OPEN ACCESS

Kashf Journal of Multidisciplinary Research
Vol: 03- Issue 03 (2026)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

INTEGRATED NUTRIENT MANAGEMENT WITH INORGANIC NPK FERTILIZERS IMPROVES GROWTH AND YIELD OF MILLET

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***DOI:**(https://doi.org/10.71146/kjmr955)*

Article Info

Abstract

The integrated application of inorganic NPK fertilizers significantly improved the growth, yield, and forage quality of millet compared with the unfertilized control. Increasing fertilizer rates progressively enhanced plant height, stem diameter, leaf area per tiller, and green fodder yield. The highest NPK treatment (180 + 35 + 30 kg ha^{-1}) produced the maximum plant height (223.61 cm), stem diameter (0.92 cm), leaf area per tiller (1792.53 cm^2), and green fodder yield (78.36 t ha^{-1}), whereas the control treatment recorded the lowest values of 154.20 cm, 0.59 cm, 798.45 cm^2, and 50.15 t ha^{-1}, respectively. Plant density showed only a slight increase with fertilizer application, ranging from 151.18 to 154.08 plants m^{-2}. However, the number of leaves per tiller increased markedly from 10.08 in the control to 12.56 under the highest NPK level. Likewise, dry matter content increased from 8.12% to 14.68%, while crude fiber content improved from 7.05% to 10.41% with increasing fertilizer doses. The nutritional quality of millet forage was also enhanced by balanced nutrient application. Crude protein content increased from 42.10% in the control to 46.20% under the highest NPK treatment, whereas ash content increased from 5.00% to 7.35%. Overall, the results demonstrate that integrated nutrient management through the application of inorganic NPK fertilizers substantially enhances vegetative growth, biomass production, and forage quality of millet, with the application of 180 + 35 + 30 kg ha^{-1} NPK proving to be the most effective treatment for maximizing productivity and nutritional value.

Keywords: *Millet, Integrated nutrient management, Inorganic NPK fertilizers, Plant growth, Green fodder yield, Forage quality, Crude protein, Dry matter content, Biomass production, Nutrient management.*

Introduction

Millet (*Pennisetum glaucum* L.) is an important drought-tolerant cereal crop widely cultivated in arid and semi-arid regions of the world due to its adaptability to marginal soils and low water requirements (Reddy et al., 2013). It plays a vital role in food and fodder security, particularly in regions facing climate variability and soil fertility constraints (Flajsman et al., 2019). However, the productivity of millet is often limited by poor soil fertility and inadequate nutrient management practices. Balanced fertilization, particularly through nitrogen (N), phosphorus (P), and potassium (K), is essential for enhancing crop growth and yield (Kaleri et al., (a) 2024). Nitrogen is a key component of chlorophyll and proteins and is responsible for vigorous vegetative growth, while phosphorus plays a crucial role in energy transfer, root development, and early plant establishment. Potassium contributes to enzyme activation, water regulation, and stress tolerance in plants (Ayub et al., 2009; Fageria et al., 2011). The combined application of NPK fertilizers has been reported to significantly improve biomass production and yield in cereal crops. Several studies have demonstrated that integrated nutrient management improves crop performance by enhancing nutrient use efficiency and soil fertility status. For instance, (Sarawaleet al., 2017) reported that balanced NPK application significantly increased growth and yield attributes in cereal crops under field conditions. Similarly, (Jeyaraman, 2014). observed that nitrogen and potassium supplementation improved fodder yield and quality in forage crops. (Harika et al., 2023) also found that integrated fertilizer management enhanced photosynthetic efficiency and biomass accumulation in millet and related cereal species. Despite these advancements, nutrient management practices in millet cultivation remain suboptimal in many developing regions, leading to low productivity and poor forage quality (Triveni et al., 2028). Therefore, there is a need to optimize NPK fertilizer application to improve growth performance and nutritional quality of millet under field conditions (Peng et al., 2021). The present study was designed to evaluate the effect of integrated application of inorganic NPK fertilizers on growth, yield, and forage quality of millet, with the objective of identifying the most effective nutrient combination for maximizing productivity under local agro-climatic conditions.

