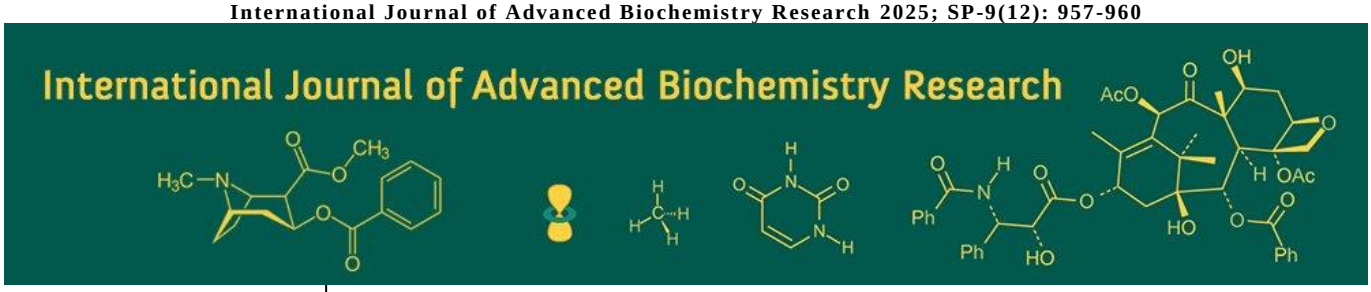

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Impact of integrated nitrogen management and plant spacing on yield and phytochemical quality of Kalmegh (*Andrographis paniculata*)

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Abstract
A field experiment entitled "Impact of Integrated Nitrogen Management and Plant Spacing on Yield and Phytochemical Quality of Kalmegh (*Andrographis paniculata*)" was conducted during the kharif season of 2024-25 at AICRP on Medicinal, Aromatic Plants and Betelvine, Nagarjun Medicinal Plants Garden, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The experiment was laid out in a factorial randomized block design (FRBD) with four nitrogen source treatments, *viz*., N_1: 75% N through vermicompost + 25% recommended dose of nitrogen (RDN) through inorganic fertilizer, N_2: 50% N through vermicompost + 50% RDN through inorganic fertilizer, N_3: 100% N through vermicompost, and N_4: 100% RDN through inorganic fertilizer, and three plant spacings, *viz*., S_1: 20 × 20 cm, S_2: 30 × 10 cm, and S_3: 30 × 15 cm, replicated thrice. Results revealed that nitrogen sources and plant spacing significantly influenced fresh foliage yield, dry foliage yield, and total andrographolide yield of Kalmegh. Among nitrogen treatments, application of 100% RDN through inorganic fertilizer (N_4) recorded the highest fresh foliage yield (8558 kg ha^{-1}), dry foliage yield (3388 kg ha^{-1}), and total andrographolide yield (44.41 kg ha^{-1}), which was statistically at par with N_2 (50% vermicompost + 50% RDN). Among spacing treatments, S_2 (30 × 10 cm) produced significantly higher fresh foliage yield (9627 kg ha^{-1}), dry foliage yield (3548 kg ha^{-1}), and total andrographolide yield (46.52 kg ha^{-1}).The interaction effect was significant, with the combination of N_4S_2 (100% RDN through inorganic fertilizer with 30 × 10 cm spacing) recording the maximum fresh foliage yield (12573 kg ha^{-1}), dry foliage yield (4910 kg ha^{-1}), and total andrographolide yield (61.07 kg ha^{-1}). The study clearly indicates that integrated nutrient management combined with optimum plant spacing plays a vital role in enhancing yield and quality of Kalmegh.

