Original Research Article

Effects of artificial soil fertility gradient strategy on the soil fertility,nutrient uptake and growth attributes of Chakravarthi keerai (*Chenopodium album*)

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ABSTRACT

The application of artificial soil fertility gradient techniques on crop growth attributes, nutrient uptake, soil fertility and soil biological properties on three strips were studied in a field trial conducted in 2023 at a horticulture research station in the Ooty area. It was done using an inductive methodology. The field was split into three equal strips, with three graded levels of N fertilizer (Urea), P_2O_5 fertilizer (Single Super phosphate) and K_2O fertilizer (Muriate of Potash) applied to strip I ($N_0P_0K_0$), II ($N_1P_1K_1$) and III ($N_2P_2K_2$). The N_1 level has been determined on the basis of the Chakravarthi keerai blanket recommendation, while the P_1 and the K_1 levels have been determined based on the fixing capacity of the soil phosphorus (250 kg ha^{-1}) and the potassium (100 kg ha^{-1}). Gradient crop, Ooty 1 was cultivated and green yield Chakravarthi keerai was observed at the time of harvesting. At the time of harvesting, plant samples were taken and examined for N, P & K content and the uptake of N, P & K was calculated. The results showed that graded levels of fertilizer N, P_2O_5, K_2O had a significant impact on soil fertility status and NPK uptake, as well as plant growth parameter Chakravarthi keerai. The article clearly shows a significant influence of the Organic Carbon, Chlorophyll content, soil enzymes activity, Microbial population, and Microbial biomass carbon.

Keywords: Chenopodium Album, Fertility Gradient, Soil Enzymes, Biomass Yield

1. INTRODUCTION

A unique field experimental approach (Inductive methodology) as followed in the All India Coordinated Research Project for Investigation on Soil Test Crop Response Correlation studies which has been evolved through creating a macrocosm of soil fertility variability within a microcosm of an experimental field (Ramamoorthy et al. 1967) by applying graded doses of fertilizers has been followed. This forms a basis for carrying out Soil Test Crop Response (STCR) studies which help to generate fertilizer prescription equations and calibration charts for recommending fertilizers on the basis of soil tests and achieving targeted yield of crops.

Chakravarthi keerai, also known as Indian Spinach, is a popular leafy green vegetable in South India. In India, the crop is predominantly cultivated in the northern region, where the winter climate is ideal. However, in southern India, it thrives year-round and is popularly consumed as a leafy vegetable. In Tamil Nadu, it is widely referred to as 'Paruppu keerai' or 'Chakravarthi keerai'. The plant is cultivated for multiple uses, including as a food source, animal feed, and for its therapeutic properties in various Asian and African nations. The crop has recently garnered global recognition for its nutritional benefits. From an economic perspective, the foliage and stalks are utilized as vegetables, either fresh or prepared, while the young leaves feature prominently in numerous Indian recipes. The seeds are also consumed as a food ingredient and can be cultivated as a pseudo-cereal.

The leaves are abundant in vitamins A and C, essential oils, minerals such as potassium, and significant levels of proteins and nitrogenous compounds. It is known for its high nutritional value and is a staple in many traditional dishes. However, in order to grow healthy and robust Chakravarthi keerai, proper fertilisation is crucial. Fertilization is the process of adding essential nutrients to the soil in order to promote plant growth and health. These nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), are crucial for the development of strong roots, leaves, and stems. Without proper fertilisation, plants may struggle to grow and produce healthy yields. The objective of this investigation was to study the impact of artificial fertility gradient strategy on crop growth attributes, nutrient uptake, soil fertility and soil biological properties of Chakravarthi keerai.

2. MATERIAL AND METHODS

Ramamoorthy et al. (1967) proposed the methodology used in this study, which is known as the Inductive Cum Targeted yield model, to provide a scientific basis for fertilizing between applied and available forms of nutrients in a balanced manner. The operational range of variations in soil fertility was intentionally constructed to provide data covering an appropriate range of values at different levels of an uncontrollable variable, such as fertilizer dose, which cannot be expected at a single location. Therefore, a field experiment with a gradient crop is conducted to generate fertility variations within the same field, in order to minimize the variability in the soil pollution, management practices, and climatic conditions. In of the foregoing considerations, the objective of this study was to evaluate the impact of an Artificial Soil Fertility Gradient Strategy (AFG) on crop growth attributes, nutrient uptake, soil fertility and soil biological properties in the Chakravarthi keerai sub-region of Ooty District, Tamil Nadu. A field trial was conducted at the Horticulture Research Station located in the village of Doddapeta, Ooty 1, during the year 2023.

