

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

ABSTRACT

Aim: The study aimed to establish and evaluate soil fertility gradient on the basis of sorghum fodder yield, nutrient uptake and post-harvest soil test values under the Soil Test Crop Response (STCR) approach.

Place and Duration of Study: The field experiment was carried out at Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, during *kharif*, 2022.

Methodology: The experimental field was divided into three plots, each receiving graded levels of N, P₂O₅ and K₂O: N₀P₀K₀ (Plot A), N₁₀₀P₁₀₀K₁₀₀ (Plot B) and N₂₀₀P₂₀₀K₂₀₀ (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.

Results: 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.

Conclusion: Such findings are essential 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 (STCR) 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 et al., 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 aspects of STCR. 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).

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). 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. 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 (29° N latitude, 79° 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.

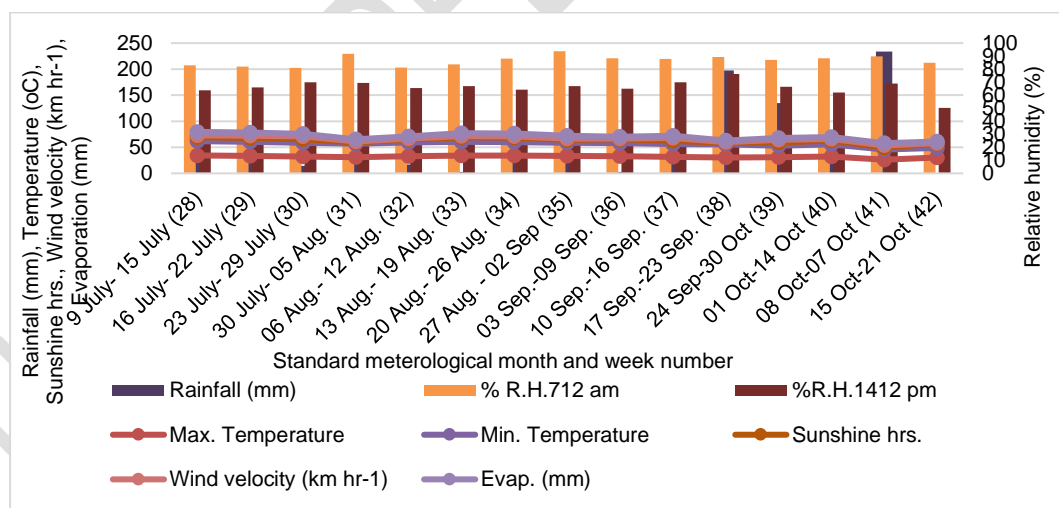


Fig. 1: Weather data for the period of soil fertility gradient experiment during *kharif* 2022

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 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 m^2 ($2\text{ m} \times 2\text{ m}$) 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 ($q\text{ ha}^{-1}$) 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 $60\pm 5^\circ\text{C}$ until constant weight was achieved for determining moisture content and dry fodder yield ($q\text{ ha}^{-1}$) 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 $KMnO_4\text{-N}$ (**Subbiah and Asija, 1956**), Olsen's-P (**Olsen's et al., 1954**) and $NH_4OAc\text{-K}$ (**Hanway and Hiedel, 1952**) represented as SN, SP and SK and expressed in $kg\text{ ha}^{-1}$. Descriptive statistics was used to present fodder yield, total nutrient uptake and post harvest soil test values of nutrients (**Gomez and Gomez, 1984**). Data analysis was conducted using Microsoft Excel 2013.

3. RESULTS AND DISCUSSION

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). 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 28.57 per cent and 5.50 per cent over plots A and B, respectively. While, Plot B, recorded 24.42 per cent increase in green fodder yield from plot A. Dry fodder yield ($q\text{ ha}^{-1}$) 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 26.78 and 8.54, respectively and Plot B over Plot A was 19.94.

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.

Nutrient uptake

Total nitrogen uptake ($kg\text{ ha}^{-1}$) 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 43.68 and 15.58, respectively and Plot B over Plot A was 33.28. Maximum phosphorus uptake ($kg\text{ ha}^{-1}$) was 23.43 under Plot C followed by 20.18 in Plot B and minimum 15.54 in Plot A. Additionally, maximum potassium uptake ($kg\text{ ha}^{-1}$) was 149.25 (Plot C) followed by 126.10 (Plot B) and least 79.55 (Plot A). Per cent increase in uptake of phosphorus and potassium in Plot C compared to plots A and B was 33.67 and 13.87 per cent; 46.70 and 15.51 per cent, respectively. While increase in uptake of phosphorus and potassium by sorghum in Plot B over Plot A was 22.99 and 36.92 per cent, respectively (Table 1). 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 and Santhi (2017)** and **Asan et al. (2023)** for sorghum.

Table 1. Sorghum fodder yield 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
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.

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 (Mopagar et al., 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 and Ramna, 1993). Consequently, the existence 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.

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). The average soil test values of alkaline KMnO₄-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 NH₄OAc-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 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).

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

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 of such nature are essential for developing better nutrient management techniques i.e. STCR approach to formulate fertilizer prescription equations and 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 and text-to-image generators have been used during the writing or editing of this manuscript.

