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Development and Evaluation of Soil Fertility Gradient under STCR Framework with Exhaust Crop Sorghum (*Sorghum bicolor*)

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Authors' contributions

This work was carried out in collaboration among all authors. Author SLY conceptualized the study, developed the methodology, conducted the investigation and data curation, and reviewed, edited, and prepared the original draft of the manuscript. Author PG conceptualized the study, developed the methodology, edited the manuscript, and provided overall guidance. Authors Jaipaul, APS, and SC conceptualized the study and developed the methodology. All authors read and approved the final manuscript.

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Abstract

A critical requirement for this approach is the development of a soil fertility gradient through graded fertilizer application, which helps to establish reliable relationships between soil test values and crop response with minimizing external influences. Field experiment was conducted at Norman E. Borlaug Crop Research

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Centre, G.B.U.A.&T., Pantnagar during *kharif* 2024 under AICRP on Soil Test Crop Response (STCR) to establish and evaluate soil fertility gradient. The experimental field was divided into three strips treated with graded doses of fertilizers: $N_0P_0K_0$ (Strip-I), $N_{100}P_{100}K_{100}$ (Strip-II), and $N_{200}P_{200}K_{200}$ (Strip-III). Nitrogen, phosphorus, and potassium were supplied through NPK fertiliser mixtures and urea. Sorghum bicolor was cultivated as an exhaust crop following the recommended agronomic practices, and the forage yield was subsequently recorded. Plant samples were analysed to determine nitrogen, phosphorus, and potassium concentrations, and the total nutrient uptake was calculated accordingly. Post-harvest soil samples were also analysed to assess the available nitrogen, phosphorus, and potassium status of the soil. Results revealed significant variation in forage yield, total nutrient uptake, and soil fertility status across the strips, confirming successful establishment of soil fertility gradient. Gradient establishment is prerequisite for developing precise STCR-based fertilizer recommendations to improve nutrient use efficiency and sustain crop productivity.

Keywords: Forage yield; NPK; nutrient uptake; post-harvest soil test value; soil fertility gradient; sorghum; STCR.

1. Introduction

Sustaining soil fertility and side by side enhancing crop productivity remains a critical challenge in modern agriculture, particularly under increasing population pressure and resource constraint conditions. Efficient nutrient management plays a pivotal role in achieving higher yields, improving input-use efficiency, and reducing environmental risks. Fertilizers, being the most essential as well as costly input, must be applied judiciously based on soil fertility status and crop demand to ensure both economic and ecological sustainability (Kimetu et al., 2004; Jan et al., 2007). However, the widespread practice of imbalanced fertilizer application, often in the absence of soil testing, has resulted to declining soil health and poor nutrient use efficiency (Ray et al., 2000). In India, despite a substantial rise in fertilizer consumption due to agricultural intensification, a persistent negative nutrient balance of 8–10 million tonnes annually has been reported, with projections indicating further escalation (Tandon, 2004). Continuous cropping systems, coupled with disproportionate use of major nutrients (N, P, and K), have accelerated nutrient mining and depletion of soil reserves. This unsustainable approach has also been associated with deterioration of soil physical properties, reduced microbial activity and increased environmental pollution (Pahalvi et al., 2021).

To address the limitations of conventional application of fertilizer, site-specific nutrient management strategies such as Soil Test Crop Response (STCR) approach have gained importance. This methodology integrates soil test values, crop nutrient requirements, and fertilizer use efficiency to develop precise fertilizer prescriptions for targeted yields. By balancing nutrient supply from both soil and applied sources, STCR enhances crop productivity, nutrient uptake, and economic returns while sustaining soil fertility (Vamshi et al., 2023) A critical requirement for this approach is the development of a soil fertility gradient through graded fertilizer application, which helps to establish reliable relationships between soil test values and crop response with minimizing external influences (Shrivastav et al., 2023). Use of an exhaust crop further supports this process by facilitating nutrient uptake and redistribution within the soil system.