The field was split into three equal strips. The first strip did not receive any fertilizer ($N_0P_0K_0$). The second and third strips received fertilizer ($N_1P_1K_1$) and ($N_2P_2K_2$), respectively (table 1). The standard P_2O_5 fertilizer dosage and the standard K_2O fertilizer dosage were determined on the basis of the soil's phosphorus and potassium fixing capabilities. The standard N dosage is based on the blanket recommendation for gradient crops of Chakravarthi keerai (Table 1). The blanket recommended dose of fertilizer N for Chakravarthi keerai is 25 kg ha^{-1}. In strip II and III, 50% N and 100% P_2O_5 and K_2O were applied as basal and remaining 50% N was applied at 30 days after sowing. The fertilizer sources used were Urea, Single Super Phosphate and Muriate of Potash. Eight soil samples each at pre-sowing and post-harvest stages were collected from each fertility strip thus making a total of 24 samples, air dried and passed through 2 mm sieve and analysed for alkaline $KMnO_4$-N (Subbiah and Asija, 1956), bray-P (Bray and Kurtz, 1945) and NH_4OAc-K status (Hanway and Heidal, 1952). At harvest eight plant samples from each strip were collected, processed and analyzed for total N (Humphries, 1956), P and K (Piper, 1966) contents and uptake of N, P and K were computed. The gradient crop was harvested at 70 th day as fodder and strip wise green fodder yield was recorded. The wet oxidation method of Walkley and Black (1934) was used to determine by the Organic Carbon. The chlorophyll content of gradient crop determined by SPAD chlorophyll meter reading.

Table 1. Fertilizer doses applied to the gradient crop of Chakravarthi keerai

Strip	Levels of Nutrients			Fertilizer doses (kg ha^{-1})		
	N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
I	N_0	P_0	K_0	0	0	0
II	N_1*	P_1**	K_1**	25	250	100
III	N_2	P_2	K_2	50	500	200

* N_1:As per blanket recommendation, ** P_1 and K_1: As per P and K fixing capacities of the experimental field

2.1 Estimation of microbial population

Soil samples were collected at research field and analyzed for microbial population and enumeration was done using the serial dilution techniques of Parkinson et al. 1971. Soil microbial analysis was done for enumeration of bacteria, fungi and actinomycetes population using serial dilution 10^7, 10^4 and 10^3 respectively and in appropriate medium (Nutrient Agar, Rose Bengal Agar and Ken Knights Agar) in sterile plates. Enumeration was done after 24 hours for bacteria, 48 hours for fungi and six days for actinomycetes.

3. RESULTS AND DISCUSSION

3.1 Growth attributes

3.1.1 Plant height

Fertilization had a significant impact on plant height. Fertilization with different levels of N, P and K fertilizers increased the height of the Chakravarthi keerai plant (Table 2). Experiment result found that strip III had the highest average plant height at 72.00 cm, which had been fertilized twice with N, P, and K. It was 25% and 40.3% higher than strips II and I. The average plant height was 54.00 cm in strip II and 43.00 cm in strip I. The percentage of plant height that increase in strip II was 20.3%, which could be because of better nutrient uptake from Chakravarthi keerai and a higher fertility rate in strip II. As nitrogen levels increased, the plant height increased significantly. The increased plant height observed due to higher nitrogen levels was primarily due to increased availability and utilization of nitrogen by crop, resulting in increased vegetative growth and accelerated cell division, expansion, and differentiation, thus leading to luxuriant growth. Fodder sorghum's height growth has been shown as a result of N fertilisation according to Moghimi and Emam (2015).

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).

Fig. 1. Plant height of three different level fertilizer strips

3.1.2 Chlorophyll content

At harvest, the chlorophyll content of Chakravarthi keerai ranged from 40.45 to 47.82 across the three strips. The lowest mean value of gradient crop Chlorophyll content was observed in Strip I (40.45) which is 8.81 and 15.41 per cent lower than Strip II and Strip III respectively.

