Journal of Applied and Natural Science
15(3), 1061 - 1070 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

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

Maragani Vamshi*
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641003 (Tamil Nadu), India
S. Maragatham
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641 003 (Tamil Nadu), India
R. Santhi
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641003 (Tamil Nadu), India
M. K. Kalarani
Directorate of Crop Management, Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore-641003 (Tamil Nadu), India
A. Sankari
Department of Vegetable Science (Tamil Nadu) Agricultural University, Coimbatore-641003, Tamil Nadu, India
M. Gopalakrishnan
Horticultural College and Research Institute, Tamil Nadu Agricultural University, Jeenur, Krishnagiri (Tamil Nadu), India
R. Rajeswari
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641003 (Tamil Nadu), India

*Corresponding author E-mail: maraganivamshi999@gmail.com

Article Info
https://doi.org/10.31018/jans.v15i3.4788
Received: June 5, 2023
Revised: August 20, 2023
Accepted: August 25, 2023

How to Cite

Vamshi, 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 and Natural Science*, 15(3), 1061 - 1070. https://doi.org/10.31018/jans.v15i3.4788

Abstract

Soil test crop response (STCR's) soil fertility gradient approach is based on the idea that complex treatments are superimposed in a field to obtain crop responses for correlating with soil test values that are artificially created by differential fertiliser treatments prior to conducting the regular experiment, thereby providing a scientific basis for balanced fertilisation between applied and available forms of nutrients. The present study aimed to develop the fertility gradient with sorghum as test crop in the field concerning N, P, and K and also to evaluate its impact on sorghum nutrient uptake, and soil fertility. The experimental field was split into three equal strips. Strips I, II, and III each received three graded levels of fertiliser N (nitrogen), P_2O_5 (phosphorus pentoxide), and K_2O (potassium oxide) as urea, single super phosphate, and muriate of potash, respectively. The green fodder yield of sorghum recorded at harvest in strip I, II & III was 16.4, 23.4 and 28.2 t $ha^{-1,}$ respectively. Whereas post-harvest soil available nitrogen in strip I, II & III was 155, 190 & 214 kg ha^{-1} respectively, for available phosphorus 12.5, 23.2 & 31.8 kg ha^{-1} respectively and for available potassium it is 332, 370 & 396 kg ha^{-1} respectively. Wide variations in green fodder yield and soil fertility were observed among the strips, establishing the influence of graded amounts of fertiliser treatment on these parameters and the formation of a soil fertility gradient.

Keywords: Fertility gradient, Soil enzymes, Sorghum, *Sorghum bicolor,* SCMR

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a potential multifunctional crop; its grain may be used for food, its stalk for ethanol and bagasse, and the stripped leaves for fodder. Sorghum has a high potential to boost the income of smallholding farmers in the semi-arid tropics due to its ample tolerance to dry conditions and numerous uses (Redai *et al*., 2018). Sorghum is the crop of choice for arid regions and locations with inconsistent rainfall due to its drought tolerance and a broad range of ecological adaptability (Joseph *et al*., 2019), and it is found growing in areas unfavorable for most cereals. It is one of the most important staple food crops for the world's poorest and most vulnerable populations (Timu *et al*., 2012). This crop covers around 45 million hectares across Africa and India, accounting for more than 80% of the global farmed area (Mwadalu *et al*., 2022). Like sweet sorghum, grain grows quickly, is salt tolerant, and has a high biomass production (Almodares and Hadi, 2009). In India, the area of cultivation is 4.89 m ha, with a production of 4.40 million tonnes (Source: E&S Division, DA&FW, 2020-21), whereas in Tamil Nadu, it is cultivated in an area of 0.40 million hectares and with the production of 0.30 million tonnes (Source: Dep. of Economics and Statistics, 2020-21, Chennai).

Producing adequate food, fibre, and high-quality goods will be the nation's key problem in the coming years. The only way to achieve this aim is to boost the yield of different crops by using an organic and integrated farming strategy. Because of the imbalance and increased use of inorganic fertilisers, which deplete the soil nutrients, productivity has fallen in several regions across the country (Maragatham *et al*., 2018). Fertiliser is one of the most expensive crop husbandry inputs. Thus, the right quantity is crucial for farm profitability and safeguarding the environment (Singh, 2016).

Fertilisers are necessary for food production around the world. Given their high cost, fertilisers ought to be used sparingly. The General Recommendation Dose (GRD) technique does not account for variations in soil fertility. Therefore, the general fertiliser recommendations are only suitable for soils with medium fertility (Choudhary *et al*., 2022). Since the fertility of the state's soils varies greatly, uniformly implementing GRD does not guarantee economy and efficiency in fertiliser use in high-fertility soils and underuse in low-fertility soils. The Soil Test Recommended Dose (STRD), which is determined by classifying soils into low, medium, and high categories according to the nutrient status in issue, is based on soil test data. The fertiliser recommendation (STRD) is adjusted for soil testing as low or high by adding or subtracting 25% from the general guideline. The STRD technique is preferable to GRD since it accounts for changes in soil fertility when recommending fertiliser dosages. It has the drawback of recommending the same amount of fertiliser for severely deficient soils and those only slightly deficient. The identical recommendations for fertiliser are made for soils with extremely high and moderately high levels of available nutrients (Arvind Kumar Shukla *et al*., 2022). If site-specific soil test results are utilised to formulate fertiliser recommendations, significant savings on fertiliser consumption can be realised. Although the target yield strategy for recommending fertiliser to crops is also based on soil testing, it goes one step further than STRD since it bases its recommendations on the actual quantity of nutrients that are anticipated to be made accessible to crops throughout crop growth. It provides a true balance between the applied nutrients in relation to one another and the nutrients that are already found in the soil. This method takes into consideration the crop's nutritional needs, the availability of nutrients in the soil that are naturally occurring, and the effectiveness of recovering nutrients from applied fertiliser. The balance between "fertilising the crop" and "fertilising the soil" is achieved here (Khosa *et al*., 2012). Additionally, this method gives the farmer the choice to select the production goal in accordance with his available resources and management circumstances.

