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Effect of Nitrogen Sources and Plant Spacing on Soil properties in growing season of Kalmegh (*Andrographis paniculata* Nees) under Malwa Agro-Climatic Conditions of Madhya Pradesh

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***Abstract*— *The field experiment trial titled "Effect of Nitrogen Sources and Plant Spacing on Soil properties in growing season of Kalmegh (Andrographis paniculata Nees) under Malwa Agro-Climatic Conditions of Madhya Pradesh" was carried out in the 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 soil parameters were recorded using standard methods. The study assessed key soil parameters, including Available nitrogen (kg ha^{-1}), Available phosphorus (kg ha^{-1}) and Available potassium (kg ha^{-1}) in soil. The results indicated that the pre-transplant soil analysis has a field variation in the soil fertility, as nitrogen, phosphorus, and potassium content. Among the treatment plots, S_1 and N_1 plots showed more fertility as compared to the other plots. The post-harvest soil analysis showed similar trends, with S_1 and N_1 plots showing higher nutrient levels in the soil. The combination $S_1 \times N_1$ resulted in the maximum retention of nitrogen, phosphorus, and potassium, indicating efficient nutrient cycling.*

***Keywords*— Kalmegh, nitrogen sources, plant spacing, soil nutrients, nutrient cycling**

I. INTRODUCTION

Kalmegh (*Andrographis paniculata* Nees), commonly referred to as the "King of Bitters," is an annual, upright herb indigenous to India and widely cultivated throughout Asia, particularly in states like Uttar Pradesh, Andhra Pradesh, and Telangana (Meena *et al*., 2024). In Indian traditional medicine, especially in West Bengal, Kalmegh plays a crucial role in the household remedy 'Alui,' which is used to alleviate general weakness and digestive issues in both children and adults. Both the fresh and dried leaves, as well as the juice extracted from the plant, are officially recognized in Ayurvedic and Unani medicinal systems for their broad therapeutic potential, including immune-boosting, antibacterial, anti-inflammatory, anticoagulant, and liver-protective properties (Bahadur *et al*., 2024). The primary active constituents of Kalmegh are diterpenoids, with andrographolide being the most notable, known for its diverse pharmacological effects, such as anticancer, antipyretic, antihepatotoxic, antihistamine, analgesic, antibacterial, antifertility, and immunosuppressive activities. It is traditionally employed to manage a wide range of conditions, including dysentery, diarrhea, gastrointestinal infections, fevers, respiratory issues like cough and bronchitis, joint pain, reproductive health issues, hypertension, and even snakebites (Mehta *et al*., 2020). However, the rising demand for Kalmegh and its unregulated harvesting from the wild have led to a notable reduction in its natural availability. Despite its medical significance, there has been limited progress in developing efficient agronomic practices for its large-scale cultivation. One of the major challenges in this regard is the overuse of synthetic fertilizers, which contribute to soil degradation and environmental pollution (Jnanesha *et al*., 2024). To overcome these issues, integrated nutrient management (INM) has emerged as a sustainable approach. Studies have demonstrated that combining organic and inorganic fertilizers improves Kalmegh's growth and productivity (Basak *et al*., 2020). Effective nutrient strategies are critical not only for maximizing plant biomass and yield but also for enhancing the concentration of its medicinal compounds. While macronutrients like nitrogen (N), phosphorus (P), and potassium (K) are essential for core physiological functions, micronutrients such as zinc (Zn) and iron (Fe) are vital for metabolic processes that influence plant health and medicinal quality. Integrating organic fertilizers and biofertilizers into cultivation practices improves soil fertility and supports sustainable agriculture. This review focuses on how such nutrient management strategies, especially for the CIM Megha variety, can be optimized to achieve high yields and enhanced medicinal quality. By carefully managing macro- and micronutrients, using organic amendments, and adopting INM, farmers can not only boost Kalmegh's productivity and therapeutic potential but also ensure environmentally friendly farming practices (Shukla *et al*., 2018).

