** | **0.54** |
| **CD at 5%** | | **0.81** | **1.29** | **0.85** | **1.43** | **1.55** |

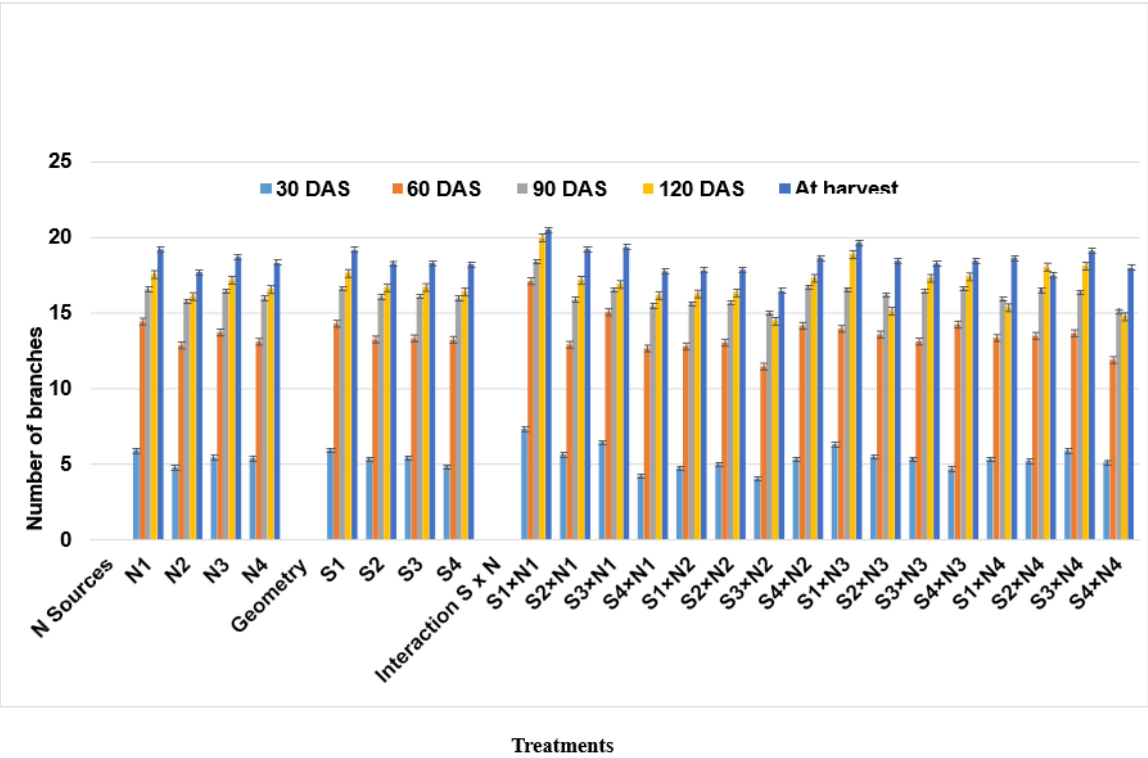


*Fig.-2 Effect of nitrogen sources, planting geometries, and their interactions on number of branches (plant$^{-1}$) at various growth stages in Kalmegh.*

**Number of leaves (plant$^{-1}$) at 30, 60, 90, 120 DAT and at harvest**

Nitrogen sources, planting geometries, and their interactions had a significant impact on the number of leaves at various growth stages (30, 60, 90, 120 days after transplanting, and at harvest). These findings are summarized in Table 3 and visually represented in Figure 3.

