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Development of artificial fertility gradient using fodder sorghum and its effect on soil nutrients, nutrient uptake and fodder yield

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Abstract

Fertilizers play a vital role in enhancing crop production, and optimizing their application is essential for achieving higher yields. This study examines the effects of an artificial fertility gradient on soil fertility, nutrient uptake, and fodder yield of sorghum (*Sorghum bicolor*) using the Inductive cum Targeted Yield Model. A field experiment was conducted at the N.M. College of Agriculture, Navsari Agricultural University, Gujarat, during the kharif 2022. The experimental site was divided into three strips with graded doses of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O): Strip I ($N_0P_0K_0$: 0-0-0 kg ha^{-1}), Strip II ($N_1P_1K_1$: 80-40-40 kg ha^{-1}), and Strip III ($N_2P_2K_2$: 160-80-80 kg ha^{-1}). Results indicated that fertilizer application significantly influenced soil fertility, nutrient uptake, and fodder yield. Post-harvest soil nutrient levels showed a considerable increase in Strip III compared to Strips I and II, confirming the creation of an artificial fertility gradient. Sorghum fodder yield was significantly higher in Strip III (29.87 t ha^{-1}), representing a 480% and 90.3% increase over Strips I and II, respectively. Nutrient uptake followed a similar trend, with maximum N, P, and K uptake observed in Strip III (75.55, 69.88, and 131.58 kg ha^{-1} , respectively). The findings demonstrate that higher fertilizer application enhances nutrient availability, uptake, and crop productivity. This study provides empirical evidence supporting targeted fertilization strategies for optimizing fodder sorghum production and improving soil fertility management.

Keywords: Fertilizer application, fodder sorghum, nutrient uptake, soil fertility gradient, sorghum yield

Introduction

Fertilisers play a crucial role in enhancing crop production, with their judicious application being essential for achieving high yields. A pioneering field experimental approach, known as the Inductive Methodology, was introduced under the All India Coordinated Research Project (AICRP) for Soil Test Crop Response (STCR) studies. This method involves creating a macrocosm of soil fertility variability within a microcosm of an experimental field by applying graded doses of fertilisers, as outlined by Ramamoorthy *et al.* (1967) [9]. The STCR approach facilitates the development of fertiliser prescription equations and calibration charts, enabling recommendations based on soil test results to achieve targeted crop yields. Fodder sorghum, cultivated across approximately 3.97 million hectares in India during the 2023-2024 period, holds significant importance as the country's fourth most vital cereal crop, following rice, wheat, and maize. Major sorghum-producing states include Maharashtra, Karnataka, Rajasthan, and Andhra Pradesh, where it serves as a crucial food and fodder crop during the kharif season. Renowned for its rapid growth, fodder sorghum provides palatable and nutritious feed during lean periods. It is utilized in various forms, including silage, hay, and fresh fodder, contributing significantly to livestock nutrition and, consequently, dairy production (Anonymous, 2023) [3]. Sorghum, being a nutrient-demanding crop, depletes significant amounts of soil nutrients (Dwivedi *et al.*, 2001) [4], and its increased biomass yield further enhances nutrient uptake. The aim of this study was to evaluate the effect of an artificial fertility gradient strategy on soil fertility, nutrient uptake, and fodder sorghum yield.

Methodology

The study utilized the "Inductive cum Targeted Yield Model," as outlined by Ramamoorthy *et al.* (1967)^[9], which provides an empirical framework for optimizing fertilization by balancing nutrients from both external inputs and the natural soil reserves. The deliberate manipulation of soil fertility levels was carried out to create a detailed dataset, incorporating a wide range of fertilizer doses for each uncontrollable factor, while considering varying levels of an-uncontrolled variable-soil fertility. This approach was employed to address the natural variability in soil fertility, which typically does not occur uniformly within a single location. To manage this variability, along with differences in management practices and prevailing climatic conditions, an experimental study was conducted in the field. The aim was to create variations in soil fertility within the same field by implementing a fertility gradient. Building on this premise, the present study was designed to examine the effects of a simulated soil fertility gradient on sorghum fodder production, nutrient uptake by sorghum plants, and changes in soil fertility. The field experiment was conducted during the kharif season of 2022, using the nutrient-demanding sorghum variety "Rangeela" to facilitate nutrient transformation through applied fertilizers in the soil. The study was conducted at the college farm of N.M. College of Agriculture, Navsari Agricultural University, located in Navsari. The farm is situated in the coastal region of South Gujarat, at a latitude of 20° 37' N and longitude of 72° 54' E, with an altitude of 11.98 meters above mean sea level. The experimental area was divided into three distinct strips: Strip I (N₀P₀K₀), Strip II (N₁P₁K₁), and Strip III (N₂P₂K₂). Each strip received varying levels of major nutrient fertilizers (NPK), applied as urea, single superphosphate (SSP), and muriate of potash (MOP), corresponding to the respective fertilizer treatments.