Sorghum (*Sorghum bicolor*) is an ideal crop for soil fertility and nutrient management studies due to its high biomass production, extensive root system, and strong nutrient extraction capacity. As one of the major cereal crops globally, it serves multiple purposes including food, forage, and various industrial applications. Its remarkable adaptability to diverse agro-climatic conditions, particularly drought-prone and marginal environments, makes it highly suitable for sustainable agricultural systems (Redai et al., 2018; Mwadalu et al., 2022). Sorghum (*Sorghum bicolor*) is widely cultivated in India and plays a vital role in ensuring food and forage security, particularly in semi-arid regions. It occupies a significant area among cereal crops, covering approximately 3.99 million hectares, with a total production of about 4.95 million tonnes and an average productivity of 1240 kg ha^{-1} (Ministry of Agriculture & Farmers Welfare, 2024). In Uttarakhand, sorghum is cultivated on a relatively smaller scale, predominantly under rainfed conditions, where its productivity is often limited by poor soil fertility and inadequate nutrient management practices. The crop is nutritionally rich and contributes significantly to livestock feeding systems due to its appreciable crude protein and fiber content (Sriagtula et al., 2021). Furthermore, as an exhaustive crop, sorghum (*Sorghum bicolor*) exhibits a pronounced ability to absorb large quantities of essential nutrients such as nitrogen, phosphorus, and potassium, thereby facilitating the development of distinct soil fertility gradient (Prajapati et al., 2023). Its robust growth, adaptability, and high nutrient uptake efficiency make it particularly suitable for gradient experiments, where forage sorghum cultivation enhances nutrient cycling and transformation, providing a reliable framework for assessing soil fertility status and crop response under varying environmental conditions.

In this context, the present study was undertaken to develop a soil fertility gradient using sorghum as an exhaust crop to assess its effect on forage yield, nutrient uptake, and soil fertility. The findings are used to provide a scientific basis for formulating STCR-based fertilizer prescription equations aimed optimizing nutrient management and sustaining crop productivity.

2. Materials and Methods

The field experiment was conducted at the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, situated in Udham Singh Nagar District, Uttarakhand, India. The experimental site is geographically located at 29° N latitude and 79°29′ E longitude, at an altitude of 243.84 m above mean sea level. The study was conducted during the Kharif season of 2024. The region is characterised by a subtropical climate with pronounced seasonal variations. During the crop growth period, meteorological parameters were systematically recorded and presented in Fig. 1. The average maximum and minimum temperatures were 33.6 °C and 25.7 °C, respectively. The relative humidity ranged from 84.6% in forenoon to 68.1% in the afternoon. Total rainfall received during the season was 216.4 mm, and the mean daily sunshine duration was 5.5 hours. These weather conditions prevailed during the cropping season and influenced crop growth and development.

The experiment was conducted to establish soil fertility gradient within same field using sorghum (*Sorghum bicolor*) as an exhaust crop, following the inductive approach methodology as outlined under All India Coordinated Research Project on Soil Test Crop Response (STCR). The experimental soil was sandy loam in texture with initial fertility having of low nitrogen, medium phosphorus and medium potassium. The inductive methodology was adopted to create a wide variation in soil fertility levels within the same field, thereby enabling the development of corresponding variability in crop yield while minimizing the influence of extraneous factors (Ramamoorthy et al., 1967).

To achieve the desired soil fertility gradient, the field was divided into three equal strips (60 m x 7.5 m), and graded doses of nitrogen, phosphorus, and potassium were applied as $N_0P_0K_0$ (No N, P_2O_5, K_2O ha^{-1}), $N_{100}P_{100}K_{100}$ (100 kg each of N, P_2O_5, K_2O ha^{-1}), and $N_{200}P_{200}K_{200}$ (200 kg each of N, P_2O_5, K_2O ha^{-1}), as per treatments using NPK mixture (12:32:16), urea (46% N) and MOP (60% K_2O) as the fertilizer sources. Phosphorus and potassium were applied as basal doses, whereas nitrogen was applied in split applications in accordance with recommended agronomic practices.

