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Optimizing STCR-IPNS fertilizer prescription for targeted rice yield in North Eastern agro climatic zone of Tamil Nadu

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Abstract

Rice is the major crop in the North Eastern zone of Tamil Nadu. In Tiruvallur district, rice is the major crop cultivated in 96967 ha with a share of 6.7% of the state. At present, the productivity of rice in Tiruvallur district is 4200 kg ha^{-1}. Due to intensive cropping and application of chemical fertilizers without organic manures, the organic matter content of the soils in Tiruvallur district is very low in most of the areas with the occurrence of multi-nutrient deficiencies, especially zinc and iron deficiency in rice. In Soil Test Crop Response-Integrated Plant Nutrition System (STCR-IPNS) technology, the fertilizer doses are tailored to specific yield target levels, considering the nutrient requirement of the crop, and the contribution of nutrients from soil, fertilizers, and organic manures. The field experiments were conducted during *samba* season in irrigated rice to refine the existing Fertilizer Prescription Equations (FPEs) for specific yield target levels on the Kadambady soil series in the Tiruvallur district for sustainable rice production and soil quality. Observation on growth and yield attributes was recorded. Grain yield, straw yield, and dry matter production were recorded. Post-harvest soil and plant samples were collected from all the plots. Based on the initial soil analysis of available NPK (Kg ha^{-1}) and NPK content in FYM, the STCR-based IPNS fertilizer recommendations were worked out with FPEs of Irugur soil series (Rabi) under yield target levels of 50, 60, and 70 q ha^{-1}. Using the data on the grain yield, total uptake of NPK, initial soil test values for available NPK, and doses of fertilizer N, P_2O_5, K_2O, and FYM applied, the basic parameters, *viz*., the nutrient requirement (NR), contribution of nutrients from soil (Cs), fertilizer (Cf), response ratio (RR), and farmyard manure (Cfym) were computed. Using the basic parameters, *viz*., NR, Cs, Cf, and Cfym, the FPEs were developed under NPK alone and IPNS. From the test verification trials, the STCR-based fertilizer prescriptions under IPNS for 7 t ha^{-1}, *i.e*., application of fertilizer N, P_2O_5 and K_2O based on initial soil test values with FYM at 12.5 t ha^{-1} (with a manurial composition of N: 0.48 %, P: 0.23%, K: 0.42 %, and moisture: 24%) contributed fertilizer N, P_2O_5 and K_2O at 40:20:32 kg ha^{-1} from the recommended dose of fertilizers based on soil test values. This can be recommended for achieving higher yield, RR and benefit-cost ratio (BCR) for rice. The increase in yield with STCR-IPNS-7 t ha^{-1} was 41.5% over blanket (100% RDF alone), 24.8% over blanket + FYM at 12.5 t ha^{-1}, and 56.7% over farmer's practice. The increase in RR was 4.54, 1.98 and 5.25 kg kg^{-1} due to STCR-IPNS-7 t ha^{-1} over blanket (100% RDF alone), blanket + FYM at 12.5 t ha^{-1} and farmer's practice respectively, on Kadambady soil series and allied soil series, especially in Tiruvallur district of North Eastern agro climatic zone of Tamil Nadu.

Keywords

fertilizer prescription; Kadambady soil; response ratio; STCR-IPNS; Tiruvallur district

Introduction

Fertilizer is one of the important inputs in agriculture and the use of the right amount of fertilizer is essential for farm profitability and environmental protection. The effective fertilizer recommendation should consider crop needs and nutrients already available in the soil(1). Among various methods of fertilizer recommendation such as generally recommended dose, soil test-based recommendation, critical value approach, etc., the soil test crop response (STCR) approach for targeted yield is unique in indicating both soil test-based fertilizer dose and the level of yield that can be achieved with good agronomic practices. STCR is a basis for prescribing the right amount of fertilizer to the crops (2).

The usage of chemical fertilizers in India has increased from 69.8 thousand tons in 1950-51 to 29.796 million tons in 2021-22, thus significantly increasing food grain production (3). Unbalanced fertilizer application has caused multi-nutrient deficiencies and poor soil health (4). The STCR approach optimizes fertilizer recommendations by using the soil test values for enhancing efficiency and minimizing environmental impact. The STCR-IPNS equations help in the achievement of the targeted crop yield while maintaining the fertility of the soil, which makes it sustainable for long-term productivity in agriculture (5).