Materials and Methods

Field experiment

The field experiment was conducted at Kaleri Agriculture Farm, near Latif Farm, Sindh Agriculture University, Tando Jam, Sindh, Pakistan, in 2025. Integrated Nutrient Management with Inorganic NPK Fertilizers Improves Growth and Yield of Millet. Using urea, T_1 = Control (no fertilizer), T_2 = NPK (60 + 20 + 10 kg ha^{-1}), T_3 = NPK (100 + 25 + 20 kg ha^{-1}), T_4 = NPK (140 + 30 + 25 kg ha^{-1}), and T_5 = NPK (180 + 35 + 30 kg ha^{-1}) during the course of several growth phases. With a net plot size of 5 m x 3 m = 15 m^2, each treatment was duplicated three times in a randomized complete block design. The field was laser leveled after two dry plowings to prepare the land. Water for irrigation was then used to create the right amount of moisture. To

generate a fine seedbed, the soil was leveled with a planker and plowed twice with a crosswise cultivator.

Growth and yield parameters

Plant height cm, stem diameter cm, leaf area per tiller (cm-2), green fodder yields (tha-1), Plant density (m2), Number of leaves per tiller, Dry matter%, crude fiber%, crude protein%, and ash% were recorded manually.

Statistical Analysis

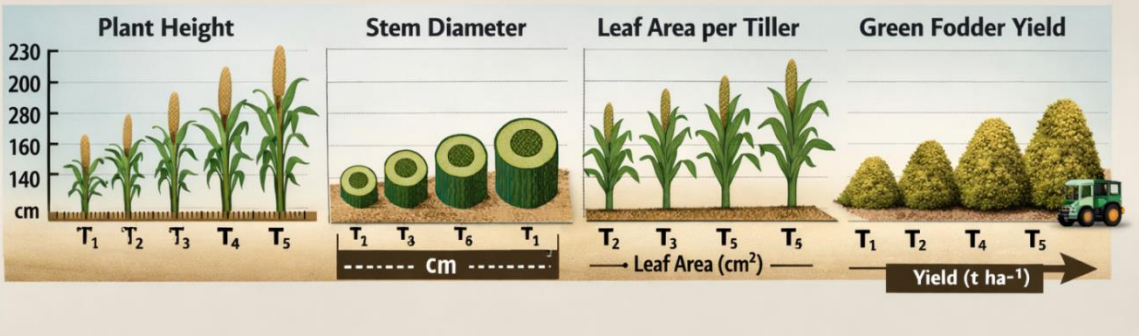
Using Statistix v. 8.1 (Analytical Software, USA), the analysis of variance (ANOVA) approach was used for the statistical analysis of the gathered data. Using the least significant design (LSD) test with $\alpha = 0.05$, the difference between treatment means was computed (Steel et al., 1997).

Results

The results of the present study on "Integrated Nutrient Management with Inorganic NPK Fertilizers Improves Growth and Yield of Millet" revealed that the application of different levels of NPK fertilizers had a significant positive effect on all measured growth, yield, and forage quality parameters of millet compared with the control treatment**.**

Table 01. Integrated Nutrient Management with Inorganic NPK Fertilizers Improves Growth and Yield of Millet

Treatment	Plant Height *(cm)*	Stem Diameter *(cm)*	Leaf Area per Tiller (cm^2)	Green Fodder Yield *(t ha^{-1})*
T_1 = Control (No fertilizer)	154.20	0.59	798.45	50.15
T_2 = NPK (60 + 20 + 10 kg ha^{-1})	170.35	0.71	1382.76	61.05
T_3 = NPK (100 + 25 + 20 kg ha^{-1})	198.86	0.80	1574.82	65.78
T_4 = NPK (140 + 30 + 25 kg ha^{-1})	210.42	0.86	1612.94	72.08
T_5 = NPK (180 + 35 + 30 kg ha^{-1})	223.61	0.92	1792.53	78.36
LSD (0.05)	0.784	0.011	0.703	0.225



Results

Plant Height (cm)

Plant height of millet was significantly influenced by the integrated application of inorganic NPK fertilizers (Table 1). The shortest plants (154.20 cm) were recorded in the control treatment (T_1), where no fertilizers were applied. Plant height increased progressively with increasing NPK levels, reaching 170.35 cm in T_2 (60 + 20 + 10 kg ha^{-1}), 198.86 cm in T_3 (100 + 25 + 20 kg ha^{-1}), and 210.42 cm in T_4 (140 + 30 + 25 kg ha^{-1}). The maximum plant height (223.61 cm) was observed in T_5 (180 + 35 + 30 kg ha^{-1}). The results indicate that balanced NPK fertilization markedly enhanced vegetative growth, likely due to improved nutrient availability and increased photosynthetic activity.