Afterwards, forage sorghum (*var.* Pant Chari-5), was cultivated following recommended agronomic practices avoiding biotic stress. At the flowering stage, crop samples were taken from three randomly selected spots within each plot using a 4 m^2 (2 m × 2 m) area, to compute average green forage yield (q ha^{-1}). The harvested crop was sun-dried in the field, and plant samples were oven-dried at 60 ± 5°C to a constant weight for determination of moisture content and estimation of dry forage yield.

Dried plant samples were analyzed for nitrogen, phosphorus, and potassium content by adopting standard procedures (Page et al., 1982) to determine nutrient uptake. Post-harvest soil samples (0–15 cm) were collected from each strip by dividing it into 24 sub-units. These soil samples were analyzed to determine available nitrogen, phosphorus and potassium; expressed as SN (alkaline $KMnO_4$-N), SP (Olsen-P), and SK (NH_4OAc-K) using (Subbiah & Asija, 1956; Olsen et al., 1954; Hanway & Heidel, 1952) methods, respectively. Data on forage yield, nutrient uptake, and soil test values were summarized using descriptive statistics (Gomez & Gomez, 1984) and analyzed using Microsoft Excel 2013.

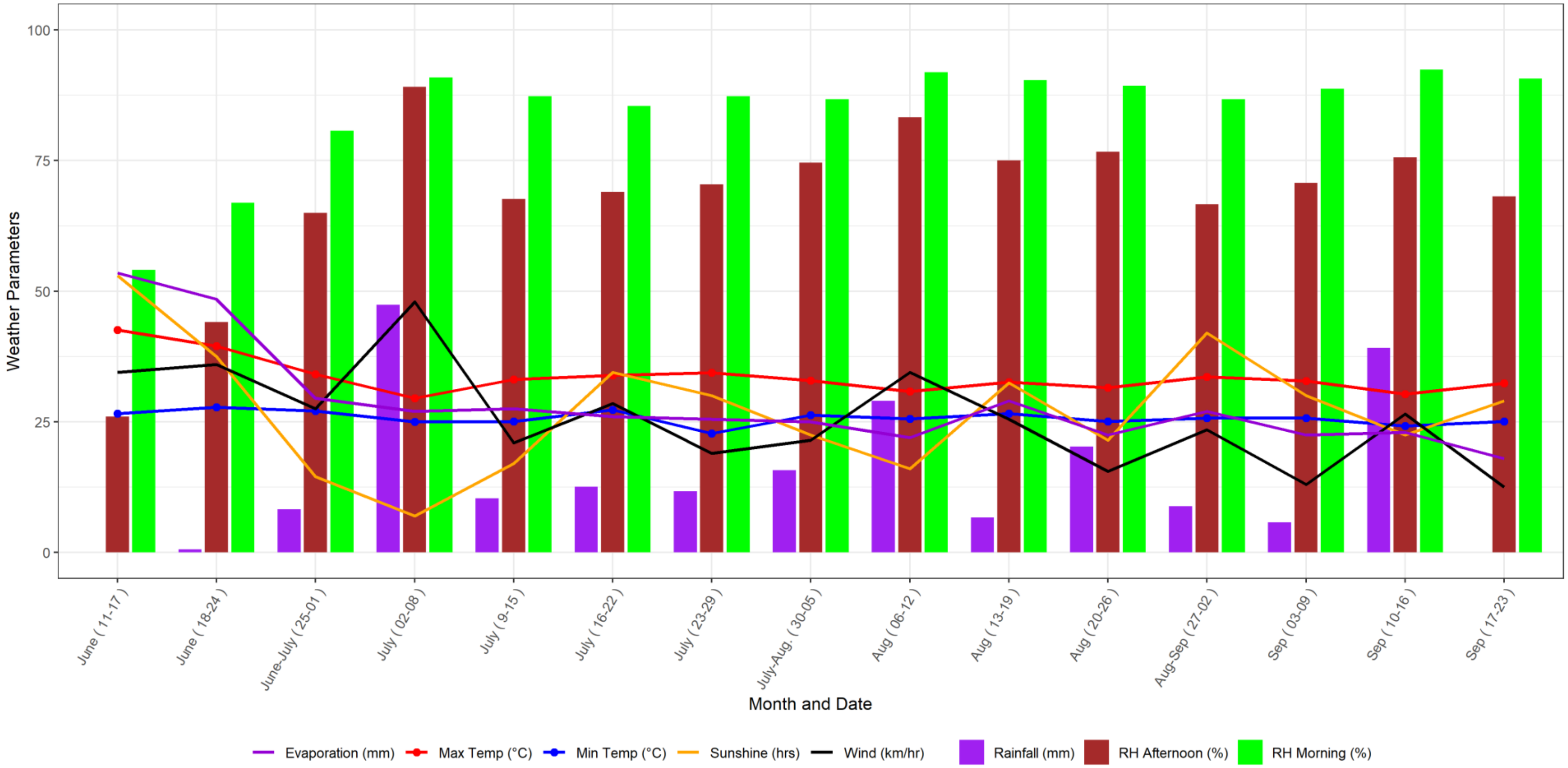

Fig. 1. Weekly weather data for the period of soil fertility gradient experiment

3. Results and Discussion

3.1 Yield

The experimental results demonstrated that graded application of nitrogen, phosphorus, and potassium significantly influenced forage and dry matter yield of sorghum (Fig. 2). Among the treatments, high fertility strip (strip-III) recorded the highest green forage yield (537.50 q ha^{-1}), followed by medium fertility strip (strip-II) (441.67 q ha^{-1}), whereas lowest fertility strip (strip-I) produced the lowest yield (312.50 q ha^{-1}). The percentage increase in forage yield in strip-III was 72.00% and 21.70% over strip-I and II, respectively, whereas strip-II showed 41.33% increase over strip-I.

