ORIGINAL RESEARCH ARTICLE

Enhancing biomass and seed production in Kalmegh [*Andrographis paniculata* (Burm. F.) Wall ex. Nees] through optimal plant spacing and nutrients under the Western Himalayan region of India

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Article History

Received: April 10, 2023
Revised: April 18, 2023
Accepted: May 09, 2023

Key Words

Andrographis paniculata
Biomass
NPK levels
Plant spacing
Seed yield

ABSTRACT

The field experiment was conducted during the winter (kharif) seasons of 2021-22 and 2022-23 at CSIR-Central Institute of Medicinal and Aromatic Plants Research Centre Purara, Bageshwar, Uttarakhand. The study's objective was to investigate the most effective combinations of plant spacing configurations and NPK levels to enhance biomass and seed yield of kalmegh [Andrographis paniculata (Burm. F.) Wall ex. Nees] under the Western Himalayan region of Uttarakhand. The experiment consisted of nine treatments, comprising three different plant spacing (60x30 cm, 60 x45 cm, 60x60 cm) and three NPK levels (40:30:20, 80:60:30, 120:90:40), arranged in factorial randomised block design. The results indicated that treatment T_3 *(120:90:40 NPK) and spacing* S_3 *(60x60 cm) consistently demonstrated superior performance, resulting in the highest plant height, number of branches, LAI, total dry matter weight, dry seed weight, and leaf stem ratio. Treatment* T_2 *(80:60:30 NPK) and spacing* S_2 *(60x 45 cm) displayed intermediate results, while treatment* T_1 *(40:30:20 NPK) and spacing* S_1 *(60 x 30 cm) exhibited relatively lower values for most parameters.*

INTRODUCTION

Kalmegh [*Andrographis paniculata* (Burm. F.) Wall ex. Nees] is an annual medicinal herb belong to the Acanthaceae family (Worakunphanich *et al.*, 2021) with hepatoprotective properties used in Ayurveda, Yunani, Siddha, and Homeopathy systems of medicine. (Mehta *et al.*, 2021). As a result, Kalmegh has therapeutic properties used for ailments like dysentery, diarrhoea, fever, cough, sore throat, bronchitis, arthralgia, menstrual disorders, hypertension, and even snake bites (Abu *et al.*, 2017). Considering its extensive therapeutic applications and increasing market demand, commercial cultivation of Kalmegh has been initiated in India. Standardising various agronomic factors to optimise the crop's yield potential in specific agro-climatic conditions is essential. Among these, plant spacing and nitrogen dosages emerge as primary considerations. Therefore, there is an urgent need to standardise plant spacing and NPK for optimising maximum yield potential and seed yield of crops in the mid hills of the Western Himalayan region of Uttarakhand, India.

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Institutional communication number: CIMAP/PUB/ 2023/126
Doi: https://doi.org/10.62029/jmaps.v45i2.verma

MATERIALS AND METHODS

The field experiment was conducted during the rainy season of July to October in year 2021-22 and 2022-23 at the research farm of CSIR-CIMAP Research Centre Purara, Bageshwar, Uttarakhand. The research farm has well-maintained facilities, optimal agricultural practices, and rigorous experimental protocols. The experimental site is situated in the Katyur valley of the Uttarakhand hills, adding to its unique ecological significance. The geographical coordinates of the experimental site were recorded as 79° 51' 38"East longitude and 29° 38' 45" North latitude, and it covers an elevation range of 1500-1560 meters above mean sea level. The Katyur Valley experiences a significant monsoon season that typically extends from June to September, ensuring an adequate and consistent water supply during the experimental period. The soil of the experimental site was sandy loam, with a pH level of 7 and moderate organic matter content.