Table 1: Fertiliser doses applied to the gradient crop of fodder sorghum

Strip (Symbol)	Nutrient level (kg ha ⁻¹)		
	N	P ₂ O ₅	K ₂ O
I. (N ₀ P ₀ K ₀)	0	0	0
II. (N ₁ P ₁ K ₁)	80	40	40
III. (N ₂ P ₂ K ₂)	160	80	80

Note: N₁P₁K₁ = RDF of Fodder Sorghum

The recommended dosage of N, P₂O₅, and K₂O for sorghum cultivation was determined based on standard guidelines (Table 1). In experimental treatments II and III, 50% of the nitrogen (N) and 100% of the phosphorus (P) and potassium (K) were applied initially, with the remaining 50% nitrogen applied at 30 days after sowing (DAS). Soil samples were collected both before and after the application, air-dried, sieved through a 2 mm sieve, and analyzed for available nitrogen (Subbiah and Asija, 1956)^[12], available phosphorus (Olsen *et al.*, 1954), and available potassium (Hanway and Heidal, 1952)^[5]. At harvest, plant samples were collected from each strip, processed, and analyzed for total nitrogen, phosphorus, and potassium content (Jackson, 1973)^[6]. Nutrient uptake by fodder sorghum was calculated by multiplying the nutrient content percentage in the plant by the total dry matter. On the 60th day, the fodder crop was harvested, and the green fodder yield was systematically assessed for each strip.

Results and Discussion

Soil properties

The soil used in the experiment was classified as deep black soil with a clayey texture. It was non-saline, with an electrical conductivity (EC) of 0.18 dS m⁻¹ and a pH of 6.70, indicating neutral conditions. The initial soil characteristics included 0.35% organic carbon (OC), low available nitrogen levels (160.19 kg ha⁻¹), medium available phosphorus (46.28 kg ha⁻¹), and medium available potassium (219.90 kg ha⁻¹). The levels of cationic micronutrients-iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn)-in the soil were found to be within the sufficient ranges as per the DTPA extraction method.

Table 2: The impact of applying varying levels of nitrogen (N), phosphorus (P₂O₅), and potassium (K₂O) on the fertility of soil in a gradient experiment

Gradient strips	Graded doses (kg ha ⁻¹)			Pre-sowing soil test values			Soil test values after harvest (kg ha ⁻¹)		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
				(kg ha ⁻¹)					
I	0	0	0	160.25	45.70	218.60	146.5	43.49	202.74
II	80	40	40	158.8	47.28	219.35	175.62	44.61	222.66
III	160	80	80	161.52	45.86	221.75	181.88	65.8	249.84
SD							18.88	12.57	23.64
CV%							11.24	24.50	10.50

Pre-sowing soil available nutrients

Before sowing the fodder sorghum (a nutrient-exhaustive crop), soil samples were collected to analyze the available NPK status. The mean values for the KMnO₄-N content in the corresponding strips were 160.25, 158.8, and 161.52 kg ha⁻¹, with a range of 158.8 to 161.52 kg ha⁻¹ (Table 2). The Olsen-P levels ranged from 45.70 to 47.28 kg ha⁻¹, with corresponding strip averages of 45.70, 47.28, and 45.86 kg ha⁻¹, respectively. The mean values for NH₄OAc-K in strips I, II, and III were 218.60, 219.35, and 221.75 kg ha⁻¹, respectively.

Post - harvest soil available nutrients

Soil samples were collected from the sorghum field after harvest to assess the nutrient status and evaluate the impact of graded fertilizer application on the development of an artificial fertility gradient. Table 2 presents the available nutrient status in the soil, including the range and mean values. The available nitrogen (N) in strips I, II, and III were 146.5, 175.62, and 181.88 kg ha⁻¹, respectively. The available phosphorus (P) in these strips were 43.49, 44.61, and 65.8 kg ha⁻¹, respectively. The available potassium (K) in strips I, II, and III were 202.74, 222.66, and 249.84 kg ha⁻¹, respectively. The results indicate a significant increase in soil available N, P, and K in strip III compared to strips II and I, highlighting the creation of an artificial fertility gradient due to the application of graded fertilizer levels. The post-harvest soil test data were statistically analyzed, revealing significant variations in soil nutrient status among the three strips.