**(30 DAT)** Among the main factors as planting geometry, the highest number of leaves was recorded in $S_1$-20 X 10 cm (29.03), followed by $S_3$-20 X 20 cm (28.31) and $S_2$-20 X 15 cm (27.99). The lowest number of leaves was observed in $S_4$-30 X 10 cm (27.67) under sub factor as nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the maximum number of leaves (29.03), lagged behind the former $N_3$-80 kg N through vermicompost (28.44). The lowest number of leaves was observed with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (27.16). The interaction effects (S × N) showed significant variation in the number of leaves. The combination $S_1$ × $N_1$ produced the highest number of leaves (31.23), followed by $S_3$ × $N_4$ (29.20) and $S_3$ × $N_1$ (29.63). Conversely, the lowest number of leaves was recorded in $S_3$ × $N_2$ (26.63). **(60 DAT)** Among the main factor as planting geometry, the maximum number of leaves was observed in $S_1$-20 X 10 cm (170.76), followed by $S_3$-20 X 20 cm (165.73) and $S_2$-20 X 15 cm (165.25). The lowest number of leaves was recorded in $S_4$-30 X 10 cm (160.46) under sub factor as nitrogen sources, $N_1$- 40 kg N through vermicompost+40 kg N through urea recorded the highest number of leaves (168.82), followed by $N_3$-80 kg N through vermicompost (166.53). The lowest number of leaves while less with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (161.43). During The interaction effects (S × N) exhibited significant variation. The combination $S_1$ × $N_1$ produced the highest number of leaves (176.87), followed by $S_1$ × $N_3$ (173.13) and $S_3$ × $N_4$ (172.40). On the other hand, the lowest number of leaves was recorded in $S_4$ × $N_3$ (155.13). **(90 DAT)** Among the main factor as planting geometry, the maximum number of leaves was observed in $S_1$-20 X 10 cm (197.76), followed by $S_3$-20 X 20 cm (195.23) and $S_2$-20 X 15 cm (194.88). The lowest number of leaves was recorded in $S_4$-30 X 10 cm (193.48). Under sub factor nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea recorded the highest number of leaves (197.25), came after the highest $N_3$-80 kg N through vermicompost (197.10). The nitrogen sources $N_2$-60 kg N through vermicompost + 20 kg N through Urea (193.45) showed a lower number of leaves. The interaction effects (S × N) exhibited statistically variations. The combination $S_1$ × $N_1$ produced the highest number of leaves (202.84), followed by $S_1$ × $N_3$ (202.07) and $S_3$ × $N_4$ (200.27). On the other hand, the lowest number of leaves was recorded in $S_4$ × $N_4$ (187.20). **(120 DAT)** The planting geometry, the maximum number of leaves was recorded in S1-20 X 10 cm (215.48), followed by $S_3$-20 X 20 cm (212.69) and S2-20 X 15 cm (212.43). The least number of leaves was observed in $S_4$-30 X 10 cm (211.73) under sub factors as nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea produced the highest number of leaves (215.25), followed closely by $N_3$-80 kg N through vermicompost (215.11). $N_2$- 60 kg N through vermicompost + 20 kg N through Urea had the lowest (209.52). The interaction effects (S × N) exhibited significant variation. The combination $S_1$ × $N_1$ resulted in the maximum number of leaves (221.47), followed by $S_1$ × $N_3$ (221.07) and $S_3$ × $N_4$ (219.27). On the other hand, the lowest number of leaves was observed in $S_3$ × $N_2$ (205.43). (At harvest) In terms of planting geometry, the highest number of leaves was recorded in $S_1$-20 X 10 cm (142.83), followed by $S_3$-20 X 20 cm (140.58) and $S_2$-20 X 15 cm (137.92). The lowest value was observed in $S_4$-30 X 10 cm (137.71). Under the nitrogen sources, $N_1$-40 kg N through vermicompost+40 kg N through urea exhibited the highest number of leaves (143.38), followed closely by $N_3$-80 kg N through vermicompost (141.92). The lowest number of leaves was recorded with $N_2$-60 kg N through vermicompost + 20 kg N through Urea (136.42). The interaction effects (S × N) revealed statistically variation. The combination $S_1$ × $N_1$ produced the highest number of leaves (152.33), followed by $S_1$ × $N_3$ (146.33) and $S_3$ × $N_1$ (145.67). On the contrary, the lowest number of leaves was recorded in $S_2$ × $N_4$ (128.00).

