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Establishment and Evaluation of Soil Fertility Gradient on the Basis of Sorghum Fodder Yield, Nutrient Uptake and Post-Harvest Soil Test Values

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Field experiment was carried out with fodder sorghum at N.E. Borlaug Crop Research Centre, G.B.U.A.&T., Pantnagar during *kharif*, 2022 under AICRP on Soil Test Crop Response (STCR) approach aimed to establish and evaluate soil fertility gradient on the basis of sorghum fodder yield, nutrient uptake and post-harvest soil test values. The experimental field was divided into three plots, each receiving graded levels of N, P_2O_5 and K_2O: $N_0P_0K_0$ (Plot A), $N_{100}P_{100}K_{100}$ (Plot B)

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and $N_{200}P_{200}K_{200}$ (Plot C). Thereafter, fodder sorghum was grown and fodder yield was recorded from each plot. Chemical analysis of plant samples was performed to estimate nitrogen, phosphorus and potassium content and total nutrient uptake was worked out. Post-harvest soil samples were collected across the three plots and analysed for available N, P and K. Findings revealed wide variation in sorghum fodder yield, nutrient uptake and post-harvest soil fertility status for available N, P and K in different plots confirming the establishment of soil fertility gradient for the respective nutrients. The establishment of soil fertility gradient is necessary and serves as a pre-requisite for developing improved nutrient management strategies i.e. STCR-based fertilizer recommendations to sustain crop yield and optimize fertilizer requirements.

Keywords: Soil fertility gradient; STCR; sorghum; NPK; fodder yield; nutrient uptake; post-harvest soil test values.

1. INTRODUCTION

Consequent upon migration, death and fertility, India's annual population grew by 0.1 per cent in 2023 representing 14.71 per cent increase in growth rate over 2022 (O'Neill 2024). Hence, nation's agricultural productivity must either increase or remain stable without negatively affecting soil health, a key driver for maintaining crop productivity. Soil supplying capacity of macronutrients like nitrogen (N), phosphorus (P) and potassium (K) has significantly decreased, due to excessive cultivation and imbalanced fertilizer use. It also compiles a substantial expenditure on crop cultivation, where site specific application of fertilizer holds supreme significance with respect to economical and ecological sustainability. Exclusive use of chemical fertilizers lead to decline in microbial activity in the cropping systems as an outcome of hardening of soil, lowering soil fertility and contaminating air and water (Pahalvi et al. 2021). Consequently, nutrient management techniques, viz. Soil Test Crop Response approach, can be extremely important in creating scientific framework which supports crop’s output while reducing problems associated with nutrient depletion and environmental degradation (Batabyal 2015).

Considerable reduction in fertilizer consumption can be achieved if tailored soil test findings are used to create fertilizer recommendations (Vamshi et al. 2023). By calibrating soil test results and crop response to fertilizers, STCR studies have provided more precise fertilizer recommendations that achieve the adequate equilibrium between added nutrients and those already present in soil. This approach provides a more accurate, scientific foundation for harmonious fertilization by taking the farmer's financial commitment to the crop into account (Ray et al. 2000). Numerous studies have also demonstrated the critical role that fertilizer recommendations based on STCR has played in raising net returns and biomass output (Santhi et al. 2002).

The creation of soil fertility gradient *i.e.,* a surface variation in soil fertility levels, is one of the pre-requisites for STCR approach to optimize fertilizer doses. This is often accomplished by applying graded amounts of N, P and K fertilizers to soil. Without taking into account additional variables like climate or crop management, these gradients make it possible to relate soil fertility levels to crop response, such as crop yield and nutrient uptake (Shrivastav et al. 2023). It offers a rationale for balanced fertilization using both applied and readily available nutrient types (Dey 2015).

An issue to be faced by nation in the upcoming years will be producing enough food, fiber and high-quality commodities. This is where the multipurpose crop, sorghum (*Sorghum bicolor* (L.) Moench) comes into play. It is a versatile crop with several uses, among other exhaustive crops like cotton, wheat, sugarcane, etc. (Yousaf et al. 2023) and can be used for fodder and feed purposes. About 15.41% crude protein, 8.44% ether extract and 11.03% crude fibre is found in fodder sorghum (Sriagtula et al. 2021). In addition to its many applications, its strong tolerance to dry situations makes it a promising crop for increasing farmer’s surviving on small and marginal holdings, by improving income outcomes (Redai et al. 2018). Approximately 45 Mha of sorghum are grown in Africa and India, making up approximately 80% of all agricultural land worldwide (Mwadalu et al. 2022). In India, 14.53 Lha have been covered with sorghum in 2023–2024 (DES 2023) and as per the 3rd advance estimates, Government of India (2022-23), the estimated sorghum production has reached 3.99 Mt (Vanakalam (Kharif) 2023-24).