A similar trend was observed for dry matter yield, which was 98.96 q ha^{-1} in strip-I, 137.96 q ha^{-1} in strip-III, with strip-II (114.83 q ha^{-1}) occupying an intermediate position. The percentage increase in dry matter yield in strip-III was 39.41% and 20.14% over strip-I and II, respectively, whereas strip-II showed 16.04% increase over strip-I.

Observed enhancement in growth and yield with higher fertilizer levels which may be attributed to improved nutrient availability and uptake. These findings are in agreement with earlier reports on sorghum and wheat, which highlighted the positive response of crops to graded fertilization (Vamshi et al., 2023; Isha et al., 2024). Furthermore, the pivotal role of nitrogen in promoting vegetative growth and forage productivity has also been well documented (Singh, 2014).

3.2 Total Nutrient Uptake

Nutrient uptake by sorghum (*Sorghum bicolor*) increased progressively with higher fertility levels, following the order strip-III > strip-II > strip-I (Fig. 3). Nitrogen uptake was highest in strip-III (137.79 kg ha^{-1}), followed by strip-II (109.47 kg ha^{-1}) and strip-I (92.36 kg ha^{-1}), showing increase of 49.19% and 25.86% in strip-III over strip-I and II, respectively, while strip-II exceeded strip-I by 18.53%. A similar trend was observed for phosphorus and potassium uptake, with maximum values recorded in strip-III (25.25 and 147.70 kg ha^{-1}), followed by strip-II (19.52 and 102.20 kg ha^{-1}) and strip I (15.24 and 79.40 kg ha^{-1}). The increase in phosphorus and potassium uptake in strip-III over strip-I was 65.66% and 86.03%, respectively, whereas strip-II showed improvements of 28.10% (P) and 28.72% (K) over strip-I. Phosphorus and potassium uptake in strip-III exceeded strip-II by 29.32% and 44.52%, respectively.

