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Integrated nutrient management for optimizing yield, quality and nutrient uptake in Kalmegh (*Andrographis paniculata*)

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Abstract
The experiment was conducted at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, using a factorial randomized block design with three replications. The results indicated that Vermicompost @ 2.5 t/ha (M3) significantly improved seed yield (21.15 kg ha^{-1}) compared to FYM @ 5 t/ha (M2) (19.72 kg ha^{-1}) and control (18.55 kg ha^{-1}). 100% RDF (80:40:50 kg NPK/ha) resulted in the highest seed yield (20.83 kg ha^{-1}) and the highest fresh foliage yield (5619 kg ha^{-1}), followed by 75% RDF (5586 kg ha^{-1}). The highest dry foliage yield (2324 kg ha^{-1}) was recorded under 100% RDF, while the combination of Vermicompost @ 2.5 t/ha and 75% RDF produced the highest fresh (6540 kg ha^{-1}) and dry (2489 kg ha^{-1}) foliage yields. Nutrient uptake was significantly enhanced with Vermicompost and higher fertilizer doses, leading to increased nitrogen uptake (66.92 kg ha^{-1}), phosphorus uptake (6.57 kg ha^{-1}), and potassium uptake (58.39 kg ha^{-1}). In conclusion, INM using Vermicompost and balanced inorganic fertilizers (75% or 100% RDF) effectively improved Kalmegh's yield, quality, and bioactive content, supporting sustainable cultivation practices.

Keywords: Kalmegh, vermicompost, integrated nutrient management

Introduction
Kalmegh (*Andrographis paniculata*), a herbaceous annual plant from the Acanthaceae family, has long been revered in traditional medicine for its diverse therapeutic applications. Kalmegh, native to South Asia, Kalmegh is extensively used in Ayurveda, Siddha, and Unani systems of medicine. Commonly referred to as "Bhui-neem" for its bitter taste akin to neem (*Azadirachta indica*), it is also known globally as "King of Bitters". The plant holds significant value due to its bioactive compounds, particularly andrographolide, a diterpenoid lactone known for its anti-inflammatory, hepatoprotective, antipyretic, and immunomodulatory properties (Gupta *et al.*, 2017) [4]. Medicinally, Kalmegh is employed as a bitter tonic and stomachic to improve digestion. Its anthelmintic and antiperistalsis properties make it effective in treating intestinal worms and diarrhoea. Decoctions of Kalmegh are traditionally used as blood purifiers and have shown efficacy in managing liver disorders, respiratory infections, and fevers (Sharma *et al.*, 2009) [14]. Studies have also highlighted its potential as an antiviral agent, particularly in combating HIV, adding to its prominence in modern pharmacology (Kurian & Sankar, 2007) [6]. The fresh leaves, dried herb, and extracted juice are recognized as official drugs in the Indian Pharmacopoeia, with an estimated annual demand of 1,000 tons (Anonymous, 2009) [1].
The increasing demand for medicinal plants like Kalmegh necessitates sustainable cultivation practices. Traditional agricultural practices heavily reliant on inorganic fertilizers have led to declining soil health, reduced microbial activity, and unsustainable farming systems. Integrated Nutrient Management (INM) offers a solution by combining organic manures such as farmyard manure (FYM) and vermicompost with inorganic fertilizers to ensure balanced nutrient availability, enhanced soil fertility, and improved crop productivity (Dauda *et al.*, 2008) [2].
Vermicomposting, a process where earthworms accelerate the decomposition of organic matter, produces nutrient-rich compost with high microbial activity, thereby improving soil structure and fertility (Gandhi *et al.*, 1997) [3].

While organic manures are slower in nutrient release compared to chemical fertilizers, their long-term use fosters sustainability and environmental health (Naguib, 2011) [9]. INM practices optimize the benefits of both organic and inorganic sources, ensuring higher nutrient use efficiency, sustained productivity, and improved quality of produce (Malewar *et al*., 1998) [7].