The number of leaves per plant varied significantly in response to planting geometry, nitrogen sources, and their interaction. Among the spacing treatments, $S_1$ (20 × 10 cm) recorded the highest number of leaves—29.03, 170.76, 197.76, 215.48, and 142.83 at 30, 60, 90, 120 days after transplanting, and at harvest, respectively—likely due to higher plant density and more efficient utilization of available resources. In contrast, $S_4$ (30 × 10 cm) resulted in the lowest leaf count—27.67, 160.46, 193.48, 211.73, and 137.71—possibly due to wider spacing and reduced inter-plant competition. With respect to nitrogen treatments, $N_1$ (40 kg N from vermicompost + 40 kg N from urea) produced the highest number of leaves—29.03, 168.82, 197.25, 215.35, and 143.38—demonstrating the benefits of balanced fertilization in promoting vegetative growth. On the other hand, $N_2$ (60 kg N from vermicompost + 20 kg N from urea) resulted in the lowest leaf numbers—27.16, 161.43, 193.45, 209.52, and 136.42—at the respective growth stages. The interaction effects further supported these trends. The $S_1$ × $N_1$ combination led to the maximum number of leaves—31.23, 176.87, 202.84, 221.47, and 152.33—across all stages, indicating the synergistic benefits of close spacing and integrated nutrient management. Conversely, the $S_3 \times N_2$ treatment produced the fewest leaves—26.63, 156.60, 190.13, 205.43, and 132.33—confirming the reduced effectiveness of wider spacing combined with less balanced fertilization. These results are consistent with the findings of (Sharma *et al.* 2021). Similar findings were also reported by (Cheena *et al.*, 2020), (Mishra and Jain 2014), (Salmaben *et al.*, 2022) and (Shakywa *et al.*, 2022) who highlighted the significance of plant spacing and nutrient management in improving leaf development.

*Table 3:- Effect of N sources, planting geometries, and their interactions on number of leaves (plant$^{-1}$) at various growth stages in Kalmegh.*

| **Treatments** | | **30 DAT** | **60 DAT** | **90 DAT** | **120 DAT** | **At harvest** |
|---|---|---|---|---|---|---|
| **N Sources** | | | | | | |
| **$N_1$** | **40kg N by vermi +40 kg N by Urea** | 29.03 | 168.82 | 197.25 | 215.25 | 143.38 |
| **$N_2$** | **60kg N by vermi +20 kg N by Urea** | 27.16 | 161.43 | 193.45 | 209.52 | 136.42 |
| **$N_3$** | **80 kg N by Vermi** | 28.44 | 166.53 | 197.10 | 215.11 | 141.92 |
| **$N_4$** | **RDF** | 28.37 | 165.43 | 193.56 | 212.46 | 137.33 |
| **S.Em ±** | | **0.20** | **1.56** | **0.94** | **1.20** | **1.46** |
| **CD at 5%** | | **0.57** | **4.52** | **2.71** | **3.48** | **4.21** |
| **Geometry** | | | | | | |
| **$S_1$** | **20 X 10 cm** | 29.03 | 170.76 | 197.76 | 215.48 | 142.83 |
| **$S_2$** | **20 X 15 cm** | 27.99 | 165.25 | 194.88 | 212.43 | 137.92 |
| **$S_3$** | **20 X 20 cm** | 28.31 | 165.73 | 195.23 | 212.69 | 140.58 |
| **$S_4$** | **30 X 10 cm** | 27.67 | 160.46 | 193.48 | 211.73 | 137.71 |
| **S.Em ±** | | **0.20** | **1.56** | **0.94** | **1.20** | **1.46** |
| **CD at 5%** | | **0.57** | **4.52** | **2.71** | **3.48** | **4.21** |
| **Interaction S (Geometry) x N (Sources)** | | | | | | |
| **$S_1 \times N_1$** | | 31.23 | 176.87 | 202.84 | 221.47 | 152.33 |
| **$S_2 \times N_1$** | | 28.33 | 165.33 | 197.90 | 218.23 | 142.67 |
| **$S_3 \times N_1$** | | 29.63 | 168.07 | 195.73 | 215.73 | 145.67 |
| **$S_4 \times N_1$** | | 26.93 | 165.00 | 192.53 | 205.57 | 132.83 |
| **$S_1 \times N_2$** | | 27.03 | 165.20 | 192.93 | 206.43 | 133.00 |
| **$S_2 \times N_2$** | | 27.10 | 165.37 | 193.20 | 207.47 | 139.67 |
| **$S_3 \times N_2$** | | 26.63 | 156.60 | 190.13 | 205.43 | 132.33 |
| **$S_4 \times N_2$** | | 27.87 | 158.57 | 197.53 | 218.73 | 140.67 |
| **$S_1 \times N_3$** | | 29.47 | 173.13 | 202.07 | 221.07 | 146.33 |
| **$S_2 \times N_3$** | | 28.67 | 171.97 | 194.87 | 213.57 | 141.33 |
| **$S_3 \times N_3$** | | 27.77 | 165.87 | 194.80 | 210.33 | 140.33 |
| **$S_4 \times N_3$** | | 27.87 | 155.13 | 196.67 | 215.47 | 139.67 |
| **$S_1 \times N_4$** | | 28.40 | 167.83 | 193.20 | 212.93 | 139.67 |
| **$S_2 \times N_4$** | | 27.87 | 158.33 | 193.57 | 210.47 | 128.00 |
| **$S_3 \times N_4$** | | 29.20 | 172.40 | 200.27 | 219.27 | 144.00 |
| **$S_4 \times N_4$** | | 28.00 | 163.13 | 187.20 | 207.17 | 137.67 |
| **S.Em ±** | | **0.39** | **3.13** | **1.88** | **2.41** | **2.91** |
| **CD at 5%** | | **1.13** | **9.04** | **5.42** | **6.95** | **8.42** |