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

3.1.3 Leaf length, Leaf width and Petiole length

The morphological characteristics of Chakravarthi keerai (leaf length, width, and petiole length) showed significant variation across the three experimental strips, highlighting the potential influence of soil nutrient availability. Strip III recorded the highest mean values for leaf length (7.25 cm), width (5.62 cm), and petiole length (4.90 cm), likely due to superior soil nutrient status in this area. Studies have consistently shown that adequate levels of macronutrients such as nitrogen, phosphorus, and potassium, along with essential micronutrients, are vital for promoting vegetative growth and optimizing plant morphology (Lal et al., 2021).

The lower values in Strip I (leaf length: 3.33 cm, width: 3.01 cm, and petiole length: 1.87 cm) could be attributed to nutrient limitations or imbalances, potentially restricting physiological processes like photosynthesis and cell elongation. Intermediate growth in Strip II suggests a gradual improvement in soil nutrient status between the two extremes. Similar research has demonstrated that variability in soil fertility significantly impacts the growth parameters of leafy vegetables, underscoring the importance of site-specific nutrient management for optimal plant development (Patel et al., 2019).

3.1.4 Biomass yield

The analysis revealed a significant impact on green yield (Table 2) due to the increase in N, P, and K levels in the fertilizer compared to control. Green yield has been significantly increased due to an increase in fertilizer levels of N, P_2O_5 and K_2O. In strip I, where no fertilizers were applied, the green fodder yield was 11.56 tonnes per hectare (ha). In strip II, fertilizers were applied at a rate equal to the soil P and K fixing capacity and N 25 kilograms per hectare (kg/ha) (blanket recommendation), resulting in a green fodder yield of 23.74 tones per hectare (ha) (105.36 per cent higher than in strip I). Green fodder yield in Strip III was 27.14 t ha^{-1} which resulted in an increase of 134.77% over Strip I and 14.32% biomass over yield over Strip II. This could be because the fertilizer levels were graded, which made it easier for plants to take in nutrients and grow taller, which led to an increase in total green yields.

Verma et al., (2014) also found that application of graded level of fertilizers to gradient crop of rice recorded higher grain and straw yield. Udayakumar and Santhi (2017) the fact that graded levels of fertilizer application enhanced the nutrient uptake and growth parameters like plant height which ultimately reflected in increased total green yields.

Table 2. Effect of application of graded levels of fertilizer N, P_2O_5 and K_2O on plant height, chlorophyll content, leaf length , leaf width, petiole length and biomass yield of Chakravarthi keerai

Strip	Levels of Nutrients			Plant height (cm)	Chlorophyll content	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Biomass yield (t ha^{-1})
	N	P_2O_5	K_2O						
I	0	0	0	43.00	40.45	3.33	3.01	1.87	11.56
II	25	250	100	54.00	44.36	5.02	4.26	3.53	23.74
III	50	500	200	72.00	47.82	7.25	5.62	4.90	27.14
SEd				4.01	0.52	0.58	0.52	0.58	1.01
CD (*P*=0.05)				8.60	1.12	1.24	1.12	1.24	2.18

3.2 Nutrient uptake

There was a positive relationship between the quantity of fertilizer used and the levels of nitrogen, phosphorus, and potassium utilized by the plant. The mean nitrogen uptake values for each consecutive strip were 41.62, 89.42, and 100.43 kg ha^{-1}, respectively. Strip III showed a 12.3% higher nitrogen uptake compared to strip II and a 141.3% enhanced uptake compared to strip I, while strip II exhibited a 114.8% increase over strip I. Notable differences in phosphorus uptake were observed across the fertility strips, with average values of 10.97, 17.76, and 21.69 kg ha^{-1} for Strips I, II, and III, respectively. Potassium uptake in Strips I, II, and III was recorded at 61.33, 138.89, and 149.19 kg ha^{-1}, respectively. Phosphorus uptake was higher by 22.12% and 97.72%, while potassium uptake higher by 7.41% and 143.25% in strip III compared to strips II and I, respectively. Likewise, phosphorus and potassium uptake in strip II recorded an increase of 61.89% and 126.46% over strip I, respectively.

Udayakumar and Santhi (2017) report that exist a linear relationship between yield and uptake. It is evident from the present investigation that N, P and K uptake by crop was significantly influenced due to the application of graded levels of fertilizer N, P_2O_5 and K_2O over control and uptake of N, P and K increased with increasing levels of fertilizer doses. Singh et al., (2020) reported that graded levels of nutrient application enhanced nutrient uptake and growth parameters.