This study explores the impact of INM on the yield and quality of Kalmegh under field conditions. The objective is to evaluate various combinations of organic manures and inorganic fertilizers to identify the most effective nutrient management strategy for achieving optimal productivity while maintaining soil health and quality of medicinal produce.

Materials and Methods

The study was conducted during the Kharif season of 2016-17 at Nagarjun Medicinal Plants Garden, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The experimental site lies at 22°42' N latitude, 77°02' E longitude, and an elevation of 307.41 m above mean sea level, in a semi-arid climate. The soil, classified as black cotton soil (Vertisol), was clayey in texture (50.96% clay, 29.8% silt, and 18.2% sand) with good water-holding capacity and drainage. Soil fertility analysis revealed low nitrogen (180 kg ha^{-1}), medium phosphorus (23 kg ha^{-1}), and high potassium (345 kg ha^{-1}) availability. During the cropping period, the region received 823.7 mm of rainfall across 43 rainy days, slightly above the normal (738.4 mm). Uniform rainfall distribution during the vegetative growth stage was beneficial, and cooler temperatures from the 37th to 42nd meteorological week supported photosynthesis and crop growth.

The experiment was laid out in a factorial randomized block design (FRBD) with three replications. Treatments included three levels of organic manures Control, FYM (5 t ha^{-1}), and Vermicompost (2.5 t ha^{-1}) and four levels of inorganic fertilizers Control, 50% RDF (40:20:25 kg NPK/ha), 75% RDF (60:30:37.5 kg NPK/ha), and 100% RDF (80:40:50 kg NPK/ha). A total of 12 treatment combinations were tested. Organic manure nitrogen content was determined using the Kjeldahl method, with FYM containing 0.77% nitrogen and Vermicompost containing 1.5%. The layout ensured even distribution and minimized variability in soil fertility and microclimatic conditions. Kalmegh seedlings were transplanted on August 9, 2016, after sufficient soil moisture was ensured by monsoon rains. This study emphasized the synergistic effects of combining organic and inorganic fertilizers for sustainable crop production, soil health improvement, and enhanced yield quality. Yield attributes like fresh and dry foliage yield, number of pods, and seed yield were measured at harvest. Foliage was oven-dried at 60°C to determine dry weight. The andrographolide content in leaves was estimated using High-Performance Liquid Chromatography (HPLC). For both parameters, standard protocols were followed to ensure accuracy and reproducibility.

Results and Discussion

Yield attributes and seed yield

The data pertaining to the total and filled pods per plant and seed yield (kg/ha) are presented in Table 1 (a, b and c).

Total Number of Pods Plant^{-1}

The application of Vermicompost @ 2.5 t/ha (M3) significantly increased the total number of pods per plant, recording a mean of 452.08 pods compared to 410.00 pods in the control (M1). The application of FYM @ 5 t/ha (M2) resulted in a similar increase (450.50 pods) and was statistically on par with M3. Organic manures such as Vermicompost improve soil fertility by enhancing microbial activity and nutrient release, which can support the production of more flowers and pods. However, it is important to note that although the total number of pods per plant increased, the number of filled pods remained sporadic due to the non-synchronized flowering nature of Kalmegh. Inorganic fertilizer doses significantly influenced the total number of pods per plant. The highest number was recorded with 100% RDF (80:40:50 kg NPK/ha), with a mean of 484.33 pods, significantly greater than 419.78 pods in control (F1), 426.11 pods in 50% RDF (F2), and 438.56 pods in 75% RDF (F3). The balanced nutrient availability from the recommended fertilizer dose likely optimized plant growth, leading to more pods per plant. These results align with Ramesh *et al*. (2011) [11], who noted that higher fertilizer doses increased pod formation and overall growth in Kalmegh due to adequate supply of essential nutrients. The interaction effect between organic manure and inorganic fertilizer doses was non-significant,

