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Sustaining Soil Fertility and Yield by Inductive cum Targeted Yield Model-based Fertilizer Prescriptions for Finger millet (*Eleusine coracana* L.) in *Alfisols* of Tamil Nadu, Southern India

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ABSTRACT

Background: Finger millet cultivation in *Alfisols* (*Typic rhodustalf*, Palaviduthi soil series) demands an optimal integrated plant nutrient supply to achieve desired yields. In order to develop the soil test crop response to fertilizer and farm yard manure (FYM) through integrated plant nutrition system (STCR-IPNS) in terms of nutrient uptake, yield and pre-sowing STVs, a field investigation on Finger millet [*Eleusine coracana* (L.) Gaertn.] was conducted at the farmer's field of Thoppupatti village, Dindigul district, Southern Agro-climatic zone of Tamil Nadu, Southern India during December 2021-August 2022.

Methods: By adopting the Inductive cum Targeted Yield Model before the test crop of Finger millet, a artificial soil fertility gradient was created by the application of graded levels of NPK fertilizers with fodder sorghum as a gradient crop.

Result: The basic data *viz*., N, P and K nutrients for producing 1 tonne of finger millet grain were 48 kg, 23 kg and 44 kg; the soil contributed 14.86%, 19.18% and 18.95%; fertilizer contributed 44.16%, 32.79% and 59.75% for N, P and K and farmyard manure (FYM) contributed 28.47%, 11.77% and 33.78%, respectively. Fertilizer prescription equations for finger millet and ready reckoners for the operational range of soil test results for the intended yield target under NPK alone and IPNS (NPK + FYM) were produced using the basic data.

Key words: Fertilizer prescription equations, Finger millet, Soil fertility gradient, STCR-IPNS, User's friendly Ready reckoner of fertilizer doses.

INTRODUCTION

Millets and their products are becoming increasingly popular due to their high nutritional value, numerous health advantages and ease of production. However, minor millets, such as finger millet, foxtail millet, kodo millet, little millet, proso millet and barnyard millet, have received far less research and development attention than other crops. In India, finger millet accounts for 85% of the production of all minor millets. Millet comes in sixth place in global food production and millions of people in Asia and Africa depend heavily on these underutilized crops for their food security. The Government of India has designated 2018 as the "National Year of Millet" and 2023 as the "International Year of millet" by the United Nations in recognition of the importance of climate resilience, health security and food security (FAO, 2022).

Soil fertility is an important element that has an instantaneous effect on crop output. To meet the needs of the ever-growing population, the satisfactory solution is to provide greater from confined land resources. Managing soil fertility is critical to ensure nutritional security and production by preserving soil health and sustainability. Imbalanced fertilizers can deteriorate soil quality and affect nutrient use efficiency, leading to an increased demand for agriculture. To bridge this gap, balanced use of inorganic fertilizers should be promoted. Eco-friendly fertilizers are increasingly being used to boost productivity without harming the environment.

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The integrated plant nutrition system (IPNS) increases crop output, soil fertility and resource use efficiency (Sharma *et al*., 2015). It is important to develop a nutrient management strategy based on soil analysis to improve soil quality and nitrogen recovery. Ramamoorthy *et al*. (1967) inductive cum targeted yield model is exceptional in determining soil test-based optimum fertilizer doses for achieving specific yield levels. These recommendations are useful in the real world for using fertilizers effectively and wisely to increase crop output. Recommendations for crop yield targets may be generated based on farmers' resource availability.

Millets still serve as a traditional staple crop in parts of Sub-Saharan Africa and Asia. India is the largest producer of different kinds of millet. With an output of 1.98 million tonnes and a cultivation area of 1.19 million hectares in India, finger millet has an average yield of 1661 kg per ha. Karnataka leads Tamil Nadu (9.94% and 18.27%), Uttarakhand (9.40% and 7.76%) and Maharashtra (10.56% and 7.16%) in terms of area and output of finger millet, respectively. Tamil Nadu is one of the important states in the country cultivating finger millet, which contributes 7.24 % to the area and 16.18 % to the production (INDIASTAT 2021-22).

Therefore, experiments were done for administering a soil test-based fertilizer dose for the targeted yield of finger millet in *Alfisols* (*Typic rhodustalf*, Palaviduthi soil series) of Tamil Nadu, Southern India and to construct STCR targeted yield equations with a user's friendly quick reckoner.