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 soil parameters such as Organic carbon (%), (available soil N, available P, and available K). Soil samples were collected randomly from plough layer depth with the help of soil sampling tube after harvesting of crops from each plot and finally composite soil samples were made. The samples were mixed thoroughly and dried under shade, crushed, sieved through 2 mm sieve. The soil samples so prepared were subjected to chemical analysis for evaluating soil fertility status (available soil N, available P, and available K) following standard procedures. Different methods adopted for chemical analysis of soil samples. 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

Soil parameters

Pre-transplanting and post-harvest available N P K status in soil

The nitrogen sources, planting geometries, and their interactions were exhibited significant response on Pre-Transplanting and Post-harvest available nitrogen (N), phosphorus (P), and potassium (K) content in soil are summarized in Table 1 and Fig. 1-2. **Pre-transplanting Nitrogen Status** (N) Among planting geometry, S1-20 X 10 cm exhibited the highest nitrogen content (271.99 kg/ha), followed by S3-20 X 20 cm (266.38 kg/ha) and S2-20 X 15 cm (266.00 kg/ha). The lowest nitrogen content was found in S4-30 X 10 cm (261.21 kg/ha). Regarding nitrogen sources, N1-40 kg N through vermicompost+40 kg N through urea recorded the highest nitrogen content (269.16 kg/ha), followed closely by N3-80 kg N through vermicompost (269.08 kg/ha). The lowest nitrogen content was observed with N2-60 kg N through vermicompost + 20 kg N through Urea (261.43 kg/ha). Interaction effects (S × N) revealed significant variation. The combination S1 × N1 resulted in the highest nitrogen content (279.74 kg/ha), followed by S1 × N3 (278.43 kg/ha) and S3 × N4 (278.07 kg/ha). Conversely, the lowest nitrogen content was recorded in S3 × N2 (257.67 kg/ha). **Pre-transplanting Phosphorus Status (P)** Among planting geometry, S1-20 X 10 cm exhibited the maximum phosphorus content (28.18 kg/ha), followed by S3-20 X 20 cm (27.70 kg/ha) and S2-20 X 15 cm (26.97 kg/ha). The lowest phosphorus content was found in S4-30 X 10 cm (25.97 kg/ha). In terms of nitrogen sources, N1-40 kg N through vermicompost+40 kg N through urea had the highest phosphorus content (28.15 kg/ha), followed by N3-80 kg N through vermicompost (28.04 kg/ha). The lowest phosphorus content was observed with N2-60 kg N through vermicompost + 20 kg N through Urea (25.77 kg/ha). Interaction effects (S × N) showed that S1 × N1 produced the highest phosphorus content (30.39 kg/ha), followed by S3 × N1 (29.80 kg/ha) and S1 × N3 (29.33 kg/ha). The lowest phosphorus content was observed in S3 × N2 (24.33 kg/ha). **Pre-transplanting Potassium Status (K)** Among planting geometry, S1-20 X 10 cm recorded the highest potassium content (261.42 kg/ha), followed by S3-20 X 20 cm (256.50 kg/ha) and S2-20 X 15 cm (255.98 kg/ha). The lowest potassium content was observed in S4-30 X 10 cm (255.32 kg/ha). Regarding nitrogen sources, N1-40 kg N through vermicompost+40 kg N through urea had the highest potassium content (261.53 kg/ha), followed closely by N3-80 kg N through vermicompost (260.92 kg/ha). The lowest potassium content was observed in N2-60 kg N through vermicompost + 20 kg N through Urea (252.96 kg/ha). Interaction effects (S × N) indicated that the combination S1 × N1 resulted in the highest potassium content (272.43 kg/ha), followed by S3 × N4 (265.07 kg/ha) and S1 × N3 (265.78 kg/ha). On the other hand, the lowest potassium content was recorded in S4 × N4 (240.40 kg/ha).

Table 1 :- Effect of N sources, planting geometries, and their interactions on Pre-Transplanting N P K status (Soil) in Kalmegh.