The All India Coordinated Research Project for Investigation on Soil Test Crop Response Correlation studies used a novel field experimental approach (Inductive methodology) that was developed by creating a macrocosm of soil fertility variability within a microcosm of an experimental field (Ramamoorthy *et al*., 1967). By selecting one field over which elaborate treatments are superimposed to obtain crop responses for correlating with soil test values that are artificially created by differential fertiliser treatments before conducting the regular experiment, the soil fertility gradient approach seeks to eliminate the influence of other factors affecting yields like crop, climate, and management. As a result of high nutrient responsiveness, exhaust crop is planted to let the fertilisers change in the soil with plant and microbial activity. The total growth and development of the crop depends on nutrients like nitrogen, phosphorus, and potassium, which are needed in huge quantities. The present study set out to assess the effects of soil initial fertility status on the crop growth attributes, crop yield, uptake of the nutrients by the crop, development of soil fertility after harvesting the crop and biological properties of the soil.

MATERIALS AND METHODS

Location and place of the experiment

In the southern part of India and the foot of the Sirumalai Hills of Tamil Nadu, Dindigul, farmers holding, at 10° 36' N latitude and 77°97' E longitude, was an experimental site. To establish a gradient of N, P, and K over the field, graded doses of fertiliser were used in the fields at this location.

Rainfall and the climate

Having a mean annual precipitation of 700-1600 millimetres and a mean annual temperature of 27.2°C, the region has a Tropical wet and dry or savanna climate (Classification: Aw). Dindigul experiences high summer heat, with a maximum temperature of 38.6°C, and extremely cold winters, with a low temperature of 23.8°C. The months of July through September see about 80% of the annual rainfall, with the remaining months of December through February seeing the remainder.

Treatment information for the experiment

At the farmers holding, Dindigul, the graded N, P, and K fertiliser doses were applied in three fertility strips across the width of the field (Rabi season, 2022) in the manner described below. Table 1 provides the experiment's treatment information.

In the year 2022, Rabi season, fodder sorghum was grown as a major crop. In the 23 m x 32 m plots, gradients were created with a row-to-row spacing of 20 cm and a plant-to-plant spacing of 10 cm. The hybrid fodder sorghum cultivar (CO 30) was chosen. Immediately after sowing the seeds in soil, irrigation was done at 4th, 9th 15th, 28th, 40th, 52th days after sowing (DAS). A full dose of P_2O_5, K_2O and a half dose of N was applied as basal before the crop was sown. The remaining amount of N was given to the crop in two equal split doses at 15 and 30 DAS.

The goal of creating the fertility gradient was to get as much variation in the soil fertility levels with respect to N, P, and K in the same field to evaluate the legitimate connection between the yield and the level of soil fertility without interference from other factors affecting yield (Ramamoorthy *et al*., 1967). To provide data encompassing an appropriate range of values for each controllable variable (fertiliser dose) at various levels of an uncontrollable variable (soil fertility), which could not be expected at one location ordinarily. The operational range of variation in soil fertility was artificially created. As a result, a field experiment was conducted during Rabi season, 2022 by growing an exhaustive crop of fodder sorghum (var. CO 30) at farmers holding, Palaniur, Dindigul (Dist.), Tamil Nadu to create soil fertility variation in the same field and to evaluate the impact of soil fertility gradient experiment on crop yield, nutrient uptake, and soil fertility. Before applying fertilisers, the experimental field was divided into three equal strips, and an initial soil sample was taken. N, P_2O_5, and K_2O fertiliser nutrients were then applied in graded doses in strips I (N0P0K0), II (N90P100K80), and III (N180P200K160). Urea, SSP (single super phosphate), and MOP (Muriate of Potash) were used as nutrients. Fodder sorghum was grown to maturity using standard agronomic practises and collected at maturity by obtaining a crop sample from a 1 X 1 m^2 area in three randomly chosen positions on each strip.

After the vegetative stage before the grain formation, the crop was harvested and allowed to dry in the sun in the field. After the produce was threshed, the average biological yield was calculated by the average strip-wise fodder yield (kg m^{-2}). The total nitrogen, phosphate, and potassium contents of the collected straw from each strip were examined (Jackson, 1967), and the crop's total nutrient uptake was calculated.

Soil sampling and analysis

Prior to the start of the gradient experiment (Rabi season, 2022), soil samples (0–15 cm) representing the entire field were collected using a zigzag approach from at least 20 sampling points to characterise the various soil chemical properties, including electrical conductivity (EC), pH, organic carbon (OC), available N, P, and K. Following the harvest of the entire crop of sorghum, three soil samples were randomly collected from each strip between 0 and 15 cm deep. These samples were air-dried and processed according to established protocols (*i.e*., passed through a 0.5 mm sieve for OC and a 2.0 mm sieve for the remaining chemical properties). The wet oxidation method of Walkley and Black (1934) was used to calculate the OC. The availability of N by the alkaline potassium permanganate method (Subbaiah, 1956), P Spectrophotometrically (Olsen *et al*., 1954), and K by the neutral normal ammonium acetate method (Hanway and Heidal, 1952) were all other soil chemical properties that were determined.

RESULTS AND DISCUSSION

The experimental field's soil found to have a sandy clay loam in texture, taxonomically referred as "*Vertic ustropept"* with slightly alkaline (pH 8.35), non-saline (0.13 dS m^{-1}), mixed black calcareous (free $CaCo_3$ –9.7%), low in organic carbon (5.2 mg kg^{-1}), P fixing capacity (100 kg ha^{-1}) and K fixing capacity (80 kg ha^{-1}). Initially, it was found that the soil where fertility gradients were formed, had low available N (170 kg ha^{-1}), medium available phosphorus (17 kg P ha^{-1}), and high available potassium (350 kg K ha^{-1}) values, respectively.