MATERIALS AND METHODS

Experimental site

Finger millet was used as a test crop in a field experiment at a farmer's field to develop targeted yield equations in accordance with the standard procedure of Ramamoorthy *et al.* (1967). Thoppupatti village, in the Vedasandur block of the Dindigul District, Southern Agro-climatic zone of Tamil Nadu, Southern India was the experimental site. It was at 261 meters above mean sea level, latitude 10°34′49″N, longitude 78°04′35″E. The Experimental field is a sandy loam texture with a weak to a medium-fine granular structure. The soil was non-calcareous, neutral in reactivity, non-saline, low in available N, medium in organic carbon, available P and K and sufficient in available Zn, Fe, Cu and Mn.

Fodder sorghum (var. CO 30) was cultivated in a fertility gradient experiment, prior to the test crop of finger millet, which produced variations in soil fertility. Initially, the fertility gradient was artificially created by applying three grades of fertilizers, namely level 1 ($N_0P_0K_0$ - Strip I), level 2 ($N_1P_1K_1$ - Strip II) and level 3 ($N_2P_2K_2$ Strip III) doses by adopting the Inductive methodology developed by Ramamoorthy *et al.* (1967). The $N_1P_1K_1$ levels were fixed as general fertilizer recommendations for N (N_1) and P and K fixing capacities of the soil (100 and 100 kg ha^{-1} respectively) as P_1 and K_1.

Between April and August 2022, finger millet (Var. ATL 1) was grown as a test crop in the same field as the fertility gradient stabilizing experiment. For the application of three amounts of farmyard manure, each strip (established during the fertility gradient experiment) was divided into three blocks (0, 6.25 and 12.5 t ha^{-1}). Plot-wise soil samples (0-15 cm depth) were collected and analyzed for available N (Subbaiah, 1956), available P (Olsen *et al*., 1954) and available K (Stanford and English, 1949) in Soil-Test Crop Response laboratory of Department of Soil Science and Agricultural Chemistry, in Tamil Nadu Agricultural University. A fractional factorial design with 24 treatments (21 treated plots and 3 control plots) in each of the three strips and 8 treatments (7 treated plots and 1 control plot) in each FYM block (63 treated plots and 9 control plots) was used for the experiment. Four levels of N (0, 30, 60 and 90 kg ha^{-1}), P_2O_5 (0, 15, 30 and 45 kg ha^{-1}) and K_2O (0, 15, 30 and 45 kg ha^{-1}) were evaluated in a finger millet crop. The treatment schedule (Table 1) for the test crop trial (finger millet) was a half dose of N fertilizer along with full doses of P_2O_5 and K_2O and the other half was applied during the tillering stage. At harvest, grain and straw yields of each plot were recorded independently and expressed in kilograms ha^{-1}. Following procedures described by Humphries (1956) and Piper (1966), representative plant samples collected during harvest were oven dried at 60 °C to stable dry weight (72 h), crushed in a Wiley mill and their N, P and K contents were calculated. Nutrient uptake was calculated by multiplying nutrient content (%) by dry weight and total N, P and K uptake. A graphical representation of the experiment to develop the fertilizer prescription equation is shown in Fig 1.

Pre-sowing soil test results, grain and straw yields, fertilizer and manure doses and nutrient uptake by finger millet were used to calculate four crucial basic parameters: the number of nutrients needed to produce a tonne of finger millet grain (NR), the per cent contribution of nutrients from the soil (Cs), the per cent contribution of nutrients from fertilizers (Cf) and the per cent contribution of nutrients from farmyard manure (Co).