Rice, the staple food of more than half of the population of the world, is an important target to provide food security and livelihoods for millions (6). The North Eastern Zone comprises Tiruvallur, Vellore, Kancheepuram, Tiruvannamalai, Villupuram, and part of Cuddalore, Perambalur, and Ariyalur districts. In Tamil Nadu, rice is cultivated in an area of 14,42,841 ha. Rice is the major crop in the North Eastern Zone of Tamil Nadu. In Tiruvallur district, Rice is the major crop cultivated in an area of 96,967 ha with a share of 6.7% to state in three seasons *viz*., Sornavari, Samba, and Navarai. In Tiruvannamalai District, Rice is cultivated in an area of 1,12,013 ha with a share of 7.8 % to state in three seasons *viz*., Sornavari, Samba, and Navarai. At present the productivity of rice in Tiruvallur district is 4,200 kg ha^{-1} (7). Due to intensive cropping and application of chemical fertilizers without organic manures the organic matter content of the soils in Tiruvallur district is very low in most of the areas with the occurrence of multi-nutrient deficiencies, especially zinc and iron deficiency in rice.

The application of fertilizer by the farmer without understanding soil fertility status and nutrient requirements by crop and soil will affect both crop yield and environmental health (4). Soil testing is one of the best scientific means for quick and reliable estimation of soil fertility status. A greater economy in fertilizer use can be made if fertilizers are applied based on soil tests. This practice ensures balanced fertilization, higher yield, and more profitability (8). Fertilizer recommendation based on STCR correlation concept is more quantitative, precise, and meaningful because the combined use of soil and plant analysis is involved in it. While developing the STCR targeted yield equation, the contribution of nutrients from soil, fertilizer, and organics are taken into consideration. Similarly, by taking into consideration these nutrient requirements (NR) to produce a quintal of grain or any economic produce are considered. It gives a real balance between applied nutrients and the available nutrients already present in the soil (9).

In many conventional agricultural systems, nutrient recommendations are categorized into low, medium, and high input systems or follow generalized fertilizer recommendation packages. However, these approaches fail to account for regional variations in soil fertility and the specific nutrient needs of crops at a given time. Instead, they rely on uniform crop responses across large areas. These methods are relatively simple and handy but tend to result in fertilizer overuse or underuse, leading to a nutrient imbalance and reduced yield potential, with an inefficient use of resources (10).

Hence, soil test-based fertilizer prescription becomes inevitable for achieving the desired yield target in crops and here especially in rice under irrigated conditions. These fertilizer prescription equations (FPEs) have been vigorously tested and evaluated for their predictability through a series of field verification trials in farmer's holding. If 90% of the targeted yield was achieved, then the equations are found to be valid (11). Velayudham (12) suggested refinement in the estimation of the basic data for yield targeting. Similarly, the existing equations available for irrigated rice can be refined for irrigated rice on sandy clay loam soil in Tiruvallur and Tiruvannamalai districts under the North Eastern Zone of Tamil Nadu.

Fourteen STCR-based IPNS FPEs have been developed for desired yield target levels in rice in selected districts. In Tiruvallur and Tiruvannamalai district rice is the major crop and STCR-based IPNS recommendations have not been developed so far. There are 11 major soil series in Tiruvallur district. Out of which Kadambady soil series covers the extent of 59,143 ha (13). The soil characteristics are deep solum, soil color varies between dark yellowish brown to dark brown, sandy clay loam in texture, and pH varies between 6.7 and 7.3.

Hence, this project is intended to refine the existing FPEs for specific yield target levels on the Kadambady soil series in the Tiruvallur district for sustainable rice production and soil quality during *samba* season in irrigated Rice.

Materials and Methods

Refinement experiment

The field experiment was conducted in Thalakanjeri village of Kadambattur block on Kadambady soil series in Tiruvallur district during *Samba* 2020 with rice TKM 13 under irrigated conditions to refine the existing FPEs for irrigated rice on Kadambady soil series (Sandy Clay loam) following

the Inductive cum Targeted yield model of Ramamoorthy (14). The experiment was laid out in a randomized block design (RBD) comprising nine treatments—STCR-NPK alone for yield target of 5, 6, and 7 t ha^{-1}, STCR-IPNS for yield target of 5, 6, and 7 t ha^{-1}, FYM at 6.25 and 12.5 t ha^{-1} and absolute control with three replications. The treatments and specific yield targets were chosen based on the potential yield of crop varieties. The initial soil was analyzed and was found that the soil is sandy clay loam with a bulk density of 1.42, pH of 7.35, and electrical conductivity of 0.28. The other parameters like alkaline $KMnO_4$-N (15), Olsen P (16), and NH_4OAc-K (17) are given in (Table 1).