Growth parameters

Plant height

Plant height of fodder sorghum (Table 2) was significantly influenced by the application of graded levels of fertilizer N, P_2O_5 and K_2O at 30 and 60 DAS. The highest plant was recorded in strip III at both 30 and 60 DAS where N, P, and K fertilisers were applied twice, whereas strip I recorded the lowest which received no fertilisers. 104.8 cm at 30 DAS and 189.3 cm at 60 DAS was the plant height seen in strip-II. The per cent

Table 1. Nutrient dosages to create fertility gradients over the entire width of the field

strip	Levels of nutrients			Dosages of nutrients (Kg ha^{-1})		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Strip-I	N_0	P_0	K_0	0	0	0
Strip-II	N_1*	P_1**	K_1**	90	100	80
Strip-III	N_2	P_2	K_2	180	200	160

* N1: As per blanket recommendation, ** P1 and K1: As per P and K fixing capacities of the experimental field. N2, P2 & K2: Double the doses of N1, P2 & K2 respectivelly

increase of plant height in strip III over strip I was 92.2 cm and 44.5 cm at 30 and 60 DAS, respectively. The improved nutrient absorption by the fodder sorghum and the significantly higher fertility condition in strip II may be the causes of the 58.2% increase in plant height in strip II over strip I. With an increase in nitrogen level, plants grew significantly taller. The higher plant height seen as a result of higher nitrogen levels was mostly ascribed to the crop's increased availability and uptake of nitrogen, which led to more vegetative growth and an acceleration of cell division, expansion, and differentiation, culminating in luxuriant growth. Fodder sorghum's height growth has been shown as a result of N fertilisation according to Moghimi and Emam (2015).

Sujathamma *et al*. (2018) reported that there was an increase in sorghum plant height with increased fertiliser application. This could be attributed to soil enrichment with higher levels of nutrients because they provide the essential nutrients needed for various metabolic processes, ultimately leading to plant growth. As per Varshini and Babu (2022) the effect of N in promoting cell division and cell enlargement may cause the growing trend in plant height with increased N application, which eventually affects vegetative development, especially the height of the plant. The application of N could have promoted plant growth in maize by increasing the number and length of the internodes, resulting in a progressive increase in plant height (Parbati *et al*., 2016).

Green leaves per plant

Since green leaves are the natural photosynthesis factories and directly impact a plant's growth and development, their number per plant is a crucial indication of plant growth. From the results depicted in Table 2, green leaves count was more in strip III when compared with the remaining two strips. Significant variation was seen among the strips in the green leaves count, possibly due to the variation in graded doses of fertilisers. Green leaves per plant were 11.3 and 16.2 at 30 and 60 DAS, respectively, in strip III, which received double the dose of strip II. Both at 30 and 60 DAS strip I (control) showed the lowest green leaves count per plant viz., 6.8 and 8.7. Strip II receiving 90, 100, 80 kg ha^{-1} of N, P_2O_5 and K_2O fertiliser recorded 9.5 and 14.6 green leaves per plant at 30 and 60 DAS. Strip III recorded an increase of 66.1, 86.2 and 18.9, 10.9 % over strip I and II at 30 and 60 DAS, respectively. It could be increased due to protein synthesis brought on by increased nitrogen availability might account for the high number of leaves with rising nitrogen levels. The additional protein may have encouraged leaf growth and, thus, increased leaf surface area.

The results are in complete confirmation with Muhammad Aamir Iqbal *et al*. (2015) where the maximum number of leaves in maize (12.1) was obtained in plots that were given N at the rate of 180 kg ha^{-1}, while the minimum number of leaves was recorded by 100 kg ha^{-1}. Sunita *et al* (2018) found that the application of graded doses of fertilisers increased the green leaves count in sorghum.

Stem girth

As per recordings mentioned in Table 2 in strips I, II,

Table 2. Effect of graded nutrient levels on growth attributes of the exhaust crop fodder sorghum in a soil fertility gradient experiment

Strips	Plant height (cm)		Green leaves plant^{-1}		Stem girth (mm)		SCMR	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
I	62.4^{c} ± 0.92	146.8^{c}± 2.26	6.8^{c} ± 0.08	8.7^{c} ± 0.15	9.6^{c} ± 0.13	14.1^{c}± 0.22	23.2^{c}± 0.08	32.1^{c} ± 0.27
II	104.8^{b}± 1.32	189.3^{b}± 2.84	9.5^{b} ± 0.13	14.6^{b}± 0.26	14.3^{b} ± 0.17	22.8^{b}± 0.53	26.5^{b}± 0.23	39.7^{b} ± 0.33
III	120.2^{a}± 2.12	211.3^{a}± 3.30	11.3^{a}± 0.17	16.2^{a}± 0.35	15.2^{a} ± 0.27	23.6^{a}± 0.68	28.4^{a}± 0.57	43.8^{a} ± 0.58
C V	3.80	3.88	2.06	2.99	1.86	1.66	2.26	3.24
CD ($P<0.05$)	8.26	16.23	0.71	0.66	0.55	0.75	1.33	2.82

Values are means standard deviation (±SD) of three independent replications (n=3). Different letters within the column indicate statistically significant differences between treatments, according to Ducans multiple range test (P< 0.05). CV=coefficient of variation. CD is critical difference.

and III, the stem girth was 9.6, 14.3, and 15.2 mm, at 30 DAS whereas 14.1, 22.8 and 23.6 mm at 60 DAS, respectively. The stem girth at 30 DAS increased by 58.33, 4.1 % and at 60 DAS 67.3, 3.5 % above strips I and II, respectively, in strip III, when N, P_2O_5, and K_2O were treated at double the rate of strip II. In stem girth, there was a significant disparity between the strips caused by the change in the graded fertiliser dosages. The results of present study are in close conformity with the findings of Chauhan *et al*. (2019), where by application of 100% RDF stem girth recorded was 26.11 mm. The outcomes of the present study represent a clear affirmation by the findings of Muhammad Aamir Iqbal *et al*. (2015) in maize, where highest stem diameter was recorded in the plot receiving a high amount of nitrogen (180 kg ha^{-1}).

Sorghum's greatest growth performance with increased N rates is attributable to soil enrichment with greater levels of N-nutrients, which supplied sufficient N-nutrient and also made other sorbent and non-available nutrients that are crucial for various processes available (Adebola and Erick, 2019). In addition to the diameter growth brought on by raising the nitrogen fertiliser levels, Abdulsattar Hashim Ghani *et al*. (2022) showed a change in the characteristic of the stem diameter for sorghum crops.