(i) Nutrient requirement for finger millet (kg t^{-1})

Kilograms of N/P_2O_5 /K_2O required per tonnes of finger millet grain production (NR) =

$$\frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ (kg ha}^{-1})}{\text{Ragi grain yield (t ha}^{-1})}$$

(ii) Contribution per cent of nutrients from the soil to total uptake (Cs)

Percentage contribution of N/P_2O_5 /K_2O from soil (Cs) =

$$\frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ in the control plot (kg ha}^{-1})}{\text{Soil test value for available } N/P_2O_5/K_2O \text{ in the control plot (t ha}^{-1})} \times 100$$

(iii) Contribution per cent of nutrients from fertilizer to total uptake (Cf)

Percentage contribution of N/P_2O_5 /K_2O from fertilizer (Cf) =

$$\frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ in the treated plot (kg ha}^{-1}) - (\text{Soil test value for available } N/P_2O_5/K_2O \text{ in the treated plot (kg ha}^{-1}) \times \text{Average Cs}}{\text{Fertilizer } N/P_2O_5/K_2O \text{ applied (kg ha}^{-1})} \times 100$$

(iv) Contribution per cent of nutrients from farmyard manure to total uptake (Co)

Percentage contribution of $N/P_2O_5/K_2O$ from fym (Co) =

$$\frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ in FYM treated plot (kg ha}^{-1}) - (\text{Soil test value for available } N/P_2O_5/K_2O \text{ in the FYM treated plot (kg ha}^{-1}) \times \text{Average Cs}}{\text{FYM } N/P_2O_5/K_2O \text{ applied (kg ha}^{-1})} \times 100$$

Target yield equations

1. Fertilizer nitrogen (FN)

$$FN = \left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times SN\right\}$$

$$FN = \left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times SN\right\} - \left\{\frac{Co}{Cf} \times ON\right\}$$

2. Fertilizer phosphorus (FP_2O_5)

$$FP_2O_5 = \left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times 2.29 \times SP\right\}$$

FP_2O_5 =

$$\left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times 2.29 \times SP\right\} - \left\{\frac{Co}{Cf} \times 2.29 \times OP\right\}$$

3. Fertilizer potassium (FK_2O)

$$FK_2O = \left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times 1.21 \times SK\right\}$$

FK_2O =

$$\left\{\frac{NR}{Cf/100} \times T\right\} - \left\{\frac{Cs}{Cf} \times 1.21 \times SK\right\} - \left\{\frac{Co}{Cf} \times 1.21 \times OK\right\}$$

Where,

FN, FP_2O_5 and FK_2O = Fertilizer N, P_2O_5 and K_2O (kg ha^{-1}) respectively.

T = Desired yield target in t ha^{-1}.

NR = Nutrient requirement (kg t^{-1}).

Cs = Contribution of nutrients per cent from the soil.

Cf = Contribution of nutrients per cent from fertilizer.

SN, SP and SK = Soil test value for available N, P and K (kg ha^{-1}), respectively.

Co = Contribution of nutrients per cent from FYM.

ON, OP and OK = Quantities of N, P_2O_5 and K_2O supplied through FYM (kg ha^{-1}), respectively.

Using the above equations, the FPEs are generated and serve as the basis for calculating the fertilizer dose for the desired finger millet yield target (T) of the farm's soil test values.

RESULTS AND DISCUSSION

The mean soil test values in strips I, II and III were 201, 224 and 244 kg of $KMnO_4$-N ha^{-1}; 20.9, 29.6 and 34.9 kg of Olsen-P ha^{-1} and 198, 227 and 248 kg of NH_4OAc-K ha^{-1} respectively. To cover a wide range of fertility levels in the same field, it is necessary to create fertility gradients so that yield variation is significantly less affected by other factors. As a result, the presence of fertility gradients in the experimental field was effectively reflected by considerable changes in post-harvest soil test results.

Test crop-finger millet

The available N, P and K status of the soil before sowing and the nutrient uptake by grain and the yield of finger millet are shown in Table 2. Initial soil test values indicated that the available N ranged from 198 kg N ha^{-1} for Strip I to 250 kg N ha^{-1} for Strip III. Available P (Olsen-P) ranged from 18 kg ha^{-1} in the strip I to 37 kg ha^{-1} in strip III and NH_4OAc-K was in the range of 191 kg ha^{-1} in strip I to strip III from 255 kg ha^{-1}. In soil test crop response, the actual relationship between applied nutrients, crop yield and soil fertility was assessed on the same soil type with regulated environmental factors and management techniques. To reduce the cost of fertilizer usage and increase nutrient use efficiency, it is important to utilize internationally agreed organic and inorganic sources of nutrients. The additional supply of nutrients contributed to root proliferation and improved the physical environment of the soil under balanced nutrition resulting in greater absorption of water and nutrients.