Furthermore, sorghum is also one of Uttarakhand's main fodder crops during the *Kharif* season.

According to (Dwivedi et al. 2001), sorghum has ample capacity to take up nutrients from soil, owing to its exhaustive nature. As a result, it requires optimum amount of fertilizers to increase production and improve its feed quality (Prajapati et al. 2023). Kugbe et al. (2019) noted that the crop's broad range of ecological flexibility and capacity to flourish in challenging conditions make it a perfect choice for soil fertility gradient experimentation especially in areas with variable rainfall. The exhaust crop, fodder sorghum in these experiments plays a critical role in causing nutrient alteration in the soil through plant and microbial activity. In addition, growth and development of crop rely on readily available pool of nutrients viz., nitrogen, phosphorus and potassium, needed in vast quantities (Vamshi et al. 2023). This procedure aids in creating a reliable soil fertility gradient. These findings are crucial for developing improved nutrient management strategies that sustain crop yield and optimize fertilizer requirements under the STCR-based fertilizer recommendation approach.

Keeping in view the above, present study attempts to assess how soil fertility gradient has been created by exploring sorghum's ability to absorb nutrients from varying levels of soil fertility and result in varying fodder yield. This experiment aims to provide a scientific foundation for the development of STCR based fertilizer prescription equations to optimize nutrient requirement of the test crop.

2. MATERIALS AND METHODS

Field experiment was conducted at N.E. Borlaug Crop Research Centre, G.B.U.A.&T, Pantnagar, District, U.S. Nagar, Uttarakhand (29º N latitude, 79º 29"E longitude, and 243.84 meters above msl) during *kharif* 2022. The average maximum temperature during the crop season was 32.09°C with an average of 24.51°C minimum temperature (Fig. 1). There was noticeable variation in relative humidity (R.H.), with an average of 86.70 per cent in morning and 66.13 per cent in afternoon. The season's total rainfall was 1032.5 mm, with weekly variation in the distribution of rainfall. Weekly sunshine hours averaged 6.35 hrs, wind velocity averaged 3.06 km hr^{-1} and evaporation rates averaged, 4.58 mm.

Before the commencement of soil fertility gradient experiment, the soil of the experimental site was sandy loam in texture, with soil test values of available nitrogen, phosphorus and potassium under low, medium and low category of soil fertility, respectively.

Soil fertility gradient experiment using exhaust crop, belongs to initial phase of the test crop experiment on Soil Test Crop Response