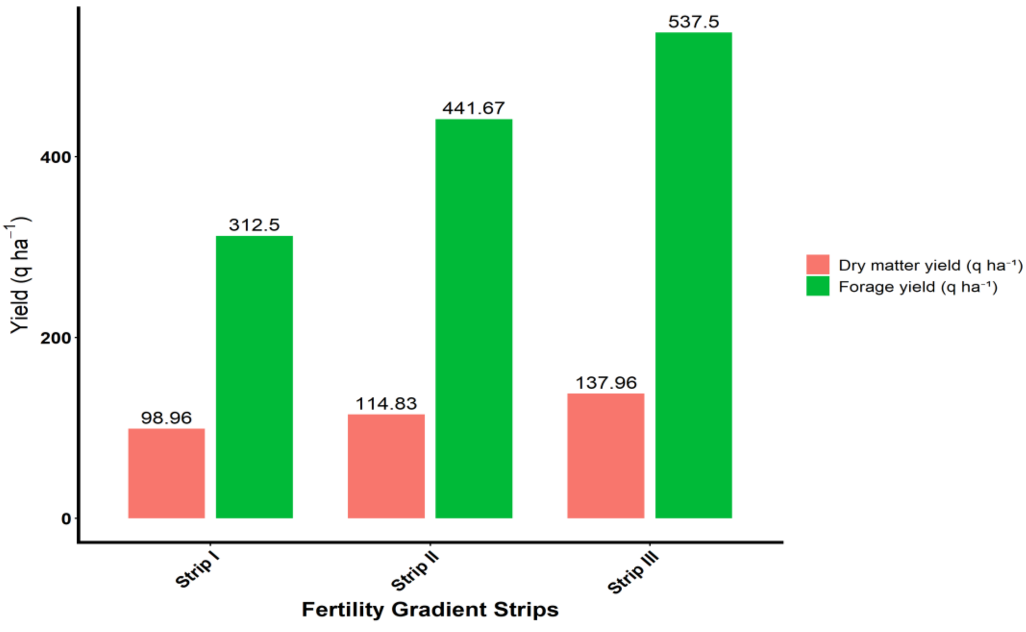

Fig. 2. Yield of sorghum in soil fertility gradient experiment

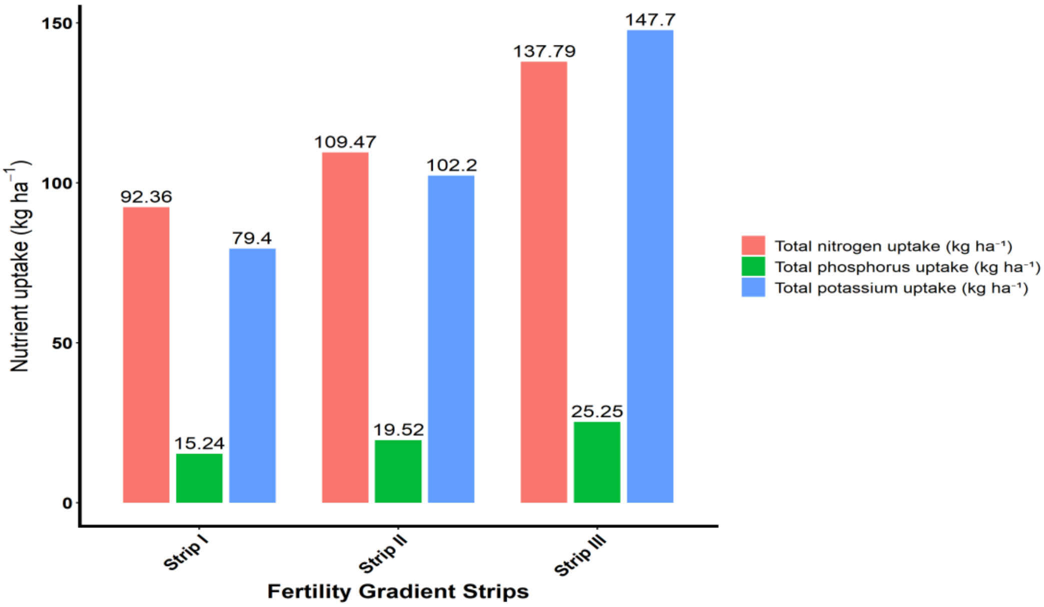

Fig. 3. Total nutrient (N/P/K) uptake of sorghum in soil fertility gradient experiment

Consistent increase in nutrient uptake across fertility levels confirms the successful establishment of a soil fertility gradient, as reflected in the response pattern of the exhaust crop. Enhanced nutrient uptake may be attributed to improved nutrient availability, better root development, and increased physiological activity under higher fertilizer inputs. Nitrogen likely promoted vegetative growth and photosynthetic efficiency, while phosphorus supported root proliferation and potassium facilitated nutrient absorption, collectively contributing to higher uptake and productivity (Manjunath Madhukar Mopagar et al., 2023). These findings are in agreement with earlier studies on sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum L.*) (Singh et al., 2020; Asan et al., 2023).