Filled Number of Pods Plant^{-1}

Vermicompost @ 2.5 t/ha (M3) significantly improved the number of filled pods per plant, with a mean of 79.39 filled pods, compared to 56.88 filled pods in the control (M1) and 75.50 filled pods in FYM @ 5 t/ha (M2). Vermicompost's higher nutrient content and its positive impact on soil health likely led to better flower pollination and pod filling, although it was still at par with FYM in terms of filled pods. The application of 100% RDF (80:40:50 kg NPK/ha) resulted in the highest number of filled pods (80.29 filled pods) compared to 55.50 filled pods in the control (F1), 71.81 filled pods in 50% RDF (F2), and 74.76 filled pods in 75% RDF (F3). The increased filled pods with the highest fertilizer dose is likely due to better overall plant nutrition, which optimized flower formation and pod development. These results confirm the findings of Sanjutha *et al*. (2008) [12], who showed that balanced application of NPK fertilizers improves pod filling in medicinal plants. The interaction effect between organic manure and inorganic fertilizer doses was non-significant.

Seed Yield (kg ha^{-1})

Organic manure significantly improved seed yield. Vermicompost @ 2.5 t/ha (M3) recorded the highest seed yield (21.15 kg ha^{-1}), significantly higher than the control (M1) (18.55 kg ha^{-1}) and FYM @ 5 t/ha (M2) (19.72 kg ha^{-1}). Organic amendments, particularly Vermicompost, improve the soil's nutrient content, moisture retention, and microbial activity, which enhances plant growth and, consequently, seed yield. The application of 100% RDF (80:40:50 kg NPK/ha) recorded the highest seed yield (20.83 kg ha^{-1}), which was significantly higher than 18.45 kg ha^{-1} in the control (F1), but similar to 20.27 kg ha^{-1} in 75% RDF (F3) and 19.68 kg ha^{-1} in 50% RDF (F2). This demonstrates that adequate and balanced fertilization, as provided by the recommended dose of NPK, significantly enhances seed yield by supporting better plant health and development. These results corroborate the work of Sanjutha *et al.* (2008) [12], who found that balanced inorganic fertilization led to increased seed yield in Kalmegh. The interaction between organic manure and inorganic fertilizer doses had no significant impact on seed yield.

Yield and Quality

The data in respect of fresh and dry foliage yield (kg/ha) and andrographolide content (%) and yield (kg/ha) as influenced by different organic manure and inorganic fertilizer doses are

presented in Table 2.

Fresh Foliage Yield (kg ha⁻¹)

The application of Vermicompost @ 2.5 t/ha (M3) significantly improved the mean fresh foliage yield, recording 5490 kg ha⁻¹, compared to 5135 kg ha⁻¹ for FYM @ 5 t/ha (M2) and 4609 kg ha⁻¹ for the control (M1). Organic manure, particularly Vermicompost, enhances soil fertility by increasing microbial activity, improving soil structure, and enhancing nutrient availability. This results in better growth conditions and higher foliage production. These findings are consistent with Mishra and Jain (2013) [8], who reported that organic amendments like vermicompost promote plant growth and productivity by improving soil's nutrient-holding capacity and enhancing root development. Significant increases in fresh foliage yield were observed with the application of inorganic fertilizers. 100% RDF (80:40:50 kg NPK/ha) resulted in the highest fresh foliage yield (5619 kg ha⁻¹), followed by 75% RDF (5586 kg ha⁻¹). The 50% RDF (4753 kg ha⁻¹) and control (4353 kg ha⁻¹) treatments recorded the lowest yields. The availability of essential nutrients, particularly nitrogen, phosphorus, and potassium, is crucial for the production of foliage in Kalmegh. These results are in agreement with Ramesh *et al.* (2011) [11], who found that balanced NPK fertilization significantly increased foliage yield in medicinal plants. Higher doses of fertilizers enhance photosynthetic activity, resulting in better biomass production. The interaction between organic manure and inorganic fertilizer doses was found to be significant, with the highest fresh foliage yield (6540 kg ha⁻¹) recorded in the combination of Vermicompost @ 2.5 t/ha (M3) and 75% RDF (F3). The lowest yield (4093 kg ha⁻¹) was recorded in the control (M1) + control fertilizer (F1) combination. The synergy between organic and inorganic inputs likely improved nutrient cycling, enhanced water retention, and promoted metabolic activities, leading to increased foliage production.