Treatments		N	P	K
N Sources				
N1	**40kg N by vermi+40 kg N by Urea**	269.16	28.15	261.53
N2	**60 kg N by vermi+20 kg N by Urea**	261.43	25.77	252.96
N3	**80 kg N by Vermicompost**	269.08	28.04	260.92
N4	**RDF**	265.92	26.86	253.81
S.Em ±		**1.02**	**0.53**	**1.71**
CD at 5%		**2.96**	**1.52**	**4.95**
Geometry				
S1	**20 X 10 cm**	271.99	28.18	261.42
S2	**20 X 15 cm**	266.00	26.97	255.98
S3	**20 X 20 cm**	266.38	27.70	256.50
S4	**30 X 10 cm**	261.21	25.97	255.32
S.Em ±		**1.02**	**0.53**	**1.71**
CD at 5%		**2.96**	**1.52**	**4.95**
Interaction S (Geometry) x N (Sources)				
S1×N1		279.74	30.39	272.43
S2×N1		274.50	26.75	261.74
S3×N1		264.07	29.80	264.14

S4×N1	258.33	25.67	247.79
S1×N2	259.70	26.33	248.71
S2×N2	260.00	27.67	249.40
S3×N2	257.67	24.33	246.67
S4×N2	268.33	24.74	267.07
S1×N3	278.43	29.33	265.78
S2×N3	272.43	25.79	261.77
S3×N3	265.70	28.00	250.11
S4×N3	259.73	29.04	266.03
S1×N4	270.10	26.67	258.77
S2×N4	257.07	27.67	251.00
S3×N4	278.07	28.67	265.07
S4×N4	258.46	24.42	240.40
S.Em ±	**2.05**	**1.05**	**3.43**
CD at 5%	**5.92**	**3.04**	**9.90**

Post-Harvest Soil NPK Status Nitrogen (N)

Among planting geometry, S1-20 X 10 cm showed the highest nitrogen status (220.94 kg/ha), followed by S3-20 X 20 cm (218.76 kg/ha) and S2-20 X 15 cm (217.80 kg/ha). The lowest nitrogen level was recorded in S4-30 X 10 cm (216.53 kg/ha). For nitrogen sources, N1-40 kg N through vermicompost+40 kg N through urea retained the highest nitrogen content in the soil post-harvest (220.59 kg/ha), followed by N3-80 kg N through vermicompost (219.62 kg/ha). The lowest nitrogen content was observed with N2-60 kg N through vermicompost + 20 kg N through Urea (214.93 kg/ha). Interaction effects (S × N) revealed the highest nitrogen status in the combination S1 × N1 (225.33 kg/ha), followed by S1 × N3 (224.00 kg/ha) and S3 × N4 (223.67 kg/ha). The lowest nitrogen content was recorded in S3 × N2 (212.00 kg/ha). **Phosphorus (P)** Among planting geometry, S1-20 X 10 cm exhibited the highest phosphorus content (21.12 kg/ha), followed by S3-20 X 20 cm (19.36 kg/ha) and S2-20 X 15 cm (18.35 kg/ha). The lowest phosphorus content was recorded in S4-30 X 10 cm (17.87 kg/ha). Regarding nitrogen sources, N1 retained the highest phosphorus content (21.27 kg/ha), followed by N3-80 kg N through vermicompost (20.58 kg/ha). The lowest phosphorus content was observed in N2-60 kg N through vermicompost + 20 kg N through Urea (16.51 kg/ha). Interaction effects (S × N) showed the highest phosphorus status in S1 × N1 (27.40 kg/ha), followed by S1 × N3 (23.07 kg/ha) and S3 × N1 (23.23 kg/ha). The lowest phosphorus levels were observed in S3 × N2 (14.74 kg/ha). **Potassium (K)** Among planting geometry, S1-20 X 10 cm recorded the highest potassium content (218.77 kg/ha), followed by S3-20 X 20 cm (215.04 kg/ha) and S2-20 X 15 cm (214.18 kg/ha). The lowest potassium level was observed in S4-30 X 10 cm (209.02 kg/ha). For nitrogen sources, N1-40 kg N through vermicompost+40 kg N through urea maintained the highest potassium content (216.67 kg/ha), followed by N3-80 kg N through vermicompost (215.23 kg/ha). The lowest potassium content was found in N2-60 kg N through vermicompost + 20 kg N through Urea (211.46 kg/ha). Interaction effects (S × N) revealed the highest potassium content in S1 × N1 (223.43 kg/ha), followed by S1 × N3 (222.37 kg/ha) and S3 × N4 (221.03 kg/ha). The lowest potassium content was recorded in S4 × N3 (202.33 kg/ha). These results are supported by (Singh *et al.*, 2018), These findings align with the work of (Patel *et al.*, 2017), who emphasized the role of organic amendments in sustaining soil fertility.