This study found that finger millet grain yield was the highest in Strip III (2.92 t ha^{-1}), which was 38.9% higher than in Strip I (2.10 t ha^{-1}). The uptake of major nutrients changed significantly when different amounts of N, P and K were applied across the fertility gradient and FYM levels. Table 2 shows that the N uptake ranged from 28.5 kg ha^{-1} in strip I to 89.5 kg in strip III. Plots with the highest amount of N applied had the highest N uptake. The highest mean P uptake was with strip III, followed by strip II with 8.5 kg and strip I with 6.1 kg. The highest average K uptake was 64 kg ha^{-1}, with values ranging from 35.5 to 85.5 kg. Santhi *et al*. (2011) reported comparable outcomes, indicating that integrated application of organic and inorganic fertilizers had superior effects on nutrient uptake to application alone. Regardless of the fertility strips, NPK-treated plots had higher yields than NPK control plots.

The differences in grain yield and NPK uptake in finger millet were due to variations in the nutrient status of N, P and K available in the soil, which is a prerequisite for creating fertiliser formulae using the basic parameters for yield targets. Singh *et al*. (2021), Selvam *et al*. (2021) and Abishek *et al*. (2022) reported similar operating ranges of available N, P and K in Direct seeded Rice on *Mollisol*, barnyard millet on *Vertisol* and hybrid castor on *Alfisol*.

Generation of basic parameters

The targeted yield model's basic parameters, such as the nutrient requirement (NR) in kilograms required to produce one tonne of grain, the per cent contribution of available N, P and K from soil (Cs), fertilizers (Cf) and FYM (Co) were calculated for the purpose of developing fertilizer prescription equations for finger millet using NPK fertilizer alone and IPNS. Singh *et al.* (2014) and Singh *et al.* (2019) reported the same operational characteristics for wheat and linseed in Inceptisols.

Table 1: Treatment structure for experiment with test crop finger millet.

Treatment combination			Levels of nutrients (kg ha^{-1})		
N	P	K	N	P	K
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	2	2	0	30	30
1	1	1	30	15	15
1	2	1	30	30	15
1	1	2	30	15	30
1	2	2	30	30	30
2	1	1	60	15	15
2	0	2	60	0	30
2	1	2	60	15	30
2	2	2	60	30	30
2	2	1	60	30	15
2	2	0	60	30	0
2	2	3	60	30	45
2	3	2	60	45	30
2	3	3	60	45	45
3	1	1	90	15	15
3	2	1	90	30	15
3	2	2	90	30	30
3	3	1	90	45	15
3	3	2	90	45	30
3	2	3	90	30	45
3	3	3	90	45	45

The information showed that in order to produce 1000 kg of finger millet grain, the plant needs 21.1 kg of nitrogen, 7.5 kg of phosphorus (P_2O_5) and 26.0 kg of potassium (K_2O) (Table 3). The production of finger millet grain showed a tendency in the order of nutrient requirements: potassium > nitrogen > phosphorus. Abishek *et al.* (2022) observed a similar trend in demand for castor.

The percentage contribution of nutrients from the soil, namely N, P and K (Cs), to the total amount of absorption by finger millet was calculated using the information from the absolute control plots. Results showed that soil nutrients (Table 3) contributed significantly to the absorption of P, K and N nutrients, with available phosphorus contributing 19.18% accompanied by available potassium (18.95%) and soil accessible nitrogen (14.86%). Udayakumar and Santhi (2017) reported a comparable type of soil contribution to plant uptake. The optimal supply of N and P in combination with the priming effects of potassium might have caused the larger value of Cf for potassium for the absorption in native soil sources.

NPK fertilizer application plots of all the strips were used to compute the contribution of fertilizers to nutrient absorption and the trend for fertilizer contribution was K2O>N>P2O5. The magnitude of potassium fertilizer (59.75%) was 1.35 times more than that of nitrogen fertilizer (44.16%) and 1.82 times greater than that of phosphorus fertilizer (32.79%). When the contribution from soil and fertilizer were compared, the fertilizer's contribution was found to be higher. The per cent Cf for N, P and K was determined to be 44.16, 32.79 and 59.75, respectively, after

Table 2: Pre-sowing soil available N, P and K status and IPNS (NPK+FYM) on grain yield and N, P and K uptake by finger millet.