Dry Foliage Yield (kg ha⁻¹)

The application of Vermicompost @ 2.5 t/ha (M3) significantly increased the mean dry foliage yield to 2215 kg ha⁻¹, compared to 1823 kg ha⁻¹ for control (M1) and 2097 kg ha⁻¹ for FYM @ 5 t/ha (M2). Organic manures such as Vermicompost not only improve soil fertility but also enhance plant growth and dry matter accumulation. These results are supported by Mishra and Jain (2013) [8], who observed that organic manures enhance plant growth, dry matter production, and overall crop yield by improving soil conditions and nutrient availability. The increase in dry foliage yield is also attributed to the improved nutrient balance and soil structure promoted by organic fertilizers. Inorganic fertilizer application also significantly affected dry foliage yield. 100% RDF (80:40:50 kg NPK/ha) recorded the highest dry foliage yield (2324 kg ha⁻¹), followed by 75% RDF (2228 kg ha⁻¹) and 50% RDF (2034 kg ha⁻¹). The control (1594 kg ha⁻¹) recorded the lowest yield. Higher doses of NPK fertilizers supply essential nutrients that support plant growth, increase photosynthetic activity, and enhance dry matter accumulation. These findings are consistent with Ramesh *et al.* (2011) [11], who found that higher fertilizer levels resulted in increased biomass production in medicinal plants like Kalmegh. The increase in dry foliage yield under higher fertilizer doses is attributed to enhanced nutrient availability for plant growth.

The interaction effect between organic manure and inorganic fertilizer doses was significant. The highest dry foliage yield (2489 kg ha⁻¹) was recorded in the combination of Vermicompost @ 2.5 t/ha (M3) and 75% RDF (F3). This combination improved soil health, nutrient availability, and plant growth, leading to enhanced biomass production. The lowest dry foliage yield (1331 kg ha⁻¹) was recorded in the control (M1) + control fertilizer (F1) combination. This highlights the importance of integrated nutrient management, where the combination of organic and inorganic fertilizers leads to optimal nutrient availability, enhancing both growth and yield. These results are supported by Patel *et al.* (2016) [10], who observed that integrated nutrient management improved growth parameters and dry matter production in Kalmegh.

Andrographolide Content (%)

Although the effect of organic manure on andrographolide content was non-significant, M3 (Vermicompost @ 2.5 t/ha) recorded the highest mean andrographolide content (1.864%). Vermicompost is rich in essential nutrients and organic compounds, which likely facilitated better secondary metabolite synthesis and plant health, indirectly enhancing andrographolide content. Delayed harvesting for seed production reduced quality due to leaf shattering and increased fiber content, as observed by Patel *et al.* 2008. These findings emphasize that precise timing of harvest is crucial for maximizing quality.

Similarly, inorganic fertilizer doses showed a non-significant impact on andrographolide content. However, F4 (100% RDF: 80:40:50 kg NPK/ha) recorded the highest content (1.858%). This result suggests that an optimal balance of nutrients promotes the physiological conditions necessary for synthesizing secondary metabolites, supporting the conclusions of Sanjutha *et al.* (2008) [12], who emphasized the role of balanced fertilization in medicinal plant quality improvement. The interaction between organic manures and inorganic fertilizers did not significantly affect andrographolide content.