SCMR (SPAD chlorophyll meter reading)

The SCMR values (Table 2) varied significantly from 23.2 to 43.8 between the two growth phases. When comparing with 30 DAS as 60 DAS showed high SCMR values *i.e.*, 32.1, 39.7 and 43.8 in strip I, II & III, correspondingly. Among the three strips the strip receiving 180, 200 and 160 kg ha^{-1} dose of fertilizer N, P_2O_5 & K_2O recorded the highest spade values of 28.4 and 43.8 at 30 & 60 DAS, respectively. Regarding nitrogen application done at basal and two top dressings, this evidence demonstrates that SCMR values of hybrid sorghum increased with higher doses of nitrogen application and extended split applications up to 60 days after sowing. The extended split application of this maintains SCMR values at higher levels than those with a lower dose of nitrogen. Varshini and Babu (2020) found out that the same kind of SCMR results in hybrid maize by applying nitrogenous fertilisers.

According to Darwin et al. (2018) , 450 kg ha^{-1} of urea fertiliser can still boost sweet corn's SPAD chlorophyll content. Increased levels of chlorophyll suggested that the inorganic nitrogen fertiliser (urea) could be absorbed by plant roots and utilised to generate more chlorophyll. The greater the urea fertiliser dose, the higher the SPAD value in the leaves.

Green fodder yield

According to the findings (Table 3), N, P, and K levels substantially impacted the yield of green fodder. The production of green fodder was greatly increased by raising the fertiliser's N, P_2O_5, and K_2O levels compared to the control. Sorghum produced 16.40 t ha^{-1} of green fodder in strip I (N0P0K0) without the use of fertilisers. The fodder production in strip II, which was 42.6 % greater than in strip I, was achieved by applying nitrogen at 90 kg ha^{-1} (the blanket guideline) and phosphorus and potassium fertilisers in amounts corresponding to the soil's P and K fixing capabilities. The yield in strip III, which had twice as much N, P_2O_5, and K_2O applied as in strip II, was 28.2 t ha^{-1}, an increase of 71.9 and 20.5% over strips I and II, respectively. It could be because applying fertiliser at graduated levels improved the uptake of nutrients and growth factors, including plant height, eventually leading to higher overall green yields.

Singh *et al*. (2019) reported more evidence of increased grain and straw yields in sorghum crop treated with graded levels of fertilisers. The significant influence of N on enhancing plant development characteristics may be the cause of the increase in green and dry fodder yields of sorghum following N treatment (Singh *et al*., 2015). Additionally, Goyal and Bhardwaj, (2020) demonstrated a favourable impact of nitrogen fertilisation on the fodder output of sorghum. The current study's findings in sorghum and the findings by Singh (2020), and Singh (2014) in sorghum crops are quite similar because of fodder yield. This may be because more soil nutrients are available due to higher levels of N, P, and K fertilisers and because N, P, and K nutrients promote the growth of fodder crops. Rashid and Iqbal (2012) on fodder sorghum and Alias *et al*. (2003) on fodder maize both came to similar conclusions. Meena *et al*. (2012) also stated that hybrid sorghum's green fodder output significantly increased when N levels were raised from 40 to 120 kg ha^{-1}.

Nutrient uptake

The total nitrogen uptake by the crop was reported as 38.5 kg ha^{-1} in strip I, 58.7 kg ha^{-1} in strip II, and 75.6 kg ha^{-1} in strip III, according to nutrient concentration in plants measured in terms of total uptake by sorghum. With the addition of the recommended fertiliser dose (strip II) and the twofold recommended dose (strip III), the response to the uptake of nutrients was 30.7% and 17.6% over strip I, respectively. Similarly, total phosphorus uptake by sorghum was highest (20.5 kg ha^{-1}) in strip III, followed by 16.3 kg ha^{-1} in strip II, and lowest (11.8 kg ha^{-1}) in strip I. Strip III had the highest total K uptake 73.4 kg ha^{-1}, followed by Strip II with 55.6 kg ha^{-1}, and Strip I had the lowest of 36.7 kg ha^{-1}. Compared to the control (strip I), strip III and II increased phosphorus and potassium uptake of 73.7, 38.1 and 99.8, 32 %, respectively (Table 3). Higher levels of phosphorus treatment, which would have resulted in more root proliferation of the crop, were the cause of the increase in phosphorus uptake (Udayakumar *et al*., 2017).

Additionally, the % increase in potassium uptake was lower in all treatments, which may be related to the experimental site's high availability of K. As a result, the difference between the recommended and double-recommended fertiliser doses was less when compared to the control. According to Vijay Kant Singh *et al*. (2020), increasing the level of N up to 200 kg N ha^{-1} considerably boosted plant height, N, P, and K uptake by wheat. The findings from the present work in view of nutrient uptake are similar to those reported in sorghum by Sonune *et al*. (2010) and Singh (2014) and in rice by Maragatham *et al*. (2018).

Post- harvest soil test values

Before the main experiment's test crop was sown, the average soil test results in table 4 for available N, P, and K revealed that the fertility gradients regarding those nutrients were well-developed in various field strips throughout (Fig 1). The soil's available N, P, and K between strips I and III increased. The average soil test result for available nitrogen (Alkaline-$KMnO_4$-N) was 155 kg N ha^{-1}, 190 kg N ha^{-1}, and 214 kg N ha^{-1} in strips I, II, and III, respectively. The average amount of soil phosphorus that was readily available was 12.5 kg ha^{-1} in strip I, 23.2 kg ha^{-1} in strip II, and 31.8 kg ha^{-1} in strip III. In strips, I, II, and III, the average soil test value for available potassium was 332 kg K ha^{-1}, followed by 370 kg K ha^{-1}, and 396 kg K ha^{-1}. Strip III had the highest alkaline $KMnO_4$-N, Olsen's-P, and NH_4OAc-K soil test values, followed by Strip II, while Strip I had the lowest values. A noticeable rise in the fertility gradient build-up regarding the available N, P, and K was observed from strip I to strip III. The available N, P, and K declined from its beginning value in the control treatment (strip I). This might result from residual N, P, and K uptaken by the crop, leading to a drop. There was a steady improvement in the soil's nutrient availability status about N, P, and K after applying the recommended amount of fertilisers. This could result from fertiliser treatment in graded dosages, which increased N, P, and K availability in the soils while simultaneously boosting uptake.