Stem Diameter (cm)

Stem diameter showed a significant positive response to increasing NPK fertilizer application. The minimum stem diameter (0.59 cm) was recorded in the unfertilized control (T_1), while T_2 produced a diameter of 0.71 cm. Further increases in fertilizer levels resulted in stem diameters of 0.80 cm and 0.86 cm under T_3 and T_4, respectively. The thickest stems (0.92 cm) were obtained with the highest NPK dose (T_5). These findings suggest that adequate nutrient supply improved stem development and structural strength of millet plants.

Leaf Area per Tiller (cm²)

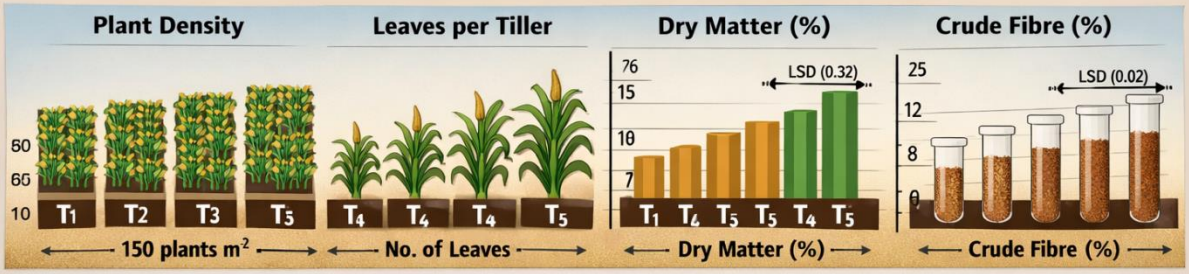
Leaf area per tiller increased significantly with increasing NPK fertilizer levels. The control treatment (T_1) produced the smallest leaf area (798.45 cm²), whereas T_2 recorded 1382.76 cm². Application of 100 + 25 + 20 kg ha^{-1} NPK (T_3) further increased leaf area to 1574.82 cm², while T_4 produced 1612.94 cm². The highest leaf area per tiller (1792.53 cm²) was recorded under T_5 (180 + 35 + 30 kg ha^{-1}). The enhanced leaf expansion under higher fertilizer levels may be attributed to improved nutrient uptake and greater chlorophyll formation, leading to vigorous canopy development.

Green Fodder Yield (t ha^{-1})

Green fodder yield was significantly improved by integrated NPK fertilization. The lowest yield (50.15 t ha^{-1}) was obtained from the control treatment (T_1). Fertilizer application increased fodder yield to 61.05 t ha^{-1} in T_2 and 65.78 t ha^{-1} in T_3. Higher fertilizer rates in T_4 further enhanced yield to 72.08 t ha^{-1}, while the maximum green fodder yield (78.36 t ha^{-1}) was achieved with T_5 (180 + 35 + 30 kg ha^{-1}). The substantial increase in fodder production under higher NPK levels demonstrates the importance of balanced nutrient management for maximizing biomass accumulation and overall millet productivity.

Table 02. Integrated Nutrient Management with Inorganic NPK Fertilizers Improves Growth and Yield of Millet

Treatment	Plant Density (m^{-2})	No. of Leaves per Tiller	Dry Matter (%)	Crude Fibre (%)	
T_1 = No fertilizers	152.94	10.08	8.12	7.05	
T_2 = NPK (60 + 20 + 10 %)	151.18	10.34	11.18	8.73	
T_3 = NPK (100 + 25 + 20 %)	152.87	10.96	12.86	9.08	
T_4 = NPK (140 + 30 + 25 %)	153.10	12.10	13.72	10.02	
T_5 = NPK (180 + 35 + 30 %)	154.08	12.56	14.68	10.41	
LSD (0.05)	0.122	0.368	0.320	0.020	



Plant Density (m^{-2})

Plant density was only slightly influenced by the application of inorganic NPK fertilizers (Table 2). The lowest plant density (151.18 m^{-2}) was recorded in T_2 (NPK 60 + 20 + 10 kg ha^{-1}), while the control treatment (T_1) produced 152.94 plants m^{-2}. Plant density increased marginally to 152.87 plants m^{-2} in T_3 and 153.10 plants m^{-2} in T_4. The highest plant density (154.08 plants m^{-2}) was observed under T_5 (NPK 180 + 35 + 30 kg ha^{-1}). These results indicate that fertilizer application had a limited but positive effect on maintaining plant stand establishment.