The results of this study demonstrate that the uptake of nitrogen, phosphorus, and potassium (N, P, and K) by feed Chakravarthi keerai is significantly affected when graded levels of nitrogen fertilizer (N_2O_5, K_2O) are applied in comparison to control levels, and the uptake of these nutrients increases with the amount of fertilizer applied. Verma et al., (2015) the significant rise in P uptake was caused by increased phosphorus application, which would have resulted in an increase in root growth in the crop. In addition, Singh et al., (2015) found that the use of graded N, P_2O_5, and K_2O fertilizer increased the uptake of N, P and K by rice crop. Siam et al., (2008) found a significant increase in plant height when the level of N was increased up to 140 kg N ha^{-1}. The significant increase in P uptake was due to higher levels of phosphorus application which would have led to higher root proliferation of the crop (Verma et al., 2015). Singh et al., (2015) also recorded that application of graded levels of N, P_2O_5 and K_2O fertilizers increased the N, P and K uptake by rice crop.

Table 3. Effect of application of graded levels of fertilizer N, P_2O_5 and K_2O on N, P and K nutrient uptake

Strip	Levels of Nutrients			Nutrient uptake (kg ha^{-1})		
	N	P_2O_5	K_2O	N	P	K
I	0	0	0	41.62	10.97	61.33
II	25	250	100	89.42	17.76	138.89
III	50	500	200	100.43	21.69	149.19
SEd				1.67	1.06	2.17
CD (*P*=0.05)				3.58	2.29	4.66

3.3 Organic carbon in post-harvest soil

The result of post-harvest soil organic carbon from 1.76 to 2.78 per cent with average value of 1.85, 2.24 and 2.47 per cent for strip I, strip II and strip III respectively. This different value found in three strips due to application of urea helps the decomposition. Crops with enhanced root biomass due to fertilization are likely to contribute more organic residues to the soil, resulting in increased organic carbon levels. These findings align with the studies of Bejbaruha et al., 2009.

Table 4. Effect of application of graded levels of N, P_2O_5 and K_2O on post-harvest soil Organic carbon

Strip	Levels of Nutrients			Organic Carbon (%)	Category
	N	P_2O_5	K_2O		
I	0	0	0	1.85	High
II	25	250	100	2.24	High
III	50	500	200	2.47	High
SEd				0.06	
CD (*P*=0.05)				0.13	

3.4 Available nutrient status of initial soil samples

A total of twenty-four soil samples, eight from each strip, were collected and analyzed for $KMnO_4$-N, Bray-P, and NH_4OAc-K prior to sowing the gradient crop (Chakravarthi keerai). The $KMnO_4$-N values ranged from 412 to 423 kg ha^{-1}, with mean values of 420, 412, and 423 kg ha^{-1}in strips I, II, and III, respectively. The Bray-P levels ranged from 181 to 190 kg ha^{-1}, with mean values of 185, 181, and 190 kg ha^{-1} for strips I, II, and III, respectively. The NH_4OAc-K values ranged from 500 to 548 kg ha^{-1}, with mean values of 548, 500, and 519 kg ha^{-1} for strips I, II, and III, respectively.

3.5 Available nutrient status of post-harvest soil samples

In order to gain an understanding of the impact of the application of fertilizers at graded levels on the formation of fertility gradients, post-harvest soil samples from Chakravarthi keerai were subjected to a mean of analysis for soil nutrients for $KMnO_4$-N, Bray-P and NH_4OAc-K. Table 5 showed the average values of the available soil nutrients.

The results of the post-harvest analysis revealed that the average post-harvest concentration of $KMnO_4$-N in the soil was 410 kg ha^{-1} for strips I, 432 kg ha^{-1} for strips II and 468kg ha^{-1} for strips III, as indicated in Table 5. The average Bray-P status for the strips I, II, and III was 178, 194, and 214 kg ha^{-1}, respectively. Furthermore, the average pre-harvest post-harvest value of NH_4OAc-K in soil for the three strips was 509 kg ha^{-1} in the I-strip, 550 kg ha^{-1} on the II-strip, and 620 kg ha^{-1} on the III-strip.