Andrographolide Yield (kg ha⁻¹)

The impact of organic manure on andrographolide yield was significant. M3 (Vermicompost @ 2.5 t/ha) produced the highest yield (59.05 kg/ha), significantly superior to the control (M1, 40.22 kg/ha) and comparable to M2 (FYM @ 5 t/ha, 56.43 kg/ha). Vermicompost's ability to improve soil fertility, enhance microbial activity, and sustain nutrient release explains its superior performance. This finding aligns with Hemalatha and Suresh (2012) [5], who reported increased yields of bioactive compounds in Kalmegh with organic nutrient amendments.

The total andrographolide yield was significantly enhanced by inorganic fertilizer doses. F4 (100% RDF) recorded the highest yield due to sufficient and balanced NPK availability, promoting optimal growth and secondary metabolite production. Sanjutha *et al.* (2008) [12] similarly observed that higher levels of NPK positively influenced andrographolide yields by enhancing metabolic efficiency in Kalmegh.

NPK uptake

The data in respect of nitrogen, phosphorus and potassium uptake (kg ha^{-1}) in dry matter of Kalmegh crop as influenced by different organic manure and inorganic fertilizer doses are presented in Table 3.

Nitrogen Uptake (kg ha⁻¹)

The application of Vermicompost @ 2.5 t/ha (M3) significantly enhanced nitrogen uptake, with a mean value of 66.92 kg ha⁻¹, compared to FYM @ 5 t/ha (M2) (57.55 kg ha⁻¹) and control (41.50 kg ha⁻¹). Vermicompost's high nutrient content and its role in improving soil physical properties, such as water retention and aeration, are likely responsible for this increased

nitrogen uptake. Organic matter in Vermicompost enhances soil microbial activity, which accelerates nitrogen mineralization, making it more available for plant uptake. These results align with findings by Sharafzadeh and Ordookhani (2011) [13], who noted that organic manures improve soil physical properties, facilitating nutrient release and enhancing plant uptake. Significant differences in nitrogen uptake were observed due to varying levels of inorganic fertilizers. The application of 100% RDF (80:40:50 kg NPK/ha) resulted in the highest nitrogen uptake (70.34 kg ha⁻¹), significantly higher than 75% RDF (61.35 kg ha⁻¹), 50% RDF (53.05 kg ha⁻¹), and control (36.55 kg ha⁻¹). This increase in nitrogen uptake is likely due to the higher herbage yield and the increased nitrogen content in the plants, facilitated by the balanced nutrient supply from inorganic fertilizers. These results are consistent with the findings of Ramesh *et al.* (2011) [11], who reported that balanced inorganic fertilizer applications enhanced nutrient uptake and growth in Kalmegh. The interaction effect between organic manure and inorganic fertilizer doses was non-significant in terms of nitrogen uptake.

Phosphorus Uptake (kg ha⁻¹)

Organic manure application also significantly influenced phosphorus uptake. Vermicompost @ 2.5 t/ha (M3) recorded the highest phosphorus uptake (6.57 kg ha⁻¹), followed by FYM @ 5 t/ha (5.69 kg ha⁻¹) and control (4.15 kg ha⁻¹). The increased phosphorus uptake with vermicompost is likely due to its ability to mobilize native soil phosphorus and improve the availability of organic phosphorus through microbial mineralization. Additionally, vermicompost may contribute to the production of organic acids, which help in solubilizing phosphorus in the soil, thus making it more available to the plants. This finding supports the work of Sharafzadeh and Ordookhani (2011) [13], who indicated that organic amendments improve phosphorus availability by enhancing soil biological activity. The application of 100% RDF (80:40:50 kg NPK/ha) resulted in significantly higher phosphorus uptake (6.95 kg ha⁻¹) compared to 75% RDF (6.14 kg ha⁻¹), 50% RDF (5.14 kg ha⁻¹), and control (3.66 kg ha⁻¹). The increase in phosphorus uptake with higher inorganic fertilizer doses is due to the sufficient phosphorus availability from the fertilizer, which directly contributes to better root development and phosphorus absorption. These results are consistent with Ramesh *et al.* (2011) [11], who found that balanced application of NPK fertilizers led to higher phosphorus uptake and overall growth in Kalmegh. The interaction effect between organic manure and inorganic fertilizer doses on phosphorus uptake was non-significant, indicating that while both treatments influenced phosphorus uptake, their combined application did not result in a significant synergistic effect.