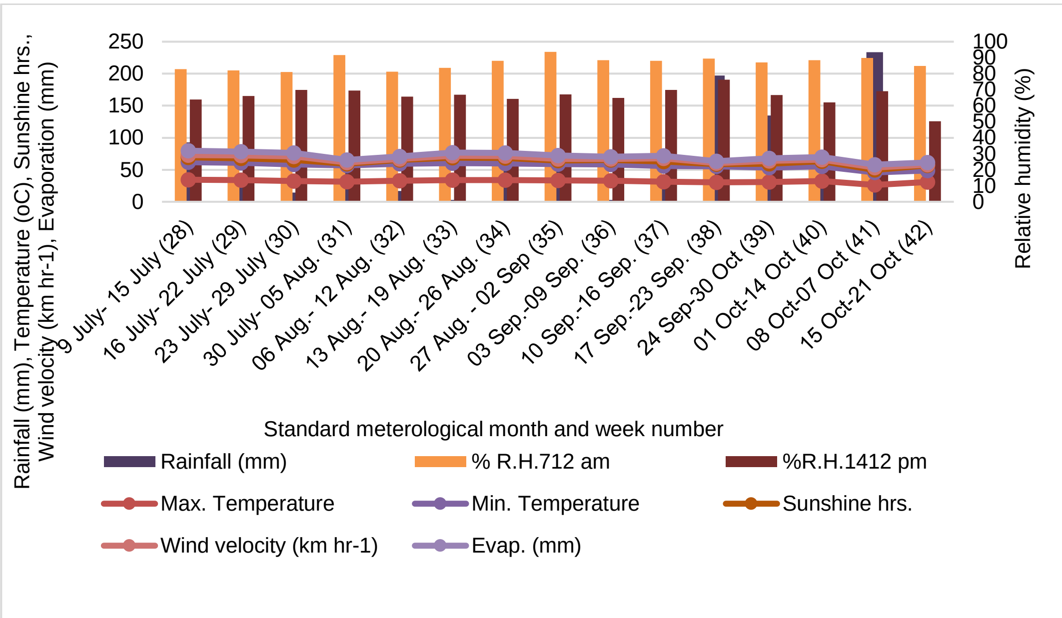

Fig. 1. Weather data for the period of soil fertility gradient experiment during *kharif* 2022

for fertilizer recommendation. The methodology followed for experiment was outlined by All India Coordinated Research Project on Soil Test Crop Response. It involved inductive methodology to establish soil fertility gradient, with the aim of getting as large variation as possible in soil fertility levels in one and the same field for establishment of variation in yield levels without interference of other extraneous factors affecting yield (Ramamoorthy et al. 1967).

The experimental area was divided into three equal-dimensional rectangular plots (60.0 m x 7.5 m) before test crop experimentation. Distinct doses of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) were applied to these plots as follows: Plot A (Low fertility) received no fertilizer $N_0P_0K_0$, Plot B (medium fertility) treated with 100 kg ha^{-1} of each nutrient ($N_{100}P_{100}K_{100}$) and Plot C (high fertility) received 200 kg ha^{-1} of each ($N_{200}P_{200}K_{200}$). The NPK mixture (12:32:16), urea (46% N) and MOP (60% K_2O) were the fertilizer sources. Basal application of full doses of phosphorus and potassium was done together with half dose of nitrogen. Two splits were used to top-dress the remaining half nitrogen.

Subsequently, the exhaust crop, fodder sorghum (var. Pant Chari-6) was grown with recommended agronomic management of crop to guard against any unwanted biological damage. At flowering stage of the crop, a sample area of 4 m² (2 m × 2 m) from three randomly selected spots was marked in each soil fertility gradient plot and crop was harvested and each plot's average green fodder yield (q ha^{-1}) was determined. The crop was then allowed to dry out in the field under the sun. Plant samples were taken from sampled area, oven dried at 60±5°C until constant weight was achieved for determining moisture content and dry fodder yield (q ha^{-1}) was estimated. Subsequently, N, P and K content in the plant samples obtained from each soil fertility gradient plot was determined (Jackson 1973) to ascertain the total nitrogen, phosphorous and potassium uptake under different soil fertility plots, respectively. Post-harvest soil samples (0-15 cm) were drawn from each plot after sub-dividing each plot into 24 sub-plots. Soil samples from sub-plots underwent chemical analysis to estimate soil test values for alkaline $KMnO_4$-N (Subbiah & Asija 1956), Olsen's-P (Olsen et al. 1954) and NH_4OAc-K (Hanway & Heidel 1952) represented as SN, SP and SK and expressed in kg ha^{-1}. Descriptive statistics was used to present fodder yield, total nutrient uptake and post-harvest soil test values of nutrients (Gomez & Gomez 1984). Data analysis was conducted using Microsoft Excel 2013.

3. RESULTS AND DISCUSSION

3.1 Fodder Yield

Findings of experiment revealed that application of nutrients viz. nitrogen, phosphorus and potassium in a gradient resulted change in fodder yield and uptake by sorghum crop (Table 1 and Fig. 2). Plot C yielded maximum green fodder yield (379.17 q ha^{-1}), followed by Plot B (358.33 q ha^{-1}) while Plot A yielded the minimum (270.83 q ha^{-1}). Green fodder yield in Plot C increased by 40.00 per cent and 5.82 per cent over plots A and B, respectively. While, Plot B, recorded 32.31 per cent increase in green fodder yield from plot A. Dry fodder yield (q ha^{-1}) by the crop followed the order: 126.48 in Plot C > 115.68 in Plot B > 92.61 in Plot A. Per cent increase observed for dry fodder yield in Plot C, over plots A and B was 36.57 and 9.34, respectively and Plot B over Plot A was 24.91.