Table 5. Effect of application of graded levels of N, P_2O_5 and K_2O on soil fertility status of gradient experiment

Strip	Fertilizer doses (kg ha^{-1})			Pre-sowing soil test values			Post-harvest soil test values		
	N	P_2O_5	K_2O	$KMnO_4$- N	Bray-P	NH_4OAc-K	$KMnO_4$- N	Bray-P	NH_4OAc-K
					(kg ha^{-1})			(kg ha^{-1})	
I	0	0	0	420	185	548	410	178	509
II	25	250	100	412	181	500	432	194	550
III	50	500	200	423	190	519	468	214	620
						SEd	3.30	1.58	6.45
						CD (*P*=0.05)	7.09	3.39	13.84

The statistical analysis revealed that each strip was statistically distinct from the other, and the inclusion of graded amounts of nitrogen, phosphorus, and potassium fertilizers significantly increased the available soil N, P, and K state of the soil, thus demonstrating the different of soil fertility gradient in the experimental environment. Consequently, the presence of soil fertility gradient for all three primary nutrients was confirmed in the soil analysis data. Furthermore, the statistical analysis of the post-harvest soil test data revealed that there were considerable differences in the soil fertility status between the three strips. Udayakumar and Santhi (2017) found that variation in the strips with regards to soil fertility was prerequisite for calculating the basic parameters and fertilizer prescription equations for calibrating fertilizer doses for desired target yield of different crops. The results corroborate with the findings of Ahmed et al., (2015). 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