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. DOI: 10.5958/0974-0228.2020.00031.6.
- Asan, M.B., Santhi, R., Maragatham, S., Ravikesavan, R., Geetha, P., Gopalakrishnan, M., & Devi, R. (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. DOI: <https://doi.org/10.31018/jans.v15i2.4601>.
- Batabyal, K., Sarkar, D., & Mandal, B. (2015). Fertilizer-prescription equations for targeted yield in radish under integrated nutrient management system. *Journal of Horticultural Science*, 10(1), 18-23.
- Dey, P. (2015). Soil Test crop response: What Can Be Learnt? In book: National Dialogue on Efficient Nutrient Management for Improving Soil Health. TAAS, ICAR, CIMMYT, IPNI, CSISA, FAI Editors: Jat ML, Majumdar K, McDonald A, Sikka AK, Paroda RS.
- Dwivedi, B.S., Shukla, A.K., Singh, V.K., & Yadav, R.L. (2001). Results of PDCO based trials from the state of Uttar Pradesh. In. Development of Farmers' Resource Based Integrated Plant Nutrient Supply System. Experience of an FAO-ICAR-IFFCO Collaborative Project and AICRP on STCR (A. Subba Rao and S. Srivastava, Eds.). pp. 50-75. IISS, Bhopal, India.
- Gomez, K.A., & Gomez, A.A. (1984). Statistical procedures for agricultural research (2nd ed.). John Wiley and Sons, New York. p. 680.
- Hanway, J.J., & Heidel, H. (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agriculture*, 57, 1-31.
- Isha, Gautam, P., and Chandra, R. (2024). Soil test crop response based site-specific integrated nutrient management in mungbean. *Journal of Plant Nutrition*, 47(5), 690-704. DOI: 10.1080/01904167.2023.2280158.
- Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall of India Private Limited press, New Delhi.
- 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. DOI: 10.5958/0974-0228.2021.00040.2.
- Kugbe, J.X., Mbawuni, A.M., & Wisdom, A. (2019). Growth, yield and yield components response of local sorghum varieties to nitrogenous fertilizer rates in Northern Ghana. *World Journal of Agricultural and Soil Science*, 3(4), 1-10. DOI: 10.33552/WJASS.2019.03.000574.
- Mopagar, M.M., 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.

- 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.
- O'Neill, A. (2024). Population growth in India 2023. Published by Statista. Available at: <https://www.statista.com/statistics/271308/population-growth-in-india/>
- 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.
- 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). DOI: <https://doi.org/10.23910/1.2023.3265>.
- Qamar, R., Altaf, M.M., Alwahibi, M.S., Al-Yahyai, R., & Hussain, M. (2022). Phosphorus and potassium application improves fodder yield and quality of sorghum in Aridisol under diverse climatic conditions. *Agriculture*, 12(5), 593. DOI: <https://doi.org/10.3390/agriculture12050593>.
- Ramamoorthy, B., Narasimham, R., & Dinesh, R. (1967). Fertilizer application for specific yield targets on Sonora 64 (wheat). *Indian Farming*, 17, 43-45.
- Ray, P.K., Jana, A.K., Mitra, D.N., Saha, M.N., Choudhury, J., Saha, S., & Saha, A.R. (2000). Fertilizer prescription on soil test basis for jute, rice, and wheat in Typic Ustochrept. *Journal of the Indian Society of Soil Science*, 48, 79-84.
- Santhi, R., Natesan, R., & Selvakumari, G. (2002). Soil test based fertilizer recommendation under IPNS for aggregatum onion in Inceptisols of Tamil Nadu. *Agropedology*, 12, 141-147.
- Sharma, P.S., & Ramna, S. (1993). Response of sorghum to nitrogen and potassium in Alfisol. *Journal of Potash Research*, 9(27), 171-175.
- 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, V.K., Gautam, P., Singh, S., Pareek, N., & Singh, V.P. (2020). Evaluation of soil fertility gradient experiment on the basis of crop yield, nutrient uptake and soil fertility. *International Journal of Current Microbiology and Applied Sciences*, 9(2), 2435-2440. DOI: <https://doi.org/10.20546/ijcmas.2020.902.278>.
- Singh, Y.V. (2014). STCR based gradient experiment with sorghum (*Sorghum bicolor* L.) to NPK fertilizers in the alluvial soil. *Indian Journal of Crop Ecology*, 2(2), 83-86.
- Singh, Y.V., Singh, S.K., Sharma, P.K., & Meena, R. (2020). STCR based fertilizer recommendation with sorghum (*Sorghum bicolor* L.) gradient experiment in alluvial soil. *Journal of Pharmacognosy and Phytochemistry*, 9(1), 484-486.
- Subbiah, B.V., & Asija, G.L. (1956). A rapid procedure for assessment of available nitrogen in soils. *Current Science*, 25(8), 259-260.
- Udayakumar, S., & Santhi, R. (2017). Impact of artificial soil fertility gradient strategy on soil fertility, nutrient uptake, and fodder yield of Sorghum. *International Journal of Current Microbiology and Applied Sciences*, 6(3), 938-944.
- Vamshi, M., Maragatham, S., Santhi, R., Kalarani, M.K., Sankari, A., Gopalakrishnan, M., & Rajeswari, R. (2023). Evaluation on the development of soil fertility gradients with nutrient exhaustive crop (*Sorghum bicolor*) regarding N, P, and K in Inceptisols in semi-arid regions of Tamil Nadu. *Journal of Applied Natural Science*, 15(3), 1061-1070.
- Verma, M., Singh, Y.V., Babu, A., Verma, S., Meena, R., & Sahi, S.K. (2015). Soil test crop response based gradient experiment on rice (*Oryza sativa* L.) to fertilizers in the alluvial soil. *Indian Journal of Agricultural and Allied Sciences*, 1(4), 51-53.
- Yousaf, G., Fayyaz, F.A., & Yousaf, M.H. (2023). Interaction of Cropping Pattern and Fertility Treatments on Yield and Sustainability of Mixed Cropping System under Moisture Regime.

UNDER PEER REVIEW