Table 2 :- Effect of N sources, planting geometries, and their interactions on Post-Harvest N P K status (Soil) in Kalmegh.

Treatments		N	P	K
N Sources				
N1	**40kg N by vermi+40 kg N by Urea**	220.59	21.27	216.67
N2	**60 kg N by vermi+20 kg N by Urea**	214.93	16.51	211.46
N3	**80 kg N by Vermicompost**	219.62	20.58	215.23
N4	**RDF**	218.89	18.34	213.66
S.Em ±		**1.16**	**0.97**	**1.94**
CD at 5%		**3.34**	**2.79**	**5.60**
Geometry				
S1	**20 X 10 cm**	220.94	21.12	218.77
S2	**20 X 15 cm**	217.80	18.35	214.18
S3	**20 X 20 cm**	218.76	19.36	215.04
S4	**30 X 10 cm**	216.53	17.87	209.02
S.Em ±		**1.16**	**0.97**	**1.94**
CD at 5%		**3.34**	**2.79**	**5.60**
Interaction S (Geometry) x N (Sources)				
S1×N1		225.33	27.40	223.43
S2×N1		220.33	19.33	219.10
S3×N1		222.03	23.23	213.40
S4×N1		214.67	15.10	210.73
S1×N2		215.03	16.47	211.07
S2×N2		216.67	18.08	212.77
S3×N2		212.00	14.74	209.33
S4×N2		216.03	16.77	212.67
S1×N3		224.00	23.07	222.37
S2×N3		220.10	18.17	219.80
S3×N3		217.33	19.03	216.40
S4×N3		217.03	22.03	202.33
S1×N4		219.40	17.53	218.21
S2×N4		214.10	17.83	205.07
S3×N4		223.67	20.44	221.03
S4×N4		218.40	17.57	210.33
S.Em ±		**2.31**	**1.93**	**3.88**
CD at 5%		**6.69**	**5.57**	**11.21**