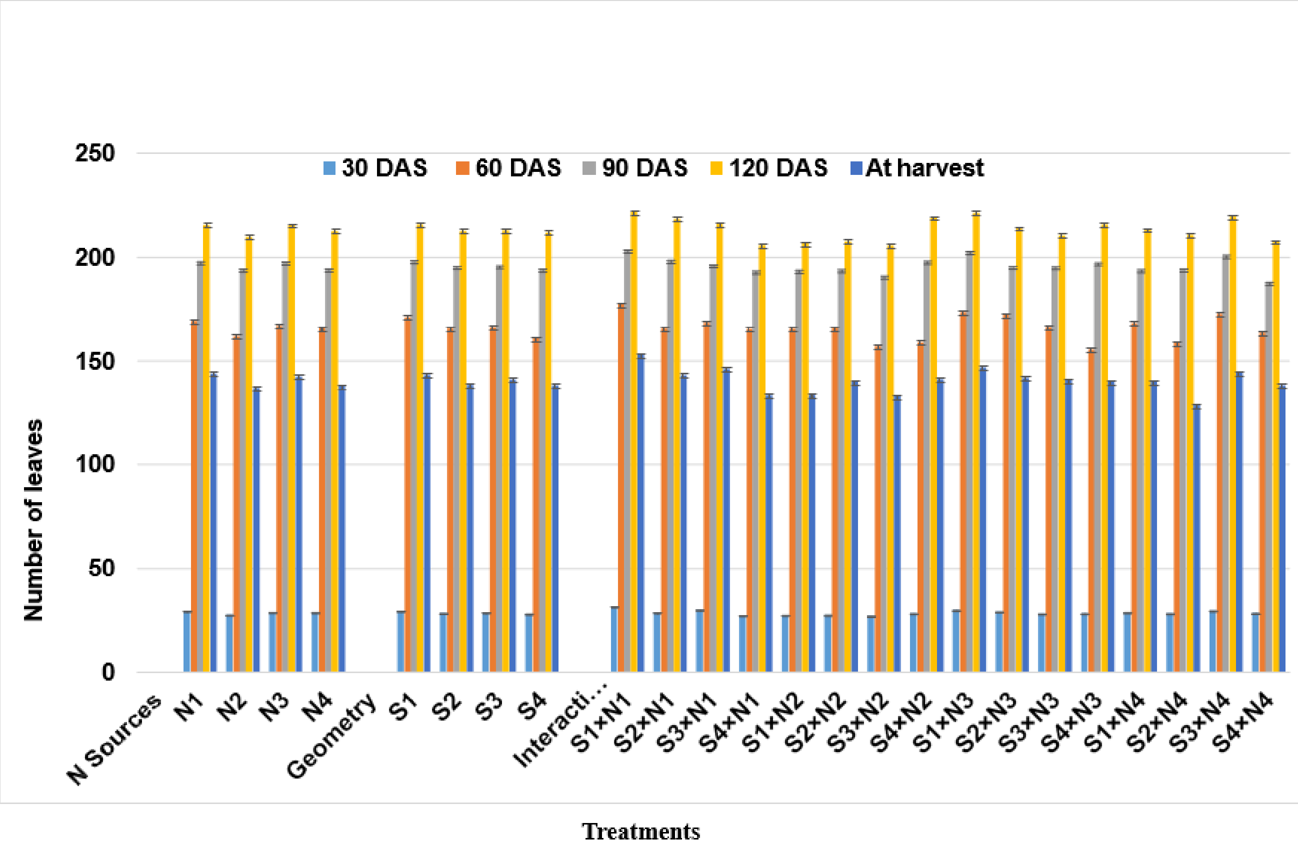


*Fig.- 3 Effect of nitrogen sources, planting geometries, and their interactions on number of leaves (plant-1) at various growth stages in Kalmegh.*

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