The availability of these nutrients increased significantly when fertiliser dosages were increased, doubling the RDF and as a result, fertility gradients for N, P, and K were detected. Udayakumar and Santhi (2017) also reported on this type of clearly defined fertility gradient build-up by an initial fertility gradient experiment. The data of the present studt showed that the soil test values for the available nutrients showed significant variability. Alkaline $KMnO_4$-N, Olsen's-P, and NH_4OAc-K in strip III above strip I were found to have fertility gradient differences of 30.9, 45.6, and 26.9 %, respectively. For alkaline $KMnO_4$-N, Olsen's-P, and NH_4OAc-K in strip II above strip I, it was 8.6, 20.4, and 8.4 %, respectively. The findings of the present study on sorghum support the conclusion made by Kaushik *et al*. (2015) on raddish about the higher post harvest soil test values after the crop harvest due to the application of graded levels of fertilizers.

Soil enzymes activity

Urease activity

The amount of microbes is correlated with soil enzyme activity. Due to the close connection between soil nutrients and soil enzyme activity, soil enzymes serve as a crucial indication of the soil's natural fertility.

Soil urease catalyzes, the hydrolysis of urea into ammonical form, which is then oxidised by nitrifiers to nitrate form, in large part. This boosts the utilisation rate of nitrogen fertiliser. As per data in Table 5, Strip III had the highest urease activity 25.6 µg NH_4 g^{-1} hr^{-1}, which differs significantly with other strips. The lowest urease activity (16.8 µg NH_4 g^{-1} hr^{-1}) was seen in strip I, which received no fertilisers. Whereas strip II receiving general recommended dose of nitrogen, P & K as per the fixing capacities of soil, showed 24.1 µg NH_4 g^{-1} hr^{-1} of urease activity. The increasing order of urease activity

Table 4. Effect of application of graded levels of N, P_2O_5 and K_2O on soil fertility status of gradient experiment

Strip	Fertiliser doses (kg ha^{-1})			Green fodder yield (t ha^{-1})	Nutrient uptake (kg ha^{-1})		
	N	**P_2O_5**	**K_2O**		**N**	**P**	**K**
I	0	0	0	16.40^c ± 0.11	38.5^c ± 0.87	11.8^c ±0.16	36.7^c ± 0.38
II	90	229	97	23.40^b ± 0.36	58.7^b ± 1.23	16.3^b ± 0.24	55.6^b ± 0.59
III	180	458	194	28.20^a ± 0.61	75.6^a ± 1.37	20.5^a ± 0.57	73.4^a ± 1.21
CV				2.92	3.71	3.06	2.25
CD (P< 0.05)				1.50	4.84	1.12	2.81

Values are means standard deviation (±SD) of three independent replications (n=3). Different letters within the column indicate statistically significant differences between treatments, according to Ducans multiple range test (P< 0.05). CV=coefficient of variation. CD is critical difference.

is strip I < strip II < strip III. The increasing availability of the substrate N (urea) may be the cause of the rise in urease activity with N levels as urea is applied in two splits. Mageshen *et al*. (2019) reported that STCR based fertilizer application showed significant urease activity compared to unfertilized plots. The above-mentioned results of the present study were in accordance with the findings of Sun *et al*. (2020) that the use of urea boosted the rhizosphere urease activity in the middle and late filling stages of wheat, which was advantageous for increasing grain production and the effectiveness of nitrogen uptake.

Phosphatase activity

Phosphatases are large categories of enzymes that may catalyse the hydrolysis of phosphoric acid esters and anhydrides. Mineral fertilisers significantly enhanced alkaline phosphatase activity (Table 5) compared to controls. Its maximum value, a 32.7% increase above control, was seen in the soil from strip III. Low activity of phosphatase (22.3 µg P-NP g^{-1} hr^{-1}) was noticed in the control (strip I). Whereas the phosphate activity of strip II is 28.2 µg P-NP g^{-1} hr^{-1}.

This could be due to applying nutrients in readily available form enhanced root growth and release of root exudates that contain a wide spectrum of carbon-containing metabolites. These served as a carbon source for the microbes. As a result, it stimulated the phosphatase activity.

Similar results were experienced by Ekta Joshi *et al*. (2021) in comparison to no fertiliser treatment, the use of all nutrients considerably boosted the alkaline phosphatase enzyme activity in soil following crop harvest. Supplying major nutrients in adequate quantity improves the root biomass and rhizosphere, leading to more root exudate release and higher microbial and phosphatase activity in soil of maize crop. In a research on maize, soil phosphatase activity was shown to be greatly boosted by adding nitrogen fertiliser (Song *et al*., 2020), which was found to be similar to the present study on sorghum that soil phosphatase activity was found to be high in plots receiving high amount of nitrogen @ 180 kg ha^{-1}.

Dehydrogenase activity

The soil's metabolic state or the microbial community's biological activity appeared to have a greater impact on dehydrogenase activity than any free enzymes present. Dehydrogenase is an indicator of soil microbial activity, and its levels are highly impacted by the presence of nitrate, which acts as an alternative electron acceptor and lowers activities (Raghavendra *et al*., 2018). An important biochemical indicator is dehydrogenase activity. After harvest of fodder sorghum it ranged from 17.6 to 31.9 µg TPF g^{-1} day^{-1}. The dehydrogenase activity (Table 5) was 17.6, 27.5 and 31.9 µg TPF g^{-1} day^{-1} in strip I, II & III, respectively. The increase of dehydrogenase activity in strip III over strip I is 81.2%.