Keywords: Kalmegh, Yield, Andrographolide, Vermicompost, Inorganic fertilizer

Introduction
Kalmegh (*Andrographis paniculata* Nees.) commonly known as "King of Bitters" is a member of the family of Acanthaceae. The fresh and dried leaves of Kalmegh, along with its extracted juice, are officially recognized as drugs in the Indian pharmacopoeia. This plant typically grows upright, reaching heights of 30 to 110 cm. Its small flowers grow on spreading racemes, and the fruit is a capsule about 2 cm long and a few millimeters wide, containing several yellow-brown seeds (Niranjan *et al*, 2010) [4]. Whole plant (stem, leaves and inflorescence) constitutes a drug which contains andrographolide content. This is the active ingredient of kalmegh being used for treatment of liver/digestive disorders, vermifuge and also used as antibiotic and antipyretic. It is mainly used in the treatment of typhoid, malaria/fever and liver cirrhosis. It is a branched annual herb of medicinal importance. Leaves and stems are used to extract the active phyto-chemicals. It is found all over India in moist-deciduous forests as well as in plains. Nitrogen encourages the plant foliage and boosts plant growth at every stage, because it is an integral part of the chlorophyll, all proteins, enzymes and structural materials. In order to strengthen the organic farming of medicinal plants, it is essential to identify which is the best organic source of nitrogen and its optimum dose, so that yield and quality of kalmegh may be increased on a sustainable basis without deteriorating the soil health. Optimal nitrogen management in Kalmegh boosts chlorophyll synthesis, photosynthetic efficiency, and and rographolide production.

Integrated use of inorganic and organic sources like vermicompost enhances nitrogen uptake and biomass, leading to higher herbage yield (Shelke *et al.*, 2024) [8]. Similarly, proper plant spacing improves light penetration and air circulation, reduces competition, and increases dry matter yield (Shahjahan *et al*., 2013) [7].

Andrographolide is present in the plant. It is used in Indian medicine as a bitter tonic, to treat hepatitis, and snake bites. Kalmegh leaves are rich in active ingredients such as Andro-grapholide, homo-andrographolide,

andrographesterol, and andrographone. report that the plant leaves have a variety of diterpene lactone derivatives, the two most significant of which are andrographolide, a bitter element, and neo-andrographolide, a non-bitter constituent.

Andrographolide content ranges from 0.81 to 2.78% on average. The concentration of these active components varies among plant parts and according to the species' geographic range. As secondary metabolites, andrographolide is affected by seasonal variations, climatic conditions and the compound throughout the plant.

Materials and Methods

The experiment entitled "Impact of Integrated Nitrogen Management and Plant Spacing on Yield and Phytochemical Quality of Kalmegh (*Andrographis paniculata*)" was carried out during *kharif* season of 2024-25 at AICRP on Medicinal, Aromatic Plants and Betelvine, Nagarjun Medicinal Plants Garden, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.The The site is situated in the subtropical region at 20^0 40' 35" North latitude and 76^0 59' 10" East longitude and at an altitude of 307.42 m above mean sea level with average annual precipitation was 750-950 mm. The site for experiment was clayey (52.00% clay) in texture. The fertility status of soil was low in available N (183 kg ha^{-1}) and medium in available P_2O_5 (21 kg ha^{-1}) and K_2O (349 kg ha^{-1}).During *Kharif* 2024-25 total rainfall of 955.1 mm was received in 44 rainy days, during crop growth period which was 31% more than normal. In the beginning, less rainfall caused delay and poor germination of Kalmegh seeds. Later, heavy rains in during early growth stage slowed down seedling development due to waterlogging. As the season continued, rainfall and weather conditions became favorable, helping in good plant stand and healthy growth. Adequate moisture, along with normal temperature and humidity, supported better leaf formation, branching, and plant height. This improved photosynthesis and helped increase the dry foliage yield. Although no rain was received at the end, timely harvest just after initiation of flowering resulted in overall good crop performance. The experiment was laid out in a factorial randomized block design with four nitrogen source treatments (N_1:75% vermicompost + 25% RDN through inorganic fertilizer; N_2: 50% vermicompost + 50% RDN through inorganic fertilizer; N_3: 100% vermicompost; N_4: 100% RDN through inorganic fertilizer) and three plant spacing (S_1: 20×20 cm, S_2: 30×10 cm, S_3: 30×15 cm), replicated thrice, involving twelve treatment combinations. In the present study, the recommended dose of fertilizers (RDF) was 80:50:30 kg $N:P_2O_5:K_2O$ ha^{-1}. In treatments involving inorganic fertilizers, 50% of nitrogen along with the full dose of phosphorus and potassium was applied as a basal dose at the time of transplanting, while the remaining 50% nitrogen was top-dressed at 30 days after transplanting (DAT). The sources of fertilizers used were urea for nitrogen, single super phosphate (SSP) for phosphorus, and muriate of potash (MOP) for potassium.