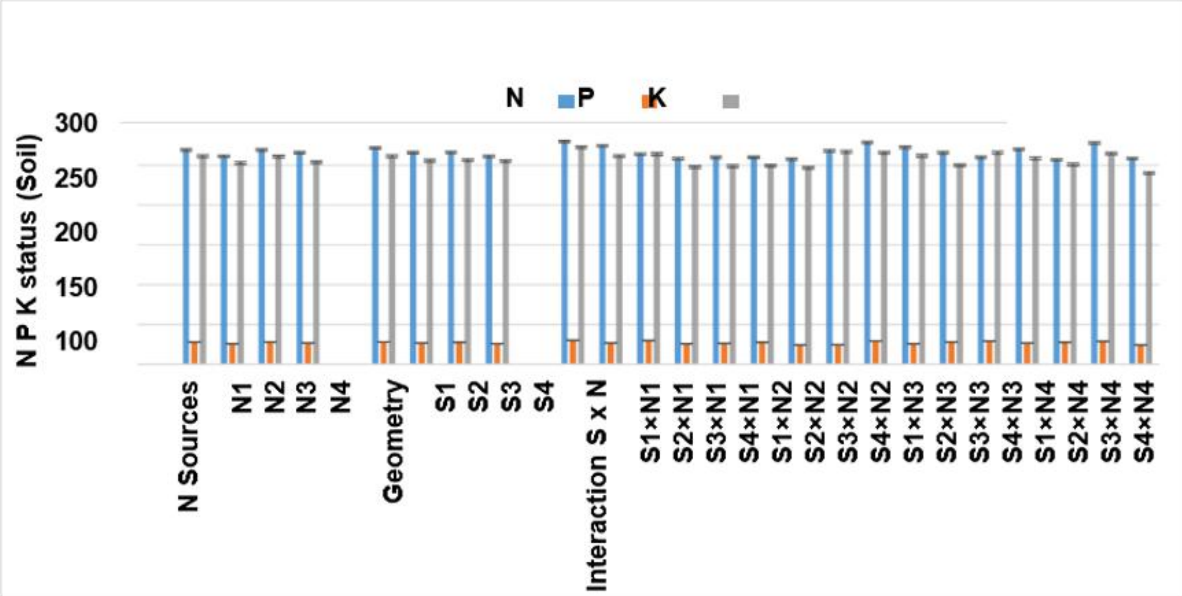

Fig.- 1 Effect of nitrogen sources, planting geometries, and their interactions on Pre-Transplanting N' P K' status (Soil) in Kalmegh.

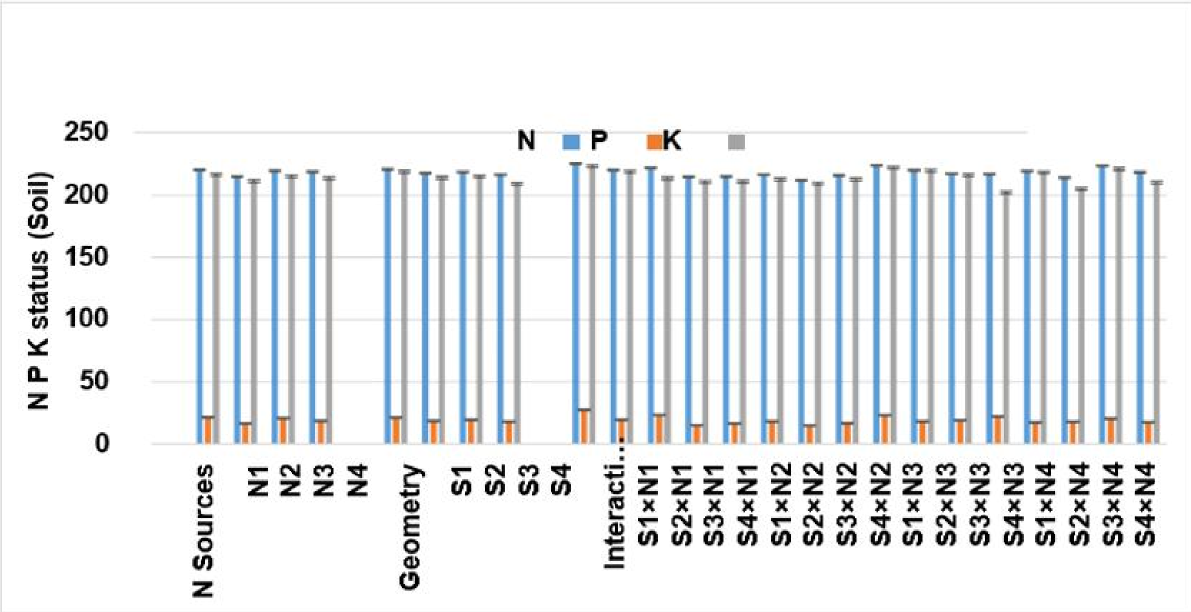

Fig.- 2 Effect of nitrogen sources, planting geometries, and their interactions on Post-Harvest N'P K'status (Soil) in Kalmegh.

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