Nine treatments of the experiment consist of three plant spacing: S_1 (60x30cm), S_2 (60x45cm) and S_3 (60x60cm) and three NPK levels: T_1 (40:30:20), T_2 (80:60:30) and T_3 (120:90:40) in both years. The experimental layout was strategically chosen as a factorial randomised block design (FRBD). About 35 days old seedlings of Kalmegh variety CIM-Megha having 5-6 inches height were used for the experiment. Transplantation was carried out in July for 2021-22 and 2022-23, precisely at the beginning of the rainy season. According to respective treatments (T_1, T_2, T_3), a full dose of phosphorus and potassium was applied in the field after transplanting. Additionally, one-third of the total nitrogen dose was applied simultaneously as a basal application. The remaining two-thirds of the nitrogen dose was split into two separate applications; the second dose of nitrogen, constituting the residual portion, was applied in field 30 DAT. Finally, the last dose of nitrogen was applied in the field 90 DAT. For the application of NPK doses, the specific fertilisers Urea, Diammonium Phosphate, and Muriate of Potash were used. These fertilisers were applied through the top dressing. Three manual weedings were conducted at 30, 60, and 90 days after transplanting to manage weed competition and promote crop growth. The crop was harvested at 110 DAT in both 2021-22 and 2022-23.

The data on plant height (cm), number of leaves/plants, number of branches/plants, and leaf area index (LAI) were recorded at different intervals of days after transplanting (15, 30, 60, 90 and 110 DAT) during experiments in both the years. Plant height (cm) was measured on ten tagged plants at each DAT interval, while the number of leaves/plant and number of branches/plants were counted for ten randomly selected plants from each treatment. LAI was calculated using the formula: LAI = Leaf area (m2) / Ground area (m2). Fully expanded leaves were randomly selected from different plants at specific intervals of days after transplanting (15, 30, 60, 90, and 110 DAT). Leaf area was measured by tracing leaf outlines on graph paper. LAI values were obtained by dividing the total leaf area by the corresponding ground area for each treatment combination. All measurements were conducted for each treatment combination.

Additionally, the total dry matter weight/plant (g) and dry seed yield/plant (g) were determined by harvesting ten selected plants from each treatment combination at the end of the experiment (110 DAT). The leaf: stem ratio was determined by dividing the total leaf count by biomass in each treatment combination. The collected data was analysed using ANOVA within a factorial randomised block design.

RESULTS AND DISCUSSION

The pooled data of both years were studied which further supports the trends observed in plant height for different fertiliser treatments and spacing patterns in Table 1. Treatment T_3 (120:90:40 NPK) consistently resulted in the highest plant height throughout the growth stages, with an average height of 12.46 cm at 15 DAT, 20.78 cm at 30 DAT, 30.54 cm at 60 DAT, 48.57 cm at 90 DAT, and 54.53 cm at 110 DAT. It significantly outperformed treatments T_1 (40:30:20 NPK) and T_2 (80:60:30 NPK) at all DAT intervals, confirming its positive effect on plant height. Treatment T_2 displayed intermediate plant height, with an average height of 11.14 cm, 19.23 cm, 28.13 cm, 46.46 cm, and 53.23 cm at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. Treatment T_1 consistently had the lowest plant height, with an average height of 10.12 cm, 17.13 cm, 26.12 cm, 44.35 cm, and 52.46 cm at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. Regarding spacing patterns, spacing S_3 (60 x 60 cm) consistently resulted in the tallest plants throughout the growth stages, with an average height ranging from 13.46 cm at 15 DAT to 58.55 cm at 110 DAT.

Spacing S_1 (60 x 30 cm) consistently exhibited the shortest plant height among the three spacings, with an average height ranging from 11.13 cm at 15 DAT to 53.46 cm at 110 DAT. Spacing S_2 (60 x 45 cm) displayed an intermediate plant height, with an average height ranging from 12.17 cm at 15 DAT to 55.24 cm at 110 DAT. The pooled data reaffirms the significant influence of NPK doses on plant height, with treatment T_3 consistently leading to taller plants compared to treatments T_1 and T_2. Additionally, wider spacing (S_3) consistently resulted in taller plants, while closer spacing (S_1) led to relatively shorter plant heights. Our research findings are consistent with a study by Jat and Gajbhiye (2019), which also reported higher dry herbage yield with NPK 80:30:50 kg/ha and split nitrogen application. Similar results were also reported by Verma *et al.*, (2015).