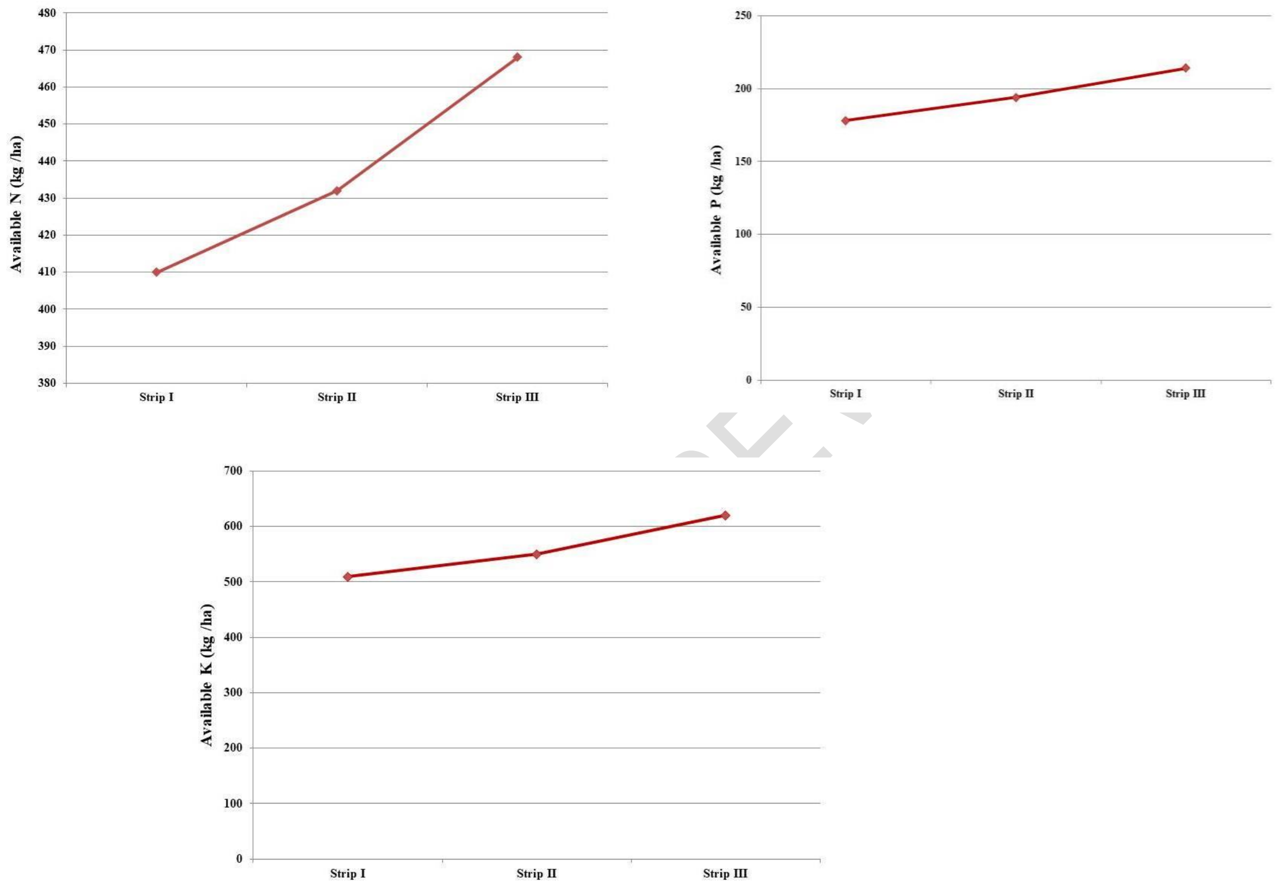

Fig. 2. Post-harvest fertility gradient of experimental fields in relation to available nitrogen, phosphorus, and potassium levels in the soil

3.6 Microbial population

Highest Fungi, bacteria and actinomycetes were obtained from strip III (44 cfu /dry soil , 13 cfu /dry soil and 17 cfu /dry soil) followed by strip II (36 cfu /dry soil, 11 cfu /dry soil and 16 cfu /dry soil) and least from strip I (31 cfu /dry soil, 8 cfu /dry soil and 13 cfu /dry soil) respectively. Microbial population 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).

Table 6. Effect of application of graded levels of N, P_2O_5 and K_2O on Microbial population and Biomass carbon

Strip	Levels of Nutrients N	P_2O_5	K_2O	Fungi (10^4)	Bacteria (10^7)	Actinomycetes (10^3)	Biomass carbon
				(cfu /dry soil)			mg of CO_2-C/100 g soil/hr
I	0	0	0	31.00	8.00	13.00	0.52
II	25	250	100	36.00	11.00	16.00	1.60
III	50	500	200	44.00	13.00	17.00	2.21
SEd				1.73	0.76	0.80	0.01
CD (*P*=0.05)				3.71	1.63	1.71	0.03

3.7 Soil enzymes

3.7.1 Acid and alkaline phosphates

The strip III plants have recorded mean maximum Acid phosphates (1194.38 µg P g^{-1} day^{-1}) compared to the strip II (1112.51 µg P g^{-1} day^{-1}) and strip I (866.83 µg P g^{-1} day^{-1}). Mean values of post-harvest soil alkaline phosphates was 304.47 µg P $g^{-1}$$day^{-1}$ in strip I, 1004.67 µg P g^{-1} day^{-1} in strip II and 14115.08 µg Pg^{-1} day^{-1} in strip III. Acid and alkaline phosphates 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 a research on maize, soil phosphatase activity was shown to be greatly boosted by adding nitrogen fertilizer (Song et al., 2020) which was found to be similar to the present study on Chakravarthi keerai that soil phosphatase activity was found to be high in plots receiving high amount of nitrogen @ 50 kg ha^{-1}.

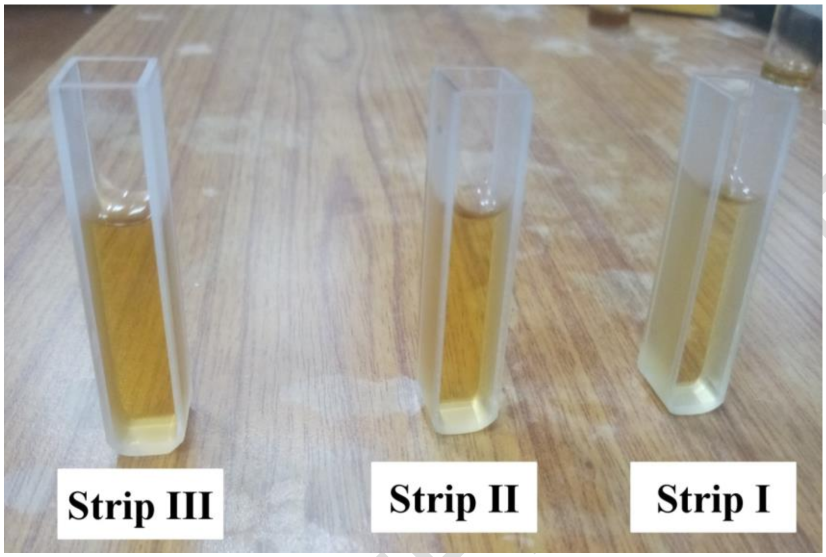

Fig. 3. Color intensity of phosphatase enzyme in three different strips

3.7.2 Dehydrogenase

The Dehydrogenase registered in strip I^{st}, II^{nd} and III^{rd} were 45.77, 82.96 and 95.22 µg TPF $g^{-1}day^{-1}$, respectively. 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).Applying the macro elements increased dehydrogenase activity, which was most likely caused by the activity and growth of the rhizosphere (Bednarz and Krzepilko, 2009).