Table 1. Initial soil characteristics of the experimental field in Tiruvallur district

Initial soil characteristics	Tiruvallur district
Soil pH	7.35
Soil EC (dSm^{-1})	0.28
Soil Texture	Sandy clay loam
Organic carbon (%)	0.39
Available –N (kg ha^{-1})	253
Available –P (kg ha^{-1})	16
Available –K (kg ha^{-1})	221

The existing FPEs of the Irugur soil series (Rabi) detailed below were taken for the refinement of FPEs on the Kadambady soil series.

$$FN = 4.88\ T - 0.68\ SN - 0.68ON \quad \text{.....(Eqn. 1)}$$

$$FP_2O_5 = 2.06\ T - 2.91\ SP - 1.65\ OP \quad \text{.....(Eqn. 2)}$$

$$FK_2O = 2.89\ T - 0.47\ SK - 0.59OK \quad \text{.....(Eqn. 3)}$$

Where, FN, FP_2O_5, and FK_2O are fertilizer N, P_2O_5, and K_2O in kg ha^{-1} respectively; T is the yield target in q ha^{-1}; SN, SP, and SK respectively are alkaline $KMnO_4$-N, Olsen-P and NH_4OAc-K in kg ha^{-1} and ON, OP, and OK are the quantities of N, P, and K in kg ha^{-1} supplied through FYM.

Based on the initial soil analysis and nutrient content in FYM STCR based IPNS fertilizer recommendation was worked out with FPEs of Irugur soil series (Rabi) under yield target levels of 50, 60, and 70 q ha^{-1}. The fertilizer recommendation for each treatment under field experiment in Tiruvallur district is as follows (Table 2).

Table 2. STCR IPNS based fertilizer recommendation to TKM 13 rice on Kadambady soil series in Tiruvallur district

Trt	Treatment details	Fertilizer nutrients applied (kg ha^{-1})		
		FN	FP_2O_5	FK_2O
T_1	STCR-NPK alone - 5 t ha^{-1}	70	42	40
T_2	STCR-NPK alone – 6 t ha^{-1}	119	62	69
T_3	STCR-NPK alone – 7 t ha^{-1}	168	83	97
T_4	STCR-IPNS - 5 t ha^{-1}	35	24	12
T_5	STCR-IPNS -6 t ha^{-1}	84	44	41
T_6	STCR-IPNS -7 t ha^{-1}	133	65	70
T_7	FYM at 6.25 t ha^{-1} alone	-	-	-
T_8	FYM at 12.5 t ha^{-1} alone	-	-	-
T_9	Absolute control	0	0	0

The crop was harvested during Jan, 2021. Grain yield and straw yield were recorded. Plant samples were collected from all the plots. Soil samples were analysed for available nitrogen, phosphorus and potassium content. Plant samples were processed and analysed for NPK nutrient content by standard methods (18,19) and total nutrient uptake was computed as detailed below.

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{(Nutrient content (\%) x Dry weight in kg ha}^{-}}{}$$

Using the data on the grain yield, total uptake of N, P, and K, initial soil test values for available N, P, and K, and doses of fertilizer N, P_2O_5, K_2O, and FYM applied, the basic parameters *viz*., NR, the contribution of nutrients from the soil (Cs), fertilizer (Cf) and farmyard manure (Cfym) were computed using the formula detailed below (3) for the refinement of FPEs to suit Kadambady soil series for the desired yield target level of rice in Tiruvallur district. Nomograms were formulated for desired yield targets of irrigated rice on the Kadambady soil series.

(i) NR for rice (kg q^{-1}

$$\text{Kg } (N/P_2O_5/K_2O) \text{ required per quintal of rice} = \frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ (kg ha}^{-1})}{\text{Grain yield of rice (q ha}^{-1})}$$

.....(Eqn. 4)

(ii) Percent contribution of nutrients from soil (Cs)

$$\text{Percent contribution of } N/P_2O_5/K_2O \text{ from soil} = \frac{\text{Total uptake of } N/P_2O_5/K_2O \text{ in the control plot (kg ha}^{-1})}{\text{Soil test value for available } N/P_2O_5/K_2O \text{ in the control plot (kg ha}^{-1})} \text{ x100}$$

.....(Eqn. 5)

(iii) Percent contribution of nutrients from fertilizer (Cf)

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

.....(Eqn. 6)

(iv) Percent contribution of nutrient from manure (Co)

$$\text{Percent contribution of } N/P_2O_5/K_2O \text{ from FYM} = \frac{[\text{Total uptake of } N/P_2O_5/K_2O \text{ in FYM treated plot (kg ha}^{-1})] - [\text{Total uptake of } N/P_2O_5/K_2O \text{ in the treated plot (kg ha}^{-1})]}{\text{Nutrient applied } N/P_2O_5/K_2O \text{ through FYM (kg ha}^{-1})} \text{ X 100}$$

.....(Eqn. 7)

Validation Experiment

A verification trial is an important experiment to ascertain the validity of the results acquired from FPEs before recommendations to farmers for