The pooled data in Table 1 also shows that treatment T_2 (80:60:30 NPK) consistently exhibited the highest number of branches/plant at all growth stages, with values of 3.16, 8.88, 15.44, 32.00, and 48.44 at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. In branch development, it significantly outperformed treatments T_1 (40:30:20 NPK) and T_3 (120:90:40 NPK). On the other hand, treatment T_1 had the lowest number of branches, with values of 3.15, 7.22, 11.56, 28.00, and 40.40 at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. Among the three spacing patterns, spacing S_2 (60 x 45 cm) exhibited the most abundant branching, with values of 3.15, 8.78, 15.51, 26.36, and 37.12 at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. Spacing S_3 (60 x 60 cm) displayed intermediate numbers of branches, with values of 2.66, 7.44, 11.44, 28.00, and 40.89 at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. Spacing S_1 (60 x 30 cm) had the fewest branches, with values of 2.36, 7.54, 12.45, 24.13, and 35.36 at 15 DAT, 30 DAT, 60 DAT, 90 DAT, and 110 DAT, respectively. The results align with Shah Jahan *et al.*, (2013) study, confirming the positive effect of NPK 80:60:30 on the number of branches. Moreover, Treatment T_2 (80:60:30 NPK) displayed the highest number of leaves/plant (Table 2) at all DAT intervals, ranging from 22.56 leaves at 15 DAT to 322.36 leaves at 110 DAT. It significantly outperformed treatments T_1 (40:30:20 NPK) and T_3 (120:90:40 NPK) in leaf production. On the other hand, treatment T_1 had the lowest number of leaves/plants, ranging from 16.12 leaves at 15 DAT to 320.25 leaves at 110 DAT. Among the spacing patterns, spacing S_2 (60 x 45 cm) exhibited the highest number of leaves per plant at all DAT intervals, ranging from 23.42 at 15 DAT to 324.23 leaves at 110 DAT. Spacing S_1 (60 x 30 cm) had an intermediate number of leaves, ranging from 17.15 leaves at 15 DAT to 322.27 leaves at 110 DAT. Spacing S_3 (60 x 60 cm) had the lowest leaves/

Table 1: Effect NPK doses and spacing on the plant height (cm) and number of branches/plant of kalmegh at various days after transplanting

Treatment	Plant height (cm) at DAT					Number of branches/plants at DAT				
	15	30	60	90	110	15	30	60	90	110
Fertilisers										
T_1	10.12b	17.13b	26.12b	44.35b	52.46b	3.15b	7.22b	11.56b	28.00b	40.40b
T_2	11.14ab	19.23ab	28.13ab	46.46ab	53.23ab	3.16b	8.88a	15.44a	32.00a	48.44a
T_3	12.46a	20.78a	30.54a	48.57a	54.53a	2.66a	7.44b	11.44b	28.00b	40.89b
LSD (0.05)	1.34	1.53	2.05	2.32	1.63	0.501	1.332	1.611	2.020	2.250
CV (%)	9.32	8.27	7.06	5.32	4.73	17.57	11.63	9.83	5.82	5.45
Spacing										
S_1	11.13b	18.24b	25.64b	42.45b	53.46b	2.36b	7.54b	12.45b	24.13b	35.36b
S_2	12.17ab	19.63ab	27.16ab	47.36ab	55.24ab	3.15ab	8.78a	15.51a	26.36ab	37.12ab
S_3	13.46a	20.45a	31.58a	50.41a	58.55a	2.12a	7.89a	13.46a	24.13b	34.16ab
LSD (0.05)	1.43	1.65	2.21	2.58	1.81	0.475	1.348	1.663	1.849	1.532
CV (%)	10.01	9.11	7.62	5.71	5.08	16.44	11.35	9.86	6.39	5.52