The results further clearly revealed that increased dehydrogenase activity is due to the increased doses of the fertilizer application. It was also found that dehydrogenase activity was lower if no soil fertilizer was applied. Application of fertilizers increased DHA , it reported by Sarita et al. (2022)

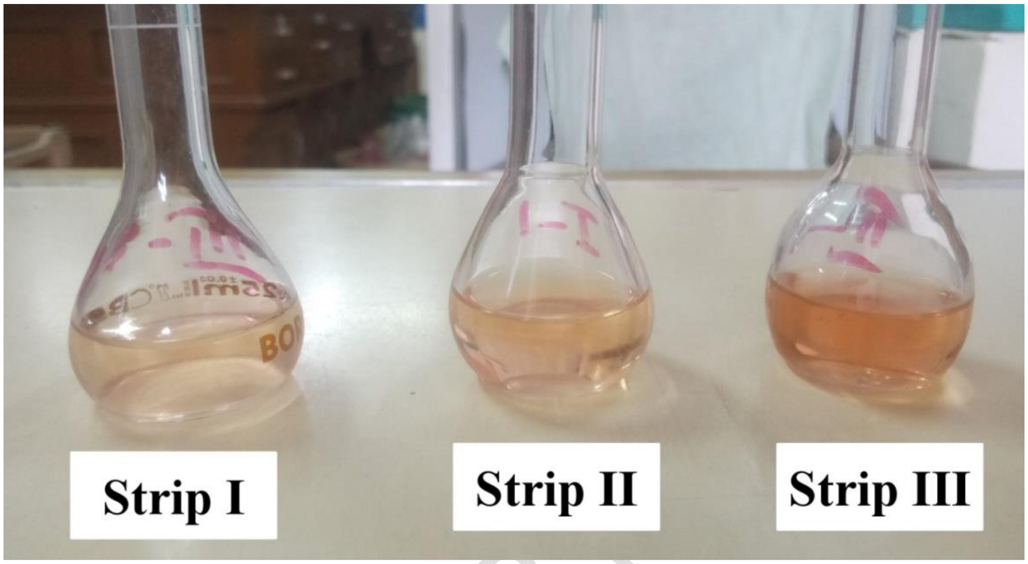

Fig. 4. Color intensity of dehydrogenase enzyme in three different strips

Table 7. Effect of application of graded levels of N, P_2O_5 and K_2O on Soil enzymes

Strip	Levels of Nutrients			Acid Phosphate (µg P g-1 day-1)	Alkaline Phosphate (µg P g^{-1} day^{-1})	Dehydrogenase (µg TPF g^{-1} day^{-1})
	N	P_2O_5	K_2O			
I	0	0	0	0866.83	304.47	45.77
II	25	250	100	1112.51	1004.67	82.96
III	50	500	200	1194.38	1415.08	95.22
SEd				1.54	1.39	1.16
CD (*P*=0.05)				3.30	2.98	2.50

4. Conclusions

In conclusion, the effect of fertilizer on the plant height of Chakravarthi keerai is significant. The application of essential nutrients such as N, P, and K fertilizers can greatly improve the plant growth parameter (plant height, leaf length, leaf width and petiole length) of Chakravarthi keerai plants. It is important to choose the right fertilizer and apply it correctly in order to promote healthy and robust growth. The article clearly showed a significant influence of the application of graded N, P & K fertilizer doses on post-harvest soil fertility status, nutrient uptake, organic carbon, chlorophyll content, biomass yield, soil enzymes activity, microbial population, microbial biomass carbon and growth attributes of Chakravarthi keerai.

DISCLAIMER (ARTIFIICIAL INTELLIGENCE)

Authos(s) hereby declares that NO generative AI technologies such as large language models (ChatGPT, COPILOT, etc) and text-to-image generators have used during writing or editing of manuscripts.

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