The results further clearly revealed that increased dehydrogenase activity is due to the increased doses of

Table 5. Effect of application of graded levels of N, P_2O_5 and K_2O on soil enzyme activities and soil microbial biomass carbon

Parameters	**Urease**	**Phosphate**	**Dehydrogenase**	**Microbial biomass**
Strips	**(µg NH_4 g^{-1} hr^{-1})**	**(µg P-NP g^{-1} hr^{-1})**	**(µg TPF g^{-1} day^{-1})**	**carbon (MBC) (µg g^{-1})**
I	16.8^c ± 0.26	22.3^c ± 0.51	17.6^b ± 0.37	80.2^c ± 1.68
II	24.1^b ± 0.43	28.2^b ± 0.71	27.5^b ± 0.73	129.7^b ± 2.34
III	25.6^a ± 0.78	29.6^a ± 1.12	31.9^a ± 0.87	146.4^a ± 4.62
CV	1.25	3.32	2.51	2.18
CD ($P< 0.05$)	0.62	2.01	1.45	5.87

Values are means standard deviation (±SD) of three independent replications (n=3). Different letters within the column indicate statistically significant differences between treatments, according to Ducans multiple range test ($P< 0.05$). CV=coefficient of variation. CD is critical difference.

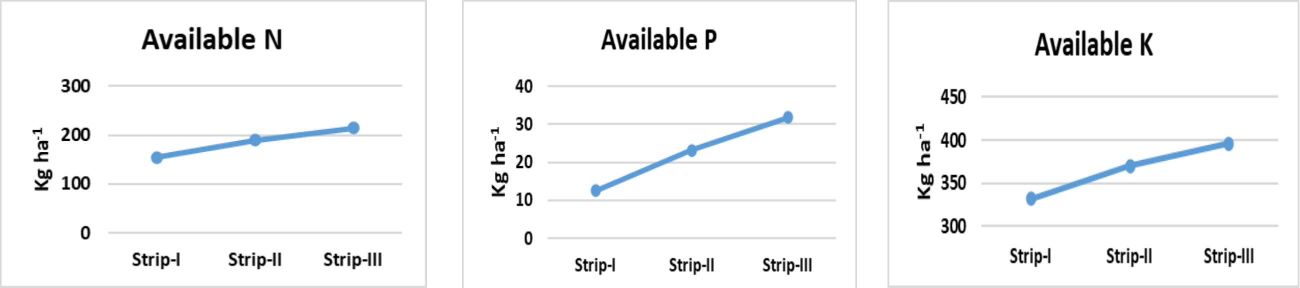

Fig. 1. *Experimental field's fertility gradient in relation to available N, P, and K in soil*

the fertilizer application. It was also found that dehydrogenase activity was lower if no soil fertilizer was applied. The results were in accordance with Sarita *et al*. (2022) in STCR alone treated plots in calcareous soil under rice-based cropping system. Application of fertilisers increased DHA. At the flowering and harvest stages, higher dehydrogenase activity was detected in the soil test-based fertiliser treatment, and this was comparable to the DHA detected in 100% RDF. Applying the macro elements increased dehydrogenase activity, which was most likely caused by the activity and growth of the rhizosphere (Bednarz and Krzepilko, 2009).

Microbial biomass carbon (MBC)

Soil microbial biomass, a living component of soil organic matter, functions as a labile reservoir for plant-available N, P, and S and acts as a transformation agent for both added and native organic matter. The data in Table 5 shows Strip III had the highest MBC 146.4 µg g-1, which differd significantly from other strips. The lowest MBC (80.2 µg g^{-1}) was seen in strip I, which received no fertilisers. Whereas strip II receiving general recommended dose of nitrogen, P & K, as per the fixing capacities of soil showed 129.7 µg g^{-1} of MBC. The increasing order of MBC was strip I < strip II < strip III. It is possible that by providing nutrients in easily obtainable form, root development will be boosted and root exudates containing various metabolites, including carbon, will be released. These provide the microorganisms with a carbon supply, increasing MBC and this could be the reason for the increasing in the MBC in strip III when compared to strip I and this result was supported by the conclusion of Zhang *et al*. (2019) who reported from incubation experiment by using artificial root (Rhizon) that increased NPK fertilisation increases soil MBC without having a negative impact because plant roots can release extracellular enzymes, they may also encourage the activity of soil microbes.

The results on the soil MBC (strip I < strip II < strip III) in present investigation on sorghum are also similar to the findings of Shuaimin *et al*. (2019) on wheat crop, where he mentioned that secretion of organic acids might be a strategy developed by plants to recruit beneficial microbes in the root zone to cope with high N input.

Conclusion

In conclusion, applying graded levels of N, P, and K fertilisers developed an artificial soil fertility gradient in the experimental field in semi-arid region of Tamil Nadu. The average soil test result for available nitrogen (Alkaline-$KMnO_4$-N) was 155 kg N ha^{-1}, 190 kg N ha^{-1}, and 214 kg N ha^{-1} in strips I, II, and III, respectively. The average amount of soil phosphorus that was readily available was 12.5 kg ha^{-1} in strip I, 23.2 kg ha^{-1} in strip II, and 31.8 kg ha^{-1} in strip III. In strips I, II, and III, the average soil test value for available potassium was 332 kg K ha^{-1}, followed by 370 kg K ha^{-1}, and 396 kg K ha^{-1}. The green fodder yield of fodder sorghum in strip III increased 71.9% and 20.5% over strips I and II, respectively. This shows a significant influence of the application of graded N, P & K fertiliser doses on post-harvest soil fertility status, nutrient uptake, green fodder yield, soil enzymes activity and growth attributes of sorghum (*Sorghum bicolor*).