Increased growth and yield of crop treated with graded doses of fertilizers have been shown by (Vamshi et al. 2023) and (Isha et al. 2024) in sorghum and wheat, respectively. Singh (2014), observed that nitrogen administration is crucial in improving plant growth characteristics and fodder production.

3.2 Nutrient Content

Per cent nitrogen content of sorghum crop followed the order: Plot C (0.910) > Plot B (0.840) > Plot A (0.700) (Table 1 and Fig. 3). Per cent phosphorus and potassium content followed the similar trend where nutrient content was found maximum in Plot C (0.185 and 1.18), followed by Plot B (0.174 and 1.09) and Plot A (0.168 and 0.859), respectively. The N, P and K content increased by 30.00, 10.12 and 37.37 per cent in Plot C, over Plots A, respectively. For Plot C, over B, the per cent increase in N, P and K content was 8.33, 6.32 and 8.26 per cent, respectively. While, The N, P and K content increased by 20.00, 3.57 and 26.89 per cent in Plot B over Plot A, respectively.

3.3 Nutrient Uptake

Total nitrogen uptake (kg ha^{-1}) by the crop followed the order: 115.10 in Plot C > 97.17 in Plot B > 64.83 in Plot A. Per cent increase in nitrogen uptake in Plot C, over plots A and B was 77.54 and 18.45, respectively and Plot B over Plot A was 49.88. Maximum phosphorus uptake (kg ha^{-1}) was 23.43 under Plot C followed by 20.18 in Plot B and minimum 15.54 in Plot A. Additionally, maximum potassium uptake (kg ha^{-1}) was 149.25 (Plot C) followed by 126.10 (Plot B) and least 79.55 (Plot A). Per cent increase in uptake in Plot C compared to plots A and B for phosphorus was 50.77 and 16.11 per cent and for potassium was 87.62 and 18.36 per cent, respectively. While increase in uptake of phosphorus and potassium by sorghum in Plot B over Plot A was 29.86 and 58.52 per cent, respectively (Table 1 and Fig. 4). The results from nutrient uptake data was suggestive of establishment of soil fertility gradient as exhaust crop, sorghum, exhibited a comparable pattern to the applied fertilizer nutrient levels in different fertility plots i.e. Plot C > Plot B > Plot A. Similar findings were also noted by (Singh et al. 2020) in wheat and (Udayakumar & Santhi 2017) and (Asan et al. 2023) for sorghum.

Nitrogen availability and uptake by the crop boosts vegetative growth and accelerate cell division, differentiation and expansion, resulting in luxuriant growth. Nitrogen fertilization increase the height of fodder sorghum which may be attributed to increase in protein synthesis and vegetative growth. This in turn might have increased photosynthetic rate and stimulated further growth (Manjunath Madhukar Mopagar & Kalaghatagi 2023). Enhancement of soil nutrients availability and improving root development may also have raised plant height and capacity to absorb N, P and K leading to greater yield (Qamar et al. 2022). Furthermore, application of potassium may have assisted the crop towards higher acquisition of nitrogen by releasing fixed ammonium ions from soil (Sharma & Ramna 1993). Consequently, the existence