T_1- 40:30:20; T_2-80:60:30; T_3- 120:90:40; S_1-60 x 30 cm; S_2-60 x 45cm; S_3-60 x 60 cm; DAT-Days after transplanting

Table 2: Effect NPK doses and spacing on the number of leaves/plant and leaf area index of kalmegh at various days after transplanting

Treatment	Number of leaves plant/plant					Leaf area index				
	at DAT					at DAT				
	15	30	60	90	110	15	30	60	90	110
Fertilisers										
T1	16.12b	50.41b	99.41b	221.24b	320.25b	0.27b	0.33b	0.42b	0.57b	1.62b
T2	22.56a	52.26ab	110.12a	241.36a	322.36a	0.36a	0.41a	0.53a	0.69a	2.04a
T3	18.14ab	49.21b	98.25ab	218.14ab	318.42ab	0.31ab	0.34ab	0.46ab	0.62ab	1.81ab
LSD (0.05)	3.267	1.958	5.029	12.435	4.350	0.042	0.043	0.047	0.054	0.067
CV (%)	9.84	5.56	5.05	5.24	1.53	11.58	10.91	10.24	9.59	8.87
Spacing										
S1	17.15b	49.46b	98.24b	222.24b	322.27b	0.28b	0.34b	0.41b	0.53b	1.61b
S2	23.42a	52.28a	108.45a	261.14a	324.23a	0.35a	0.40a	0.52a	0.72a	2.06a
S3	19.16ab	48.23b	97.23ab	212.55ab	317.45ab	0.32ab	0.36ab	0.45ab	0.63ab	1.84ab
LSD (0.05)	3.030	1.832	4.735	11.935	4.176	0.036	0.035	0.038	0.045	0.059
CV (%)	8.90	4.76	4.86	4.89	1.49	10.94	10.27	9.63	8.97	8.13
T_1- 40:30:20; T_2-80:60:30; T_3- 120:90:40; S_1-60 x 30 cm; S_2-60 x 45cm; S_3-60 x 60 cm, DAT-Days after transplanting										

Table 3: Effect of NPK doses and spacing on total dry matter weight (g), dry seed weight (g), and leaf stem ratio of kalmegh

Treatment	Total dry matter weight/ plant (g)	Dry seed weight/ plant (g)	Leaf stem ratio
Fertilisers			
T1	111.4	18.78	1.87
T2	136.0	20.56	2.9
T3	125.9	19.89	1.74
LSD (0.05)	4.30	1.65	0.21
CV (%)	5.83	4.22	8.13
Spacing			
S1	109.7	17.00	1.66
S2	127.8	20.67	2.8
S3	135.9	21.56	1.59
LSD (0.05)	3.88	1.42	0.20
CV(%)	4.72	3.84	7.97
Treatment Combinations			
T1S1	100.6	16.23	1.60
T1S2	104.2	16.88	1.63
T1S3	102.8	16.66	1.61
T2S1	120.4	19.01	2.40
T2S2	122.6	19.46	2.44
T2S3	124.1	19.77	2.50
T3S1	115.2	18.12	1.85
T3S2	117.9	18.49	1.88
T3S3	118.7	18.61	1.90
LSD(0.05)	2.43	1.11	0.12
CV(%)	3.28	2.92	5.29
T_1- 40:30:20; T_2-80:60:30; T_3- 120:90:40; S_1-60 x 30 cm; S_2-60 x 45cm; S_3-60 x 60 cm, DAT-Days after transplanting			