3.3 Post-harvest Soil Fertility Status in Soil fertility Gradient Experiment

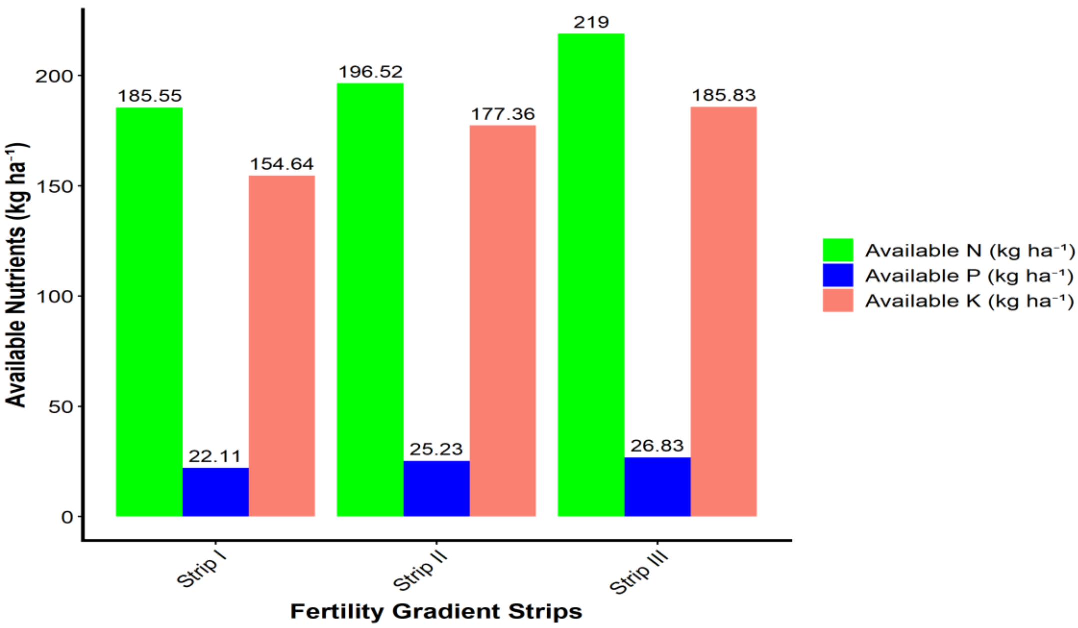

Fig. 4. Post-harvest soil test values (N/P/K) of sorghum in soil fertility gradient experiment

Post-harvest soil analysis clearly reflected the influence of graded fertilizer application on nutrient availability (Fig. 4). The available nitrogen (alkaline $KMnO_4$-N) increased was 185.55 kg ha^{-1} in strip-I, 196.52 kg ha^{-1} in strip-II and 219.00 kg ha^{-1} in strip-III. A similar increasing trend was observed for available phosphorus (Olsen-P), with values of 22.11, 25.23, and 26.83 kg ha^{-1}, and for potassium (NH_4OAc-K), with 154.64, 177.36, and 185.83 kg ha^{-1} in strip-I, II, and III, respectively. Overall, nutrient availability followed the order: strip-III > strip-II > strip-I.

The progressive buildup of soil fertility across strips indicates the successful establishment of a nutrient gradient in soil primarily due to differential fertilizer doses. Higher nutrient levels in the enriched plots may be attributed to the application of elevated doses of N, P and K, exceeding the native soil supply capacity. Similar trends have been reported in earlier studies (Jhinkwan et al., 2021; Ammal et al., 2020) and the effectiveness of graded doses of fertilization in modifying soil nutrient status and enhancing crop performance (Asan et al., 2023). However, Incorporation of organics within the soil strips may be used to create effective soil fertility gradients.