Potassium Uptake (kg ha⁻¹)

Organic manure application significantly influenced potassium uptake. Vermicompost @ 2.5 t/ha (M3) recorded the highest potassium uptake (58.39 kg ha⁻¹), compared to FYM @ 5 t/ha (52.44 kg ha⁻¹) and control (44.06 kg ha⁻¹). Vermicompost improves soil structure by increasing porosity and aeration, facilitating better root growth and nutrient absorption, particularly potassium. Furthermore, the mineralization of organic matter in vermicompost releases potassium over time, making it more available to the plants. These findings support the work of Sharafzadeh and Ordookhani (2011) [13], who emphasized the positive effect of organic manures on nutrient availability. The effect of inorganic fertilizer doses on potassium uptake was significant. 100% RDF (80:40:50 kg NPK/ha) resulted in the highest potassium uptake (60.98 kg ha⁻¹), significantly higher than 75% RDF (56.99 kg ha⁻¹), 50% RDF (51.04 kg ha⁻¹), and control (37.50 kg ha⁻¹). The higher potassium uptake is attributed to the enhanced availability of potassium from both the fertilizer and organic amendments. Potassium is vital for various plant functions, including photosynthesis and water regulation, and its increased availability under higher fertilizer doses supports better plant growth. These results are consistent with the observations of Ramesh *et al.* (2011) [11], who found that potassium uptake in Kalmegh was positively influenced by higher fertilizer applications. The interaction between organic manure and inorganic fertilizer doses on potassium uptake was significant. The highest potassium uptake (67.26 kg ha⁻¹) occurred in the combination of Vermicompost @ 2.5 t/ha (M3) and 100% RDF (F4). This suggests that the synergistic effect of organic and inorganic nutrients enhances potassium uptake, likely due to improved soil physical properties, nutrient availability, and increased metabolic activity in plants. This finding supports earlier research by Sanjutha *et al.* (2008) [12], who demonstrated the enhanced nutrient uptake when both organic and inorganic fertilizers were applied together.

Table 1: Effect of integrated nutrient management on total number of pods plant^{-1}, filled no. of pods plant^{-1}, seed yield (kg ha^{-1}) and Andrographolide yield (kg ha^{-1}) of Kalmegh.

Treatments	Total No of Pods Plant^{-1}	Filled No of Pods Plant^{-1}	Seed Yield (Kg Ha^{-1})
Factor A (Organic Manure)			
M1-Control	410.00	56.88	18.55
M2-FYM @ 5 t/ha	450.50	75.50	19.72
M3-Vermicompost@ 2.5 t/ha	452.08	79.39	21.15
SE (m) ±	11.35	2.09	0.46
CD (P=0.05)	33.12	6.09	1.34
Factor B (Inorganic fertilizer doses)			
F1-Control	419.78	55.50	18.45
F2-40:20:25 kg NPK/ha (50% RDF)	426.11	71.81	19.68
F3-60:30:37.5 kg NPK/ha (75% RDF)	438.56	74.76	20.27
F4-80:40:50 kg NPK/ha (100% RDF)	484.33	80.29	20.83
SE (m) ±	13.10	2.41	0.53
CD (P=0.05)	38.25	7.03	1.55
Interaction (A × B)			
SE (m) ±	22.70	4.17	0.92
CD (P=0.05)	NS	NS	NS

Table 2: Effect of integrated nutrient management on fresh and dry foliage yield (kg ha^{-1}) and andrographolide content (%) and yield (kg/ha) of Kalmegh