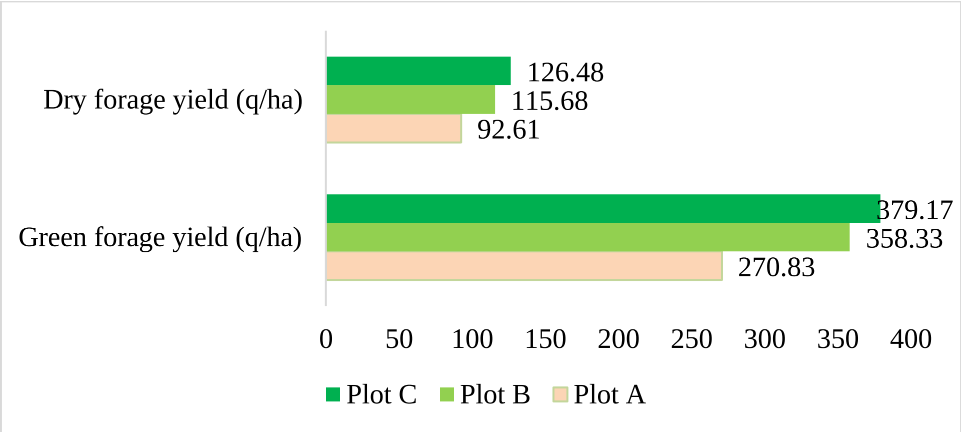

Fig. 2. Fodder yield of sorghum in soil fertility gradient experiment

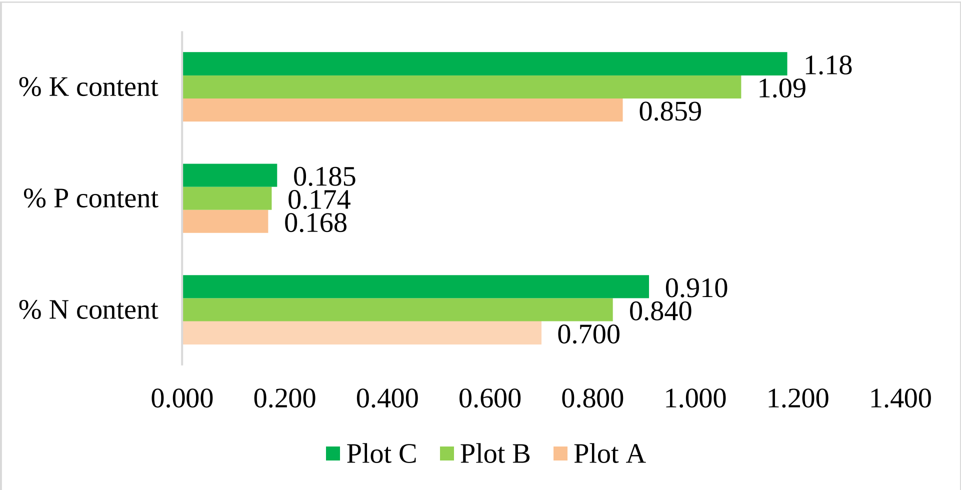

Fig. 3. Nutrient content of sorghum in soil fertility gradient experiment

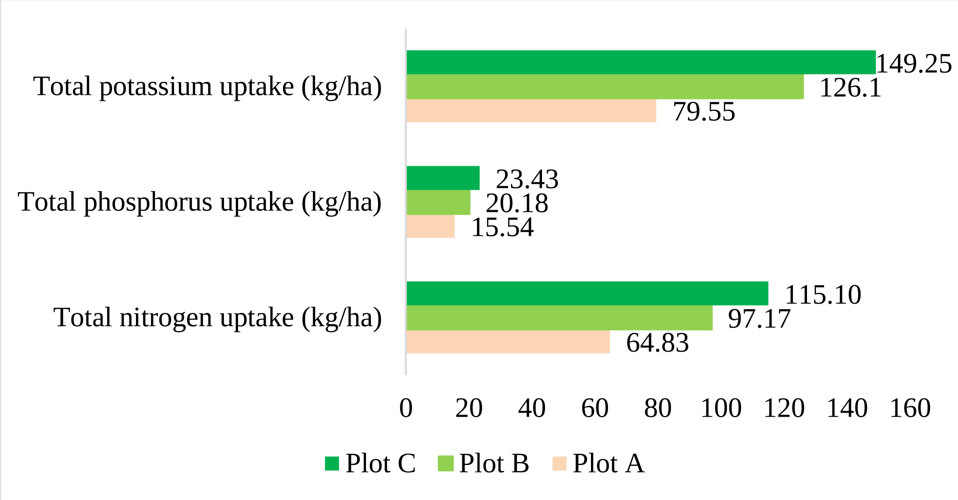

Fig. 4. Total nutrient uptake of sorghum in soil fertility gradient experiment

Table 1. Sorghum fodder yield, nutrient content and nutrient uptake in soil fertility gradient experiment

Particulars	Soil fertility gradient plot		
	Plot A	Plot B	Plot C
Green fodder yield (q ha^{-1})	270.83	358.33	379.17
Dry fodder yield (q ha^{-1})	92.61	115.68	126.48
N content in plant (%)	0.700	0.840	0.910
P content in plant (%)	0.168	0.174	0.185
K content in plant (%)	0.859	1.09	1.18
Total nitrogen uptake (kg ha^{-1})	64.83	97.17	115.10
Total phosphorus uptake (kg ha^{-1})	15.54	20.18	23.43
Total potassium uptake (kg ha^{-1})	79.55	126.10	149.25

Where, Plot A, B and C: Low, medium and high fertility plots, respectively

of K may be linked to variation in N uptake. Meanwhile, phosphorus levels encourage root to grow thus showing progressive increase in P acquisition (Verma et al. 2015, Singh et al. 2020) under different fertility plots.