Strip	Soil test values (kg ha^{-1})			Grain yield (kg ha^{-1})	Total uptake (kg ha^{-1})		
	SN	SP	SK		UN	UP	UK
I	200	22.1	197	2100	42.2	6.1	48.9
II	224	29.7	226	2719	56.6	8.5	59.5
III	244	34.2	249	2917	70.7	13.7	64

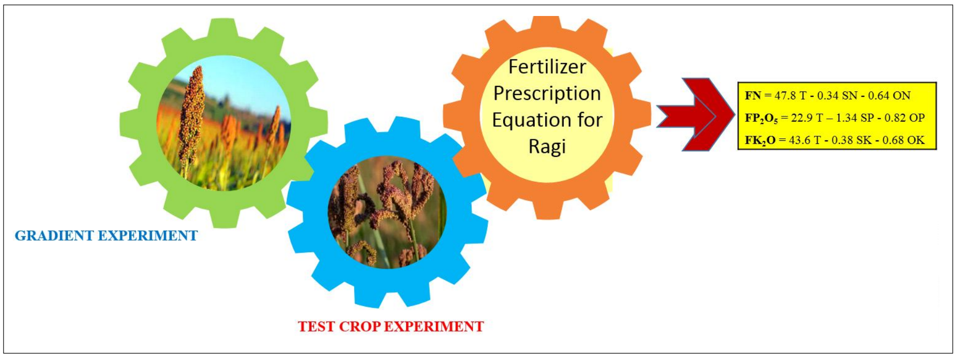

Fig 1: Graphical representation of the study.

accounting for its contribution (Table 3). These findings are consistent with reports on the role of fertilizer in aggregatum onion by Sugumari *et al*. (2021).

The nutritional contribution from farmyard manure (Co) to total absorption was calculated using FYM alone applied plots of finger millet. The results showed that FYM contributed 28.47% of N, 11.77% of P_2O_5 and 33.78% of K_2O to total nutrient uptake by finger millet, with the trend K_2O>N>P_2O_5 noted in Table 3. Abishek *et al*. (2022) demonstrated a comparable nutritional input from Co in sesame and castor grown in the Alfisol soil type. The application of FYM may have boosted and enhanced the release and availability of nutrients and, subsequently, the recovery of additional nutrients. Organic acids generated in the soil by the breakdown of additional FYM may inhibit fixation and increase phosphorus solubility.

Table 3: Nutrient requirement, per cent contribution of nutrients from the soil, fertilizer and FYM for finger millet.

Parameters	Nutrients		
	N	P_2O_5	K_2O
Nutrient requirement (kg t^{-1})	21.1	7.5	26.0
Per cent contribution from soil (Cs)	14.86	19.19	18.95
Per cent contribution from fertilizers (Cf)	44.16	32.79	59.75
Per cent contribution from FYM (Co)	28.47	11.77	33.78

Fertilizer prescriptions for desired yield target of finger millet under NPK alone and IPNS-based fertilization

Using prescription equations Table 4, it is possible to determine the precise amount of fertilizer needed for a finger millet crop under certain climatic circumstances by plugging values for the targeted yield and STVs of N, P and K into the equations. The experimental results showed that the fertilizer N, P_2O_5 and K_2O needs for the intended target of finger millet reduced with rising STVs. In other words, the amount of potassium and nitrogen fertilizer declined by 8 kg respectively, for every 20 kg increase in the availability

Table 4: Fertilizer prescription formulations for finger millet as per STCR target yield model.

Fertilizer requirement (kg ha^{-1})	Without FYM	With FYM
Nitrogen (FN)	FN = 47.8 T-0.34 SN	FN = 47.8 T-0.34 SN-0.64 ON
Phosphorus (FP_2O_5)	FP_2O_5 = 22.9 T-1.34 SP	FP_2O_5 = 22.9 T-1.34 SP-0.82 OP
Potassium (FK_2O)	FK_2O = 43.6 T-0.38 SK	FK_2O = 43.6 T-0.38 SK-0.68 OK

Table 5: Ready Reckoner of NPK alone, NPK + 6.25 t ha^{-1} FYM and 12.5 t ha^{-1} for finger millet.