Number of Leaves per Tiller

The number of leaves per tiller increased significantly with increasing levels of NPK fertilization. The control treatment (T_1) recorded the minimum number of leaves per tiller (10.08), whereas T_2 produced 10.34 leaves per tiller. Further increases in fertilizer levels resulted in 10.96 leaves in T_3 and 12.10 leaves in T_4. The maximum number of leaves per tiller (12.56) was obtained from T_5 (NPK 180 + 35 + 30 kg ha^{-1}). The increase in leaf production may be attributed to enhanced nutrient availability, which promoted vegetative growth and tiller development.

Dry Matter (%)

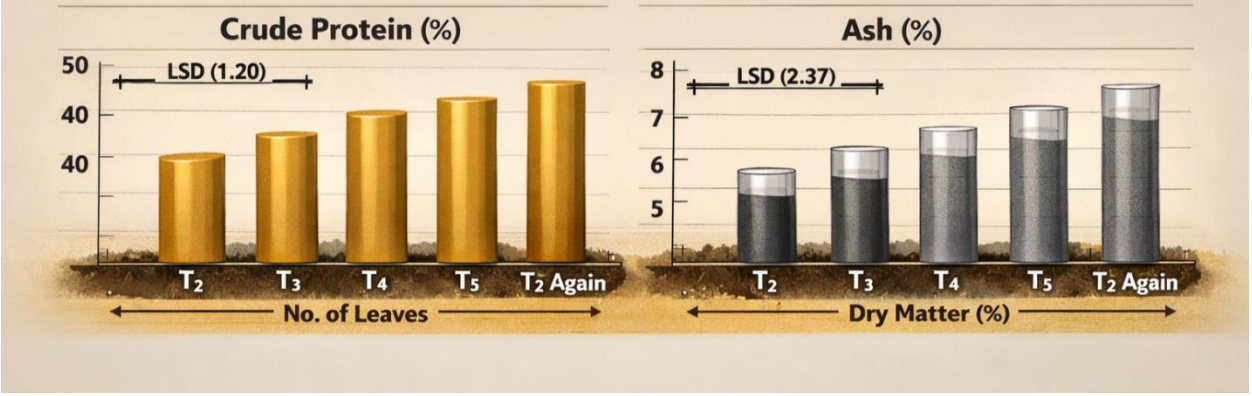
Dry matter percentage showed a significant increasing trend with higher NPK fertilizer application. The lowest dry matter content (8.12%) was recorded in the control treatment (T_1). Application of NPK at 60 + 20 + 10 kg ha^{-1} (T_2) increased dry matter to 11.18%, while T_3 produced 12.86%. Further increases were observed in T_4 (13.72%), and the highest dry matter content (14.68%) was recorded under T_5. The results suggest that balanced nutrient management improved biomass accumulation and dry matter production in millet.

Crude Fiber (%)

Crude fibre content was significantly enhanced by integrated NPK fertilization. The lowest crude fibre content (7.05%) was observed in the unfertilized control (T_1). Fertilizer application increased crude fibre content to 8.73% in T_2 and 9.08% in T_3. Higher fertilizer doses further improved crude fibre content to 10.02% in T_4, while the maximum value (10.41%) was obtained under T_5 (NPK 180 + 35 + 30 kg ha^{-1}). These findings indicate that adequate NPK nutrition improved forage quality by increasing fibre accumulation in millet plants.

Table 03. Integrated Nutrient Management with Inorganic NPK Fertilizers Improves Growth and Yield of Millet

	Crude Protein (%)	Ash (%)
T_2 = NPK (60 + 20 + 10 %)	42.10	5.0
T_3 = NPK (100 + 25 + 20 %)	43.88	6.30
T_4 = NPK (140 + 30 + 25 %)	44.19	6.90
T_5 = NPK (180 + 35 + 30 %)	45.90	7.14
T_2 = NPK (60 + 20 + 10 %) Again	46.20	7.35
LSD (0.05)	1.20	2.37



Crude Protein (%)

Crude protein content of millet was significantly influenced by the integrated application of inorganic NPK fertilizers (Table 3). The lowest crude protein content (42.10%) was recorded in

the control treatment (T_1), where no fertilizers were applied. Application of NPK fertilizers increased crude protein content to 43.88% in T_2 (60 + 20 + 10 kg ha^{-1}), 44.19% in T_3 (100 + 25 + 20 kg ha^{-1}), and 45.90% in T_4 (140 + 30 + 25 kg ha^{-1}). The highest crude protein content (46.20%) was obtained under T_5 (180 + 35 + 30 kg ha^{-1}). The progressive increase in crude protein with increasing fertilizer levels indicates that balanced nitrogen, phosphorus, and potassium nutrition enhanced nitrogen assimilation and protein synthesis in millet plants.