Results and Discussion

Yield parameters

Fresh Foliage Yield (kg ha^{-1})

Effect of Nitrogen Sources

The effect of nitrogen sources on fresh foliage yield was found to be significant. Among the treatments, the highest fresh foliage yield (8558 kg ha^{-1}) was recorded with (N4) 100% RDN through inorganic fertilizer, which was significantly superior to N3 - 100% N through vermicompost which was recorded the lowest yield (6274 kg ha^{-1}). However, N4 was found statistically at par with N2 (50% N through vermicompost + 50% RDN through inorganic fertilizer) which was recorded 7775 kg ha^{-1}. The fresh foliage yield under N1 (75% N through vermicompost + 25% RDN through inorganic fertilizer) was 7441 kg ha^{-1}.The increased yield in N4 and N2 treatments may be attributed to a more balanced and readily available supply of nutrients, resulting in improved vegetative growth and biomass accumulation. These results were in agreement with the findings of Chandana *et al*., (2018) [1] and Shrivastava *et al*., (2011) [9].

Effect of Plant Spacing

Plant geometry had a significant effect on fresh foliage yield. Among the spacings, S2(30 × 15 cm) recorded the maximum yield (6927 kg ha^{-1}), which was significantly superior to both S1 (20 × 20 cm; 5860 kg ha^{-1}) and S3 (30 × 15 cm; 7049 kg ha^{-1}). Wider spacing likely facilitated better air circulation, light penetration, and root expansion, contributing to enhanced plant growth and yield. These results were in agreement with the findings of Kanjilal *et al*., (2002) [2] &Ram *et al.,* (2008) [6].

Interaction Effect

The interaction between nitrogen source and plant geometry was found to be significant. The highest fresh foliage yield (12573 kg ha^{-1}) was recorded in the treatment combination of (N4XS3) 100% RDN through inorganic fertilizer with 30 × 15 cm spacing, which was significantly higher than other combinations. The lowest yield (5410 kg ha^{-1}) was recorded under (N2XS1) 50% N through vermicompost with 50% RDN through inorganic fertilizer with 20 × 20 cm spacing. These results are in conformity with Ram *et al.,* (2008) [6].

Dry Foliage Yield (kg ha^{-1})

The data on fresh and dry foliage yield (kg ha^{-1}) of Kalmegh at harvest as influenced by various nitrogen sources and plant geometry is presented in Table 1 and their interaction in Table No: 1 a&b.

Effect of Nitrogen Sources

Dry foliage yield was significantly influenced by nitrogen sources. The maximum dry foliage yield (3388 kg ha^{-1}) was obtained with (N4) 100% RDN through inorganic fertilizer, which is at par with (N2) 50% N through vermicompost and 50% RDN (2979 kg ha^{-1}). The lowest dry foliage yield (2121 kg ha^{-1}) was observed with (N3) 100% N through vermicompost, which was significantly lower than all other treatments. N1 recorded 2539 kg ha^{-1} of dry foliage yield. The superior performance of N4 and N2 can be attributed to enhanced nutrient uptake and better plant development due

to the integrated nutrient management approach. These results were in agreement with the findings of Shrivastava *et al*., (2011) [9] and Verma *et al.*, (2018) [10].