3.4 Post-harvest Soil Fertility Status in Soil Fertility Gradient Experiment

Plot wise average soil test values after the harvest of exhaust crop, showed the effect of graded levels of fertilizer nutrients on available nitrogen, phosphorus and potassium (Table 2 and Fig. 5). The average soil test values of alkaline $KMnO_4$-N (kg ha^{-1}) was 131.19 in Plot A, 141.64 in Plot B and 158.89 in Plot C. Average for Olsen's-P (kg ha^{-1}) was 17.54 in Plot A, 20.02 in Plot B and 22.69 in Plot C. Furthermore, average soil test values of NH_4OAc-K (kg ha^{-1}) was 132.66, 141.52 and 161.36 in Plot A, B and C, respectively. Thus, post-harvest soil test values of the available nutrient increased for the respective nutrients in the order: Plot C > Plot B > Plot A. Jhinkwan et al. (2021) also noted a similar pattern in wheat. Development of soil fertility gradient may be attributed to the addition of double dose of NPK fertilizer rather than single dose and control causing spike in nitrogen levels under high fertility plot. The application of graded levels of P and K fertilizers, either at or above the

Table 2. Post-harvest soil test values in soil fertility gradient experiment

Plot	Soil test values (kg ha^{-1})		
	SN	SP	SK
Plot A	131.19	17.54	132.66
Plot B	141.64	20.02	141.52
Plot C	158.89	22.69	161.36

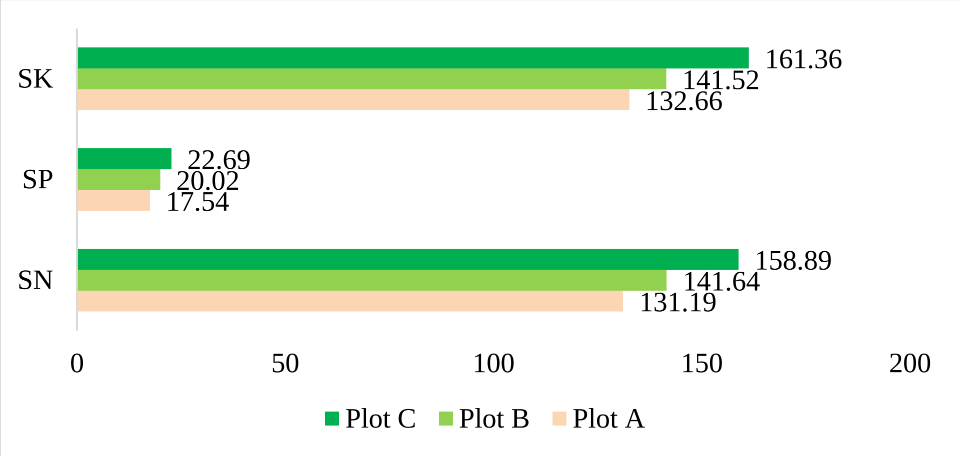

Fig. 5. Post-harvest soil test values (kg ha-1) in soil fertility gradient experiment

soil's capability to supply them, may be the reason for increased availability of P and K (Ammal et al. 2020). Graded amounts of N, P and K fertilizers produced an artificial soil fertility gradient in the test field and substantially impacted the sorghum crop's post-harvest soil test values, nutrient absorption and green fodder output (Asan et al. 2023).

4. CONCLUSION

Findings of the experiment revealed the creation of soil fertility gradient, evident by the graded variation in the fodder yield and total nutrient uptake of sorghum in the three fertility plots, following the order: Plot C > Plot B > Plot A. The results further supported the existence of soil fertility gradient by revealing differences in the post-harvest soil nutrient status for available nitrogen, phosphorus and potassium in the three fertility plots following the aforementioned order. Findings holds importance being a pre-requisite for developing better nutrient management techniques i.e. STCR approach to formulate fertilizer prescription equations to promote balanced fertilization for sustaining crop yield and reduce excessive usage of fertilizer.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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