Treatments	Fresh Foliage Yield (Kg Ha^{-1})	Dry Foliage Yield (Kg Ha^{-1})	Andrographolide Content (%)	Andrographolide Yield (Kg Ha^{-1})
Factor A (Organic manure)				
M1-Control	4609	1823	1.837	40.22
M2-FYM @ 5 t/ha	5135	2097	1.850	56.43
M3-Vermicompost@ 2.5 t/ha	5490	2215	1.864	59.05
SE (m) ±	97	60	0.008	1.51
CD (P=0.05)	284	175	NS	4.40
Factor B (Inorganic fertilizer doses)				
F1-Control	4353	1594	1.841	46.70
F2-40:20:25 kg NPK/ha (50% RDF)	4753	2034	1.846	50.88
F3-60:30:37.5 kg NPK/ha (75% RDF)	5586	2228	1.857	54.27
F4-80:40:50 kg NPK/ha (100% RDF)	5619	2324	1.858	55.76
SE (m) ±	112	69	0.010	1.74
CD (P=0.05)	328	202	NS	5.08
Interaction (A × B)				
SE (m) ±	195	120	0.016	3.01
CD (P=0.05)	568	350	NS	NS

Table 2 (b): Fresh foliage yield (kg ha^{-1}) of Kalmegh as influenced by interaction between organic and inorganic fertilizers

Treatments	M1	M2	M3	Mean
F1	4093	4738	4229	4353
F2	4512	4412	5335	4753
F3	4901	5318	6540	5586
F4	4928	6072	5858	5619
Mean	4609	5135	5490	
SE (m) ±	195			
CD (P=0.05)	568			

Table 2 (c): Dry foliage yield (kg ha^{-1}) of Kalmegh as influenced by interaction between organic and inorganic fertilizers

Treatments	M1	M2	M3	Mean
F1	1331	1946	1506	1594
F2	1852	1822	2428	2034
F3	2040	2154	2489	2228
F4	2069	2467	2437	2324
Mean	1823	2097	2215	
SE (m) ±	120			
CD (P=0.05)	350			

Table 3: Influence of integrated nutrient management on nitrogen, phosphorus, and potassium Uptake (kg ha^{-1}) in the dry matter of kalmegh crop

Treatments	N Uptake (Kg Ha^{-1})	P Uptake (Kg Ha^{-1})	K Uptake (Kg Ha^{-1})
Factor A (Organic manure)			
M1-Control	41.50	4.15	44.06
M2-FYM @ 5 t/ha	57.55	5.69	52.44
M3 – Vermicompost @ 2.5 t/ha	66.92	6.57	58.39
SE (m) ±	1.63	0.17	1.12
CD (P=0.05)	4.75	0.50	3.26
Factor B (Inorganic fertilizer doses)			
F1-Control	36.55	3.66	37.50
F2-40:20:25 kg NPK/ha (50% RDF)	53.05	5.14	51.04
F3-60:30:37.5 kg NPK/ha (75% RDF)	61.35	6.14	56.99
F4-80:40:50 kg NPK/ha (100% RDF)	70.34	6.95	60.98
SE (m) +	1.88	0.20	1.29
CD (P=0.05)	5.48	0.57	3.77
Interaction (A × B)			
SE (m) ±	3.25	0.34	2.24
CD (P=0.05)	NS	NS	6.52

Table 3 (a): K Uptake (kg ha^{-1}) in dry matter of Kalmegh crop as influenced by interaction between organic manure and inorganic fertilizers

Treatments	M1	M2	M3	Mean
F1	30.61	45.73	36.14	37.50
F2	44.45	45.55	63.13	51.04
F3	49.37	54.57	67.04	56.99
F4	51.79	63.90	67.26	60.98
Mean	44.06	52.44	58.39	
SE (m) ±	2.24			
CD (P=0.05)	6.52			

Conclusion

The best treatment for optimizing Kalmegh yield and quality was the combination of Vermicompost @ 2.5 t/ha (M3) and 75% RDF (60:30:37.5 kg NPK/ha) (F3). This treatment significantly enhanced fresh and dry foliage yield, seed yield, and nutrient uptake, particularly for potassium.

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