Effect of Plant Spacing

Spacing significantly affected dry foliage yield. Treatment S2 (30 × 10 cm) recorded the highest dry foliage yield (3548 kg ha⁻¹), which was significantly superior to S3(30 × 15 cm; 2509 kg ha⁻¹) and S1 (20 × 20 cm; 2214 kg ha⁻¹). The wider spacing under S3 possibly enhanced photosynthetic efficiency and reduced competition among plants. These results were in agreement with the findings of Kumar *et al*., (2010) [3] and Patidar *et al*., (2011) [5].

Interaction Effect

A significant interaction between nitrogen source and plant spacing was observed. The highest dry foliage yield (4910. kg ha⁻¹) was recorded under treatment combination (N4XS2) 100% RDN through inorganic fertilizer with 30 × 10 cm spacing, while the lowest dry foliage yield (1985 kg ha⁻¹) was recorded under (N3S2) 100% N through vermicompost with 30 × 10 cm spacing. The results clearly indicate that the integrated application of nitrogen, particularly through 100% RDN through inorganic fertilizer and a wider spacing of 30 × 15 cm, leads to enhanced biomass production in Kalmegh. These results are in conformity with Patel *et al.* (2016).

Total Andrographolide Yield (kg ha^{-1})

The data pertaining to total andrographolide yield (kg ha^{-1}) of Kalmegh as influenced by different nitrogen sources and plant geometry are presented in Table 2 and their interaction 2(a).

Effect of Nitrogen Sources

The maximum total andrographolide yield was recorded under N_4 (100% RDN through inorganic fertilizer) with 44.41kg ha^{-1}, which was statistically superior to all other treatments. This was followed by N_2 (50% N through vermicompost with 50% RDN through inorganics) with 38.86 kg ha^{-1}, which was at par with N_4. The lowest andrographolide yield was obtained under N_3 (100% N through vermicompost) with 27.57 kg ha^{-1}, indicating that sole organic nitrogen application was less effective in enhancing secondary metabolite content. These findings clearly demonstrate that inorganic nitrogen, either fully or partially, plays a critical role in promoting andrographolide synthesis in Kalmegh. These results were in agreement with the findings of Kumar *et al*., (2010) [3].

Effect of Spacing

Among the spacing treatments, S_2 (30 × 10 cm) recorded the highest total andrographolide yield of 46.52 kg ha^{-1}, which was significantly superior over S_3 (30 × 15 cm) and S_1 (20 × 20 cm). The results suggest that wider spacing (S_2) allowed for better plant development and secondary metabolite accumulation, possibly due to improved light penetration, air circulation, and reduced interplant competition. These results were in agreement with the findings of Singh *et al*., (2011).

Interaction Effect

The interaction effect between nitrogen sources and plant geometry was found to be significant, The highest andrographolide yield was observed under the combination N_4S2 (100% RDN through inorganic fertilizer with 30 × 10 cm spacing) with 61.07 kg ha^{-1}, which was significantly superior to all other combinations. This at par with N2S2 (50% N through vermicompost + 50% RDN through inorganic fertilizers with 30 X 10 cm) (51.33 kg ha^{-1}). The significantly lowest andrographolide yield was observed in N1S3 (75% N through vermicompost with 25% RDN through inorganic fertilizer with 30 X 15 cm) (25.26 kg ha^{-1}). It clearly indicates that optimum spacing (30 × 10 cm) when combined with either full or partial inorganic nitrogen source results in optimum andrographolide accumulation in Kalmegh.

The study reveals that both nitrogen source and plant geometry, individually and in combination, significantly influenced andrographolide yield in Kalmegh. The integration of 100% RDN through inorganic fertilizer and optimum spacing (30 × 10 cm) was found to be the most effective strategy for maximizing andrographolide content, which is crucial for the medicinal value of the crop.