plant, ranging from 19.16 leaves at 15 DAT to 317.45 leaves at 110 DAT. These findings are consistent with other research studies, such as Purwanto *et al.,* (2011), which also support the influence of NPK doses and spacing patterns on the number of leaves. Treatment T_2 (80:60:30 NPK) was also superior in leaf area index (LAI) at all stages of growth (Table 2), ranging from 0.36 at 15 DAT to 2.04 at 110 DAT. It outperformed treatments T_1 (40:30:20 NPK) and T_3 (120:90:40 NPK), which had lower LAI values throughout the growth stages. Among the spacing patterns, S_2 (60 x 45 cm) exhibited the highest LAI at all DAT intervals, ranging from 0.35 at 15 DAT to 2.06 at 110 DAT. S_1 (60 x 30 cm) had an intermediate LAI while spacing S_3 (60 x 60 cm) had the lowest LAI. These results are consistent with previous research conducted by Shukla *et al.,* (2018), indicating that treatment 80:60:30 NPK and spacing 60 x 45 cm are favourable for maximising LAI kalmegh cultivation.

The pooled data from both years of the study further supports the observations on total dry matter weight per plant and dry seed weight for different fertiliser treatments and spacing patterns (Table 3). Treatment T_2 (80:60:30 NPK) consistently exhibited the highest total dry matter weight per plant, with an average accumulation of 136.0 g. This value was significantly greater than treatments T_1 (40:30:20 NPK) and T_3 (120:90:40 NPK), which had average dry matter weights of 111.4 g and 125.9 g, respectively. Among the spacing patterns, spacing S_3 (60 x 60 cm) consistently resulted in the highest dry matter weight per plant, measuring an average of 135.9 g.

S_2 (60 x 45 cm) also exhibited substantial biomass accumulation, with an average dry matter weight of 127.8 g. On the other hand, S_1 (60 cm x 30 cm) had the lowest dry matter weight among the three spacings, with an average of 109.7 g. The pooled data reaffirms the positive influence of treatment 80:60:30 NPK on total dry matter accumulation and the benefits of wider spacing (S_3) in promoting higher biomass production. Sanjutha *et al.,* (2008) and Kumar *et al.,* (2023) provided additional evidence in favour of the notion that wider spacing (60 x 45 cm) and the application of 80:60:30 NPK treatment led to enhanced dry matter accumulation in kalmegh. In terms of dry seed weight, treatment T_2 (80:60:30 NPK) they consistently displayed the highest average value of 20.56 g, closely followed by treatments T_3 and T_1, with average dry seed weights of 19.89 g and 18.78 g, respectively. The spacing patterns (S_1, S_2, and S_3) did not significantly affect the dry seed weight per plant, as all three spacings resulted in similar seed weights ranging from 17 g to 21.56 g on average. Pooled results support the positive impact of 80:60:30 NPK treatment on dry seed weight in kalmegh, while spacing patterns showed no significant effect. This aligns with previous research on kalmegh, with studies by Kumar *et al.,* (2023) and Gundadon *et al.,* (2018) reporting increased seed weights with 80:60:30 NPK. The leaf stem ratio data for different fertiliser treatments and spacings are presented in Table 3. Treatment T_2 (80:60:30 NPK) showed the highest leaf stem ratio of 2.9, indicating a higher investment in leaf production than stem growth. Treatments T_1 (40:30:20 NPK) and T_3 (120:90:40 NPK) had lower leaf stem ratios of 1.87 and 1.74, respectively. Among the spacing patterns, S_2 (60 x 45 cm) resulted in the highest leaf stem ratio of 2.8, followed by S_3 (60 x 60 cm) with a ratio of 1.59. S_1 (60 x 30 cm) had an intermediate leaf stem ratio of 1.66. These findings are consistent with previous studies conducted by Malik (2014) and Gundadon *et al.,* (2018), supporting our findings on the influence of fertiliser treatments and spacing patterns on the leaf stem ratio.

CONCLUSION

Treatment S_3 (60 x 60 cm) and T_3 (120:90:40 NPK) consistently resulted in the highest plant height, number of branches, leaf area index, total dry matter weight, dry seed weight, and leaf stem ratio. These findings suggest that this combination of plant spacing and NPK doses is suitable for Kalmegh cultivation in the lower hills of the Western Himalayan region of Uttarakhand.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Director, CSIR-CIMAP, Lucknow, for providing them with encouragement, support, and facilities.

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