Ash Content (%)

Ash content also showed a positive response to increasing NPK fertilizer application. The minimum ash content (5.00%) was observed in the control treatment (T_1). Ash percentage increased to 6.30% under T_2, followed by 6.90% in T_3 and 7.14% in T_4. The maximum ash content (7.35%) was recorded in T_5 receiving the highest NPK dose (180 + 35 + 30 kg ha^{-1}). The increase in ash content suggests improved mineral accumulation in plant tissues due to enhanced nutrient availability under higher fertilizer application rates.

Discussion

The present study demonstrated that integrated application of inorganic NPK fertilizers significantly improved the growth, yield, and forage quality of millet. Plant height increased progressively with increasing fertilizer rates, with the highest value (223.61 cm) recorded under the application of 180 + 35 + 30 kg ha^{-1} NPK. The enhancement in plant height can be attributed to improved nitrogen availability, which promotes cell division, chlorophyll synthesis, and vegetative growth, while phosphorus and potassium enhance root development and nutrient translocation. Similar findings have been reported by (Kaleri et al., (b) 2024) and Triveni et al., 2020), who observed significant increases in cereal crop height under balanced NPK fertilization. Stem diameter and leaf area per tiller also increased significantly with increasing NPK levels, indicating improved structural development and photosynthetic capacity. Nitrogen plays a vital role in protein synthesis and leaf expansion; whereas phosphorus and potassium regulate energy transfer and water balance, resulting in stronger stems and larger leaves. Comparable improvements in stem growth and leaf area due to balanced NPK nutrition were reported by (Li et al., 2020) and Zhang et al. (2023).Green fodder yield was markedly enhanced by increasing NPK application, reaching 78.36 t ha^{-1} under the highest fertilizer level. The increased biomass production may be associated with greater photosynthetic activity and efficient utilization of nutrients, resulting in vigorous vegetative growth. Similar positive responses of fodder yield to balanced NPK fertilization have been documented by (Babu et al., 2022) and (Bekeleet al., 2016).Plant density showed only minor variation among treatments, suggesting that fertilizer application had little effect on crop establishment but substantially influenced subsequent vegetative growth. However, the number of leaves per tiller increased significantly with increasing fertilizer rates, reflecting enhanced tillering and canopy development. These

observations are consistent with the findings of (Khan et al., 2023), who reported improved tiller production under adequate nitrogen and phosphorus supply. Dry matter accumulation and crude fiber content increased steadily with higher NPK levels, indicating improved biomass production and forage quality. Potassium plays an important role in carbohydrate synthesis and translocation, while nitrogen enhances overall plant metabolism, contributing to higher dry matter accumulation. Similar improvements in forage quality traits have been reported by (Wang et al., 2023) and (Yadav et al., 2021).Crude protein and ash contents also increased significantly with increasing NPK fertilizer application. The higher crude protein concentration under the highest NPK treatment reflects improved nitrogen assimilation and amino acid synthesis, whereas increased ash content indicates greater mineral uptake by plants. These findings agree with the reports of (Leila et al. 2014) and Pan et al., 2021), who concluded that balanced NPK fertilization enhances both yield and nutritional quality of forage crops. Overall, the results confirm that integrated nutrient management using inorganic NPK fertilizers is an effective strategy for improving millet growth, biomass production, and forage quality.

Conclusion

The study concluded that integrated application of inorganic NPK fertilizers significantly improved growth, yield, and forage quality of millet compared with the control. All growth and quality parameters showed a progressive increase with increasing fertilizer levels. The highest values of plant height (223.61 cm), stem diameter (0.92 cm), leaf area per tiller (1792.53 cm^2), and green fodder yield (78.36 t ha^{-1}) were recorded under 180 + 35 + 30 kg ha^{-1} NPK, while the lowest values were observed in the control. Plant density showed only slight variation (151.18–154.08 plants m^{-2}), whereas leaves per tiller, dry matter, crude fiber, crude protein, and ash content improved notably with increasing NPK application. Overall, balanced NPK fertilization proved effective in enhancing millet productivity and forage quality, with 180 + 35 + 30 kg ha^{-1} identified as the most efficient treatment under the given conditions.

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