Table 1: Fresh and dry foliage yield of Kalmegh (kg ha^{-1}) as influenced by nitrogen sources and plant geometry

Treatments	Fresh foliage yield (Kg ha^{-1})	Dry foliage yield (Kg ha^{-1})
Factor A: Sources of N applications		
N1: 75% N through vermicompost + 25% RDN through inorganic fertilizer	7441	2539
N2: 50% N through vermicompost + 50% RDN through inorganic fertilizer	7775	2979
N3: 100% N through vermicompost	6274	2121
N4: 100% RDN through inorganic fertilizer	8558	3388
SE (m) ±	369	168
CD at 5%	1083	492
Factor B: Spacing		
S1: 20x20 cm	5860	2214
S2: 30x10 cm	9627	3548
S3: 30x15 cm	7049	2509
SE (m) ±	320	145
CD at 5%	938	426
Int. (N X S)		
SE (m) ±	640	291
CD at 5%	1876	852
CV%	14.75	18.26
GM	7512	2757

Table 1(a): Fresh foliage yield (Kg ha^{-1}) influenced by interaction between nitrogen sources and plant geometry in Kalmegh

Treatments	Fresh foliage yield (Kg ha^{-1})				
	N1	N2	N3	N4	Mean
S1	6237	5410	6266	5527	5860
S2	10384	9781	5770	12573	9627
S3	5701	8134	6787	7574	7049
Mean	7441	7775	6274	8558	
SE (m)±	640				
CD at 5%	1876				

Table 1(b): Dry foliage yield (Kg ha^{-1}) influenced by interaction between nitrogen sources and plant geometry in Kalmegh

Treatments	Dry foliage yield (Kg ha^{-1})				
	N1	N2	N3	N4	Mean
S1	2169	2169	2148	2369	2214
S2	3572	3723	1985	4910	3548
S3	1875	3045	2231	2885	2509
Mean	2539	2979	2121	3388	
SE (m)±	291				
CD at 5%	852				

Table 2: Total Andrographolide yield (Kg ha^{-1}) of Kalmegh as influenced by nitrogen sources and plant geometry

Treatments	Andrographolide	
	Andrographolide content (%)	Total Andrographolide yield Kg ha^{-1})
Factor A: Sources of N applications		
N1: 75% N through vermicompost + 25% RDN through inorganic fertilizer	1.33	33.76
N2: 50% N through vermicompost + 50% RDN through inorganic fertilizer	1.29	38.86
N3: 100% N through vermicompost	1.30	27.57
N4: 100% RDN through inorganic fertilizer	1.33	44.41
SE (m) ±	0.01	2.29
CD at 5%	NS	6.73
Factor B: Spacing		
S1: 20x20 cm	1.29	28.68
S2: 30x10 cm	1.32	46.52
S3: 30x15 cm	1.33	33.26
SE (m) ±	0.01	1.99
CD at 5%	NS	5.83
Int. (N X S)		
SE (m) ±	-	3.97
CD at 5%	-	11.66
CV%	-	19.04
GM	-	36.15

Table 2(a): Total Andrographolide yield (Kg ha^{-1}) influenced by interaction between nitrogen sources and plant geometry in Kalmegh

Treatments	Total Andrographolide yield (Kg ha^{-1})				
	N1	N2	N3	N4	Mean
S1	28.33	25.58	28.50	32.29	28.68
S2	47.69	51.33	25.99	61.07	46.52
S3	25.26	39.68	28.23	39.88	33.26
Mean	33.76	38.86	27.57	44.41	
SE (m)±	3.97				
CD at 5%	11.66				

Conclusion

The study revealed that nitrogen source and plant spacing significantly influenced yield and quality parameters of Kalmegh. Application of 100% recommended dose of nitrogen through inorganic fertilizer recorded the highest fresh and dry foliage yield as well as andrographolide yield, followed closely by integrated application of 50% vermicompost + 50% inorganic nitrogen. Among spacing treatments, 30 × 10 cm spacing proved optimum for maximizing biomass and andrographolide production. The interaction of 100% RDN with 30 × 10 cm spacing was the most effective combination. Hence, for *kharif* season cultivation of Kalmegh, either 100% inorganic nitrogen or integrated nutrient management with optimum spacing is recommended for achieving higher yield and quality.

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