Soil test values (kg ha^{-1})			Fertilizer doses (kg ha^{-1})								
			3.0 (t ha^{-1})			3.5 (t ha^{-1})			4.0 (t ha^{-1})		
$KMnO_4$-N	Olsen-P	NH_4OAc-K	FN	FP_2O_5	FK_2O	FN	FP_2O_5	FK_2O	FN	FP_2O_5	FK_2O
				NPK alone							
220	10	220	69	45**	45**	90**	45**	45**	90**	45**	45**
240	13	240	63	45**	39	86	45**	45**	90**	45**	45**
260	16	260	56	45**	31	80	45**	45**	90**	45**	45**
280	19	280	49	43	24	73	45**	45**	90**	45**	45**
300	22	300	42	39	16	66	45**	38	90	45**	45**
320	25	320	36	35	15*	59	45**	30	83	45**	45**
				NPK+ FYM @ 6.25 t ha^{-1}							
220	10	220	49	43	29	73	45**	45**	90**	45**	45**
240	13	240	43	39	22	66	45**	43	90	45**	45**
260	16	260	36	35	15*	60	45**	36	84	45**	45**
280	19	280	30*	31	15*	53	42	28	77	45**	45**
300	22	300	30*	27	15*	46	38	20	70	45**	42
320	25	320	30*	23	15*	39	34	15*	63	45**	35
				NPK+ FYM @ 12.5 t ha^{-1}							
220	10	220	30*	30	15*	53	42	34	77	45**	45**
240	13	240	30*	26	15*	46	38	26	70	45**	45**
260	16	260	30*	22 15*	40	34	18	64	45	40	
280	19	280	30*	18	15*	33	30	15*	57	41	32
300	22	300	30*	15*	15*	30*	26	15*	50	37	25
320	25	320	30*	15*	15*	30*	22	15*	43	33	17

(NB: Blanket dose: 60:30:30 kg ha^{-1} of fertilizer K_2O;*maintenance dose (50 per cent of the blanket dose); **maximum dose (150 per cent of the blanket dose).

of soil nutrients. For phosphate fertilizers, 3 kg of fertilizer was marked down for each 3 kg increase in the amount of phosphorus that was readily accessible in the soil. For initial soil nutrient status, 48 kg, 23 kg and 44 kg of fertilizer nitrogen, phosphorus and potassium are required for every 1000 kg increase in finger millet output (Table 5). When FYM was used in tandem with N, P and K fertilizers, these equations for fertiliser prescription would serve as the foundation for prescribing the actual amounts of fertiliser dosages under IPNS. With available N, P and K STVs of 215:21.3:219 kg ha^{-1} and target finger millet yields of 3.0, 3.5 and 4.0 t ha^{-1} without FYM, the amounts of fertilizer N, P_2O_5 and K_2O that ought to be applied are 70, 40 and 45 kg ha^{-1}; 90, 45 and 45 kg ha^{-1}; and 90, 45 and 45 kg ha^{-1}, respectively. The quantity of fertilizer N, P_2O_5 and K_2O was lowered to 37, 21 and 23 kg ha^{-1}; 61, 32 and 44 kg ha^{-1}; and 85, 44 and 45 kg ha^{-1}, respectively, when 12.5 t ha^{-1} FYM was treated together with NPK.

As a result, site-specific fertilizer recommendations under IPNS were constructed for finger millet on *Alfisols* (*Typic Rhodustalf*, Palaviduthi soil series) of Tamil Nadu, Southern India in the current experiment utilizing the targeted yield model.

CONCLUSION

The current work established soil test-based fertilizer prescription equations for finger millet in Tamil Nadu, Southern India and Alfisols. The STCR-IPNS technique adjusted the fertilizer dosage following the demands of the specific finger millet yield goals, taking into account the contributions of soil, fertilizer and organic manure. The results showed that finger millet responded significantly to the application of NPK fertilizers with FYM and the level of response was higher than when inorganic fertilizer (NPK) was used alone. This may be successful in generating more accurate and pertinent fertilizer recommendations with balanced nutrition to the crop, sustained crop yield and soil health, as well as reducing the use of expensive fertilizer inputs. Farmers can also choose the ideal finger millet grain production target according to their financial resources and management conditions. FPEs should be used within a limited range of experimental soil test values and cannot be generalized. As a useful tool, STCR-IPNS and STCR-NPK-based nutrient management for Finger millet are to be recommended.

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Conflict of interest: None.

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