Green fodder yield

The experimental results showed that the application of higher doses of NPK fertilizers significantly increased sorghum fodder yield (Table 3). A clear positive relationship was observed between the amount of nutrients applied and the green fodder yield. In strip I, where no

fertilizers (N0P0K0) were applied, the sorghum fodder yield was 5.15 t ha⁻¹. In strip II, where fertilizers were applied at a rate of 80 kg N ha⁻¹, 40 kg P₂O₅ ha⁻¹, and 40 kg K₂O ha⁻¹ (based on standard recommendations), fodder yield increased by 228.2%, reaching a higher yield compared to strip I. In strip III, where the fertilizer application rate was doubled compared to strip II, the sorghum yield reached 29.87 t ha⁻¹. This represented a 480% increase over strip I and a 90.3% increase over strip II. The increase in yield is likely due to the proportionally adjusted fertilizer application, which enhanced nutrient uptake and promoted growth parameters such as plant height. These factors collectively contributed to the higher fodder yield in strip III. Similar findings were reported by Udayakumar *et al.* (2017) [13], who observed that varying fertilizer levels in a gradient sorghum crop enhanced growth and fodder yield in strip III compared to strip I.

Table 3: The impact of the application of varying quantities of NPK on the sorghum fodder production and nutrient uptake

Gradient strips	Graded doses (kg ha ⁻¹)			Fodder yield (t ha ⁻¹)	Nutrient uptake (kg ha ⁻¹)		
	N	P ₂ O ₅	K ₂ O		N	P	K
L ₁	0.00	0.00	0.00	5.15	10.79	11.83	17.27
L ₂	80.00	40.00	40.00	15.69	36.65	31.41	58.18
L ₃	160.00	80.00	80.00	29.87	75.55	69.88	131.58
SD				12.40	32.60	29.53	57.92
CV%				1.36	1.26	1.28	1.19

The findings of Marsalis *et al.* (2010) [7] demonstrated a positive impact on sorghum fodder production with the application of nitrogen fertilizer. The results of the present study closely align with the research conducted by Udayakumar *et al.* (2017) and Abishek *et al.* (2023) [13, 1] in the context of sorghum. The observed increase in green fodder yield can be attributed to the improved nutrient availability in the soil due to fertilizer application, as well as the role of microorganisms in nutrient transformation. Similar results were reported by Rashid and Iqbal (2012) [10] for fodder sorghum, and Alias *et al.* (2003) [2] observed comparable outcomes in their study on fodder maize.

Nutrient uptake

The data presented in Table 3 indicates a gradual increase in nitrogen uptake by the plant in strip III compared to strip I, with mean values of 10.79, 36.65, and 75.55 kg ha⁻¹, respectively. Nitrogen uptake increased by 600.1% in strip III compared to strip I, with a 106.1% increase in strip II compared to strip I. In strip II, the nitrogen uptake was 239.6% higher than in strip I. The mean phosphorus uptake in the corresponding strips was 11.83, 31.41, and 69.88 kg ha⁻¹, showing a significant increase in available phosphorus due to the graded fertilizer application. The potassium uptake in each strip was 17.27, 58.18, and 131.58 kg ha⁻¹, respectively. The percentage increase in potassium and phosphorus uptake in strip III over strips II and I were 122.47% and 490.7%, and 126.1% and 661.8%, respectively. Similarly, the percentage increase in phosphorus and potassium uptake in strip II over strip I was 165.5% and 236.8%, respectively. This pattern suggests a linear relationship between yield and nutrient uptake. The present study demonstrates that varying concentrations of NPK fertilizers resulted in a significant increase in nutrient uptake by fodder sorghum compared to the control. In a

study by Abishek *et al.* (2023) [1], it was found that nitrogen uptake by fodder sorghum was higher in plots treated with higher fertilizer levels, which aligns with the findings of Siam *et al.* (2008) [11]. The considerable increase in phosphorus uptake can be attributed to the higher levels of phosphorus treatment, which likely promoted greater root multiplication in the crop (Verma *et al.*, 2015) [14].

Conclusion

In conclusion, the results of the study indicate that the different levels of NPK fertilizer applied to the experimental field created an artificial gradient in soil fertility. The fodder crop cultivated within this gradient exhibited notable differences in terms of growth, fodder yield, nutrient absorption, and soil nutrient content.

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