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Abdulsattar Hashim, Ghani, A., Mohamed Hussein Hamza & Ali Kareem Hussein. (2022). The Effect of Different Levels of Nitrogen Fertilizer on Some Growth Characteristics of three Cultivars of (Sorghum) *Sorghum Bicolor*.L. *Natural Volatiles & Essential Oils*, 9(2), 397-405.
2. Adebola Ajidahun & Erick Sebetha. (2019). Effects of cultivars, nitrogen fertilizer and plant density on yield and yield components of sorghum. *Research on crops*, 20(2), 275-284. DOI : 10.31830/2348-7542.2019.040
3. Arvind Kumar Shukla, Sanjib Kumar Behera, Chaudhari, S. K. & Gajendra Singh. (2022). Fertilizer Use in Indian Agriculture and its Impact on Human Health and Environment. *Indian Journal of Fertilisers*. 18 (3), 218-237.
4. Alias, A., Usman, M., Ullah, E. & Waraich, E.A., (2003). Effects of different Phosphorus levels on the growth and yield of two cultivars of maize (*Zea mays* L.). *International Journal of Agriculture and Biology*. 5(4), 632-634.
5. Almodares, A. & Hadi, M.R., (2009). Production of bioethanol from sweet sorghum: a review. *African Journal of Agricultural Research*, 4(9), 772–780.
6. Bednarz, B. S. & Krzepilko, A., (2009). Effect of different fertilization on enzyme activity in rhizosphere and non-rhizosphere of Amaranth. *International Agrophys*, 23, 409-412.
7. Singh, B. (2016). Site-specific nitrogen management in cereals in India. *Indian Journal of Fertilisers.* 12(4), 46- 57.
8. Chauhan Aditi, Sonal Tripathi, Narendra Singh, Lokesh Saini & Govind. (2019). Effect of fertilizer levels, biocompost and biofertilizer on growth and yield attributes of fodder sorghum (*Sorghum bicolor* (L.) Moench). *Journal of Pharmacognosy and Phytochemistry*. 8(6), 617-620.
9. Darwin Habinsaran Pangaribuan, Kus Hendarto, Sheilla, R., Elzhivago & Ade Yulistiani. (2018). The effect of organic fertilizer and urea fertilizer on growth, yield and quality of sweet corn and soil health. *Asian Journal Agriculture & Biology*, 6(3), 335-344.
10. Department of Agriculture cooperation and farmers welfare (2021). Annual report 2020-2021. Retrieved from https://agricoop.nic.in/Documents/annual-report-2020-21.pdf
11. Department of Economics and Statistics. (2021). Statisti-

cal hand book of Tamil Nadu 2020-21. Retrieved from https://www.tn.gov.in/deptst/agriculture.pdf

12. Ekta Joshi, Vyas, A.K., Shiva Dhar, Anchal Dass, Sasode, D.S., Kailash Prajapati, Dinesh Jinger, Vibha Singhal, Gaurendra Gupta & Dasharath Prasad. (2021). Soil microbial biomass carbon and soil enzymatic activity under nutrient omission plot technique in maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*, 66 (2), 170-179.
13. Goyal, V. & Bhardwaj, K.K., (2020). Studies on creation of soil fertility gradients with respect to N, P and K in Inceptisols of semi-arid regions of Haryana. *Haryana Agric. Univ. J. Res.,* 50. 15-19.
14. Hanway, J.J. & Hiedal, H., (1952). Soil analysis method used in Iowa State Soil Testing Laboratory, Iowa Agric. *Ameri. Soc. Agron*., 57, 1025-1027.
15. Jackson, M. L. (1967). Soil chemical analysis. Prentice Hall of India (P) Ltd., New Delhi.
16. Joseph Xorse Kugbe, Ayamba Michael Mbawuni & Agyiri Wisdom. (2019). Growth, Yield and Yield Components Response of Local Sorghum Varieties to Nitrogenous Fertilizer Rates in Northern Ghana. *World Journal of Agriculture and Soil Science*, 3(4).DOI: 10.33552/WJASS.2019.03.000574.
17. Kaushik Batabyal, Dibyendu Sarkar & Biswapati Mandal. (2015). Fertilizer-prescription equations for targeted yield in radish under integrated nutrient management system. Journal of Horticultural Sciences, 10(1), 18-23.
18. Khosa, M.K., Sekhon, B.S., Mavi, M.S., Benipa, D.S. & Benbi D.K., (2012). Performance of target yield based fertiliser prescription equations in rice-wheat cropping system in Punjab. *Indian Journal of Fertilisers*. 8(2), 14-18.
19. Mageshen, VR., Bagavathi Ammal, U., Sankar, R. & Pradip Dey. (2020). Effect of varying fertilizer doses and soil test crop response based integrated plant nutrient system on enzyme activity in Bahour soil series of Puducherry. *The Pharma Innovation Journal*, 9(7), 452-455. DOI: https://doi.org/10.22271/tpi.2020.v9.i7g.4969.
20. Maragatham, S., Santhi, R., Sellamuthu, K.M. & Pradip Dey., (2018). Yield Targeting for Rice under SRI on Alfisols of Tamil Nadu through Soil Test based Integrated Plant Nutrition System,*Int.J.Curr.Microbiol.App.Sci*.,7 (08),11341143.doi:https://doi.org/10.20546/ijcmas.2018.708.129.
21. Meena, A.M, Pushpendra Singh & Pushpa Kanwar. (2012). Effect of nitrogen levels on yield and quality of [*Sorghum bicolor* (L.) Moench] sorghum genotypes. *Forage Research*, 37(4), 238-240.
22. Moghimi, N. & Emam, Y. (2015). Growth and yield responses of two forage sorghum cultivars to different nitrogen fertilizer rates. *Iran Agricultural Research*, 34(1), 39-45. DOI: 10.22099/iar.2015.3041
23. Muhammad Aamir Iqbal, Zahoor Ahmad, Qaiser Maqsood, Sher Afza & Mian Munir Ahmad. (2015). Optimizing Nitrogen Level to Improve Growth and Grain Yield of Spring Planted Irrigated Maize (*Zea mays* L.). *Advanced Botany and Zoology*, 2(3).DOI: 10.15297/JABZ.V2I3.02.
24. Muhammad Aamir Iqbal, Zahoor Ahmad, Qaiser Maqsood, Sher Afzal & Mian Munir Ahmad. (2015). Optimizing Nitrogen Level to Improve Growth and Grain Yield of Spring Planted Irrigated Maize (*Zea mays* L.). *Journal of Advanced Botany and Zoology*, 2(3). DOI: 10.15297/JABZ.V2I3.02.
25. Mwadalu, R., Mochoge, B., Mwangi, M., Maitra, S. and Gitari, H. (2022). Response of Gadam Sorghum (*Sorghum Bicolor*) to Farmyard Manure and Inorganic Fertilizer Application. *Int. J. Ag. Env. Biotech,* 15(1), 51-60. DOI: 10.30954/0974-1712.01.2022.6
26. Olsen, S.R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture.
27. Parbati, A., Bandhu, R.B. & Jiban, S. (2016). Maize response to time of nitrogen application and planting seasons. *Journal of Maize Research and Development*, 2(1), 83-93. DOI: http://dx.doi.org/10.3126/jmrd.v2i1.16218
28. Raghavendra, K., Rao, N., Swamy, M. & Wani, S.P. (2018). Influence of nutrient management approaches on soil enzyme activity, soil microbial population and grain yield of dry direct-seeded rice. *International Journal of Current Microbiology and Applied Science*, 7(6), 2,558–2,567. DOI: https://doi.org/10.20546/ijcmas.2018.706.302
29. Ramamoorthy, B., Narasimham, R. & Dinesh, R. (1967). Fertilizer application for specific yield targets on Sonora 64 (wheat). *Indian Farming*. 17: 43-45.
30. Rashid and Iqbal, M. 2011. Response of sorghum (*Sorghum bicolor* L.) fodder to phosphorus fertilizer on torripsamment soil. The J. Animal Plant Sci., 21(2), 220-225.
31. Redai Weldegebriel, Tesfay Araya & Yemane G.Egziabher. (2018). Effect of NPK and Blended Fertilizer Application on Nutrient Uptake and Use Efficiency of Selected Sorghum (*Sorghum bicolor* (L.) Moench) Varieties Under Rain-fed Condition in Sheraro District, Northern Ethiopia. *Momona Ethiopian Journal of Science*, 10(1), 140-156. http://dx.doi.org/10.4314/mejs.v10i1.8.
32. Choudhary Sarita, Pradeep Kumar, Santosh Yadav, Prakash Chand Gurjar, Ajit Kumar Meena, Seema Pooniyan, Jaipal Yadav, Suman Dhayal & Suman Dhaka. (2022). Effect of long term continuous application of STCR based fertilizer in calcareous soil on soil properties under rice based cropping system. *The Pharma Innovation Journal*, 11(4), 1871-1874.
33. Shuaimin, C., Tatoba, R., Waghmode, Ruibo Sun, Eiko, E., Kuramae, Chunsheng Hu and Binbin Liu. (2019). Root-associated microbiomes of wheat under the combined effect of plant development and nitrogen fertilization. Microbiome*,* 7,1-13. https://doi.org/10.1186/s40168-019-0750-2
34. Singh, Y.V. (2014). STCR based gradient experiment with sorghum (*Sorghum biocolar* L.) to NPK fertilizers in the alluvial soil. *Indian J. Crop Ecol*., 2(2), 83-86.
35. Singh, Y.V., Shiva, A.M. & Dey, P. (2015). Soil test crop response based gradient experiment on rice (*Oryza sativa* L.) to NPK fertilizers in the alluvial soil of the Indo-Gangetic plains. *Crop Res*., 50(1, 2&3), 9-11.
36. Song, D., Chen, L., Zhang, S., Zheng, Q. & Wang, X. (2020). Combined biochar and nitrogen fertilizer change soil enzyme and microbial activities in a 2-year field trial. *Eur. J. Soil Biol*, 99, 103212. https://doi.org/10.1016/j.ejsobi.2020.103212
37. Sonune, B.A., S.S. Rewatkar, Prerana Gadge, & Gabhane, V.V. (2010). Effect of nitrogen levels on yield