4. Conclusion

Results clearly demonstrated the successful establishment of a soil fertility gradient, as reflected in the progressive increase in forage yield and total nutrient uptake of sorghum (*Sorghum bicolor*) across the strips in the order: strip-III > strip-II > strip-I. The similar trend was further exhibited in the post-harvest soil nutrient status of available nitrogen, phosphorus, and potassium. Findings highlighted the effectiveness of generating distinct fertility levels in soil, for developing STCR based fertilizer prescription to achieve balanced fertilization, sustaining crop productivity, and minimizing excessive fertilizer use.

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 writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

References

Ammal, U. B., Venkatakrishnan, L., Vetrivel, M., Sankar, R., Coumaravel, K., & Dey, P. (2020). Soil test based fertilizer prescriptions under IPNS for rice-rice cropping sequence in Inceptisol of Puducherry. *Journal of the Indian Society of Soil Science, 68*(4), 408–414. https://doi.org/10.5958/0974-0228.2020.00031.6

Asan, M. B., Santhi, R., Maragatham, S., Ravikesavan, R., Geetha, P., & Gopalakrishnan, M., et al. (2023). Impact of soil fertility characteristics on artificial fertility gradient approach developed using sorghum (*Sorghum bicolor*) in Alfisols. *Journal of Applied and Natural Science, 15*(2), 793–801. https://doi.org/10.31018/jans.v15i2.4601

Asan, M. B., Santhi, R., Maragatham, S., Ravikesavan, R., Geetha, P., & Gopalakrishnan, M., et al. (2023). Impact of soil fertility characteristics on artificial fertility gradient approach developed using sorghum (*Sorghum bicolor*) in Alfisols. *Journal of Applied and Natural Science, 15*(2), 793–801. https://doi.org/10.31018/jans.v15i2.4601

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley and Sons, New York. https://doi.org/10.1002/9781118625422

Hanway, J. J., & Heidel, H. (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agriculture, 57*, 1–31. https://cir.nii.ac.jp/crid/1370581626508233858

Isha, Gautam, P., Pareek, N., Chandra, S., Paul, J., & Singh, A. P. (2024). Establishment and evaluation of soil fertility gradient on the basis of sorghum fodder yield, nutrient uptake and post-harvest soil test values. *International Journal of Plant & Soil Science, 36*(12), 38–46. https://elibrary.ru/item.asp?id=79780651

Jhinkwan, S., Singh, S., Pareek, N., & Gautam, P. (2021). Optimization of integrated nutrient recommendations through soil test crop response approach for forage oats (*Avena sativa* L.) in a Mollisol. *Journal of the Indian Society of Soil Science, 69*(2), 156–161. https://doi.org/10.5958/0974-0228.2021.00040.2

Kimetu, M., Mugendi, D. N., Palm, C. A., Mutuo, P. K., Gachengo, C. N., & Nandwa, S. (2004). African network on soil biology and fertility, 207–224.

Manjunath Madhukar Mopagar, Biradar, S. A., & Kalaghatagi, S. B. (2023). Influence of graded levels of nitrogen application on growth and yield of multicut fodder sorghum genotypes. *Pharma Innovation Journal, 12*(3), 1946–1949.

Ministry of Agriculture & Farmers Welfare. (2024). *Agricultural statistics at a glance 2024–24*. Government of India, New Delhi.

Mwadalu, R., Mochoge, B., Mwangi, M., Maitra, S., & Gitari, H. (2022). Response of Gadam sorghum (*Sorghum bicolor*) to farmyard manure and inorganic fertilizer application. *International Journal of Agriculture Environment & Biotechnology, 15*(1), 51–60. https://doi.org/10.30954/0974-1712.01.2022.6

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. United States Department of Agriculture Circular 19, Washington DC, p. 939.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of soil analysis. Part 2, chemical and microbiological properties* (2nd ed.). American Society of Agronomy, Madison, Wisconsin, USA. https://doi.org/10.2134/agronmonogr9.2.2ed

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, 2*, 1–20. https://doi.org/10.1007/978-3-030-61010-4_1

Prajapati, B., Shrivastava, A. K., Sarvade, S., Agrawal, S. B., & Solanki, R. S. (2023). Nutrient management for optimizing fodder production of sorghum – A review. *International Journal of Bio-resource and Stress Management, 14*(1). https://doi.org/10.23910/1.2023.3265

Ramamoorthy, B., Narasimham, R. L., & Dinesh, R. S. (1967). Fertilizer application for specific yield targets on Sonora 64 (wheat). Indian Farming, 17(5), 43-45. https://epubs.icar.org.in/index.php/IndFarm

Ray, P. K., Jana, A. K., Maitra, D. N., Saha, M. N., Chaudhury, J., & Saha, S., et al. (2000). Fertilizer prescriptions on soil test basis for jute, rice and wheat in Typic Ustochrept. *Journal of the Indian Society of Soil Science, 48*, 79–84.
https://www.indianjournals.com/ijor.aspx?target=ijor:jisss&volume=48&issue=1&article=014

Redai, W., Tesfay, A., & Yemane, G. E. (2018). Effect of NPK and blended fertilizer application on nutrient uptake and use efficiency of selected sorghum (*Sorghum bicolor* L.) varieties under rain-fed condition in Sheraro District, Northern Ethiopia. *Momona Ethiopian Journal of Science, 10*(1), 140–156. https://doi.org/10.4314/mejs.v10i1.8

Shrivastav, A., Srivastava, A., Bahadur, R., & Dey, P. (2023). Establishment of soil fertility gradient and its statistical verification based on soil and crop response. *International Journal of Plant and Soil Science, 35*(19), 1053–1058.

Singh, Y. V. (2014). STCR based gradient experiment with sorghum (*Sorghum biocolar* L.) to NPK fertilizers in the alluvial soil. *Indian Journal of Crop Ecology, 2*(2), 83–86.

Singh, Y. V., Singh, S. K., Deepak, Sharma, P. K., & Meena, R. (2020). STCR based fertilizer recommendation with sorghum (Sorghum bicolar L.) gradient experiment in alluvial soil. Journal of Pharmacognosy and Phytochemistry, 9(1), 484-486.

Sriagtula, R., Martaguri, I., & Sowmen, S. (2021). Evaluation of nutrient solution dose and harvest time on forage sorghum (*Sorghum bicolor* L. Moench) in a hydroponic fodder system. *IOP Conference Series: Earth and Environmental Science, 888*(1), 012068. https://doi.org/10.1088/1755-1315/888/1/012068

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for assessment of available nitrogen in soils. *Current Science, 25*(8), 259–260.

Tandon, H. L. S. (2004). *Fertilizers in Indian agriculture from 20th to 21st century*. FDCO, New Delhi.

Jan, T., Jan, M. T., Arif, M., Akbar, H., & Ali, S. (2007). Response of wheat to source, type and time of nitrogen application. Sarhad Journal of Agriculture, 23(4), 871-879. https://www.aup.edu.pk/sj-agriculture.php

Vamshi, M., Maragatham, S., Santhi, R., Kalarani, M. K., Sankari, A., & Gopalakrishnan, M., et al. (2023). Evaluation on the development of soil fertility gradients with nutrient exhaustive crop (*Sorghum bicolor*) regard to N, P, and K in Inceptisols in semi-arid regions of Tamil Nadu. *Journal of Applied & Natural Science, 15*(3), 1061–1070.

Vamshi, M., Maragatham, S., Santhi, R., Kalarani, M. K., Sankari, A., & Gopalakrishnan, M., et al. (2023). Evaluation on the development of soil fertility gradients with nutrient exhaustive crop (*Sorghum bicolor*) regard to N, P, and K in Inceptisols in semi-arid regions of Tamil Nadu. *Journal of Applied & Natural Science, 15*(3), 1061–1070. https://doi.org/10.31018/jans.v15i3.4788

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