and quality of [*Sorghum bicolor* (L.) Moench] sorghum genotypes. *Ann. Plant Phys.,* 24, 33-37.

38. Subbaiah, B. (1956). A rapid procedure for estimation of available nitrogen in soil. Current Science, 25: 259-260.
39. Sujathamma, P., Kavitha, K. & Suneetha, V. (2015). Response of Grain Sorghum (*Sorghum bicolor* L.) Cultivars to different fertilizer levels under rainfed condition. *International Journal of Agricultural Sciences,* 5 (1), 381-385.
40. Sun, W., Liu, S., Feng, J., Wang, P., Ma, D., Xie, Y., Lu, H. & Wang, C. (2020). Effects of water and nitrogen source types on soil enzyme activity and nitrogen utilization efficiency of wheat. *China Journal of Applied Ecology*, 31, 2583–2592. DOI: 10.13287/j.1001-9332.202008.023
41. Sunita Rani, Geeta Kandpal, Mansukh Singh Jatana & Gurwinder Singh. (2018). Effect of Different Fertilizers on Growth Parameters of Sorghum (*Sorghum bicolor*). *Int.J.Curr. Microbiol.App.Sci*, 7(06),2086-2091.doi: https://doi.org/10.20546/ijcmas.2018.706.246.
42. Timu, A.G., Mulwa, M.R., Okello, J. & Kamau, M. (2012). The role of varietal attributes on adoption of improved seed varieties. The case of sorghum in Kenya. Tegemeo Institute of agricultural policy development, Nairobi, Kenya.
43. Udayakumar, S. & Santhi, R. (2017). Impact of Artificial Soil Fertility Gradient Strategy on Soil Fertility, Nutrient Uptake and Fodder Yield of Sorghum. *Int. J. Curr. Microbiol. App. Sci.*, 6(3), 938-944. http://dx.doi.org/10.20546/ijcmas.2017.603.111
44. Varshini, S.V. & Babu, R. (2020). Influence of graded levels and split application of nitrogen on growth and physiological attributes of hybrid maize. *The Pharma Innovation Journal*. 9(12), 180-184. DOI: https://doi.org/10.22271/tpi.2020.v9.i12c.5432
45. Vijay Kant Singh, Poonam Gautam, Sobaran Singh, Navneet Pareek & Singh. V. P. (2020). Evaluation of soil fertility gradient experiment on the basis of crop yield, nutrient uptake and soil fertility. *Int. J. Curr. Microbiol. App. Sci*, 9(02), 2435-2440. doi: https://doi.org/10.20546/ijcmas.2020.902.278.
46. Walkley, A. & Black, C.A. (1934). An examination of degtjareff method for determining soil organic carbon and a proved modification of chromic acid titration method. *Soil Sci.*, 37: 29-38.
47. Zhang, X., Dippold, M.A., Kuzyakov, Y. & Razavi, B.S. (2019). Spatial pattern of enzyme activities depends on root exudate composition. *Soil Biol. Biochem*, 133, 83–93. https://doi.org/10.1016/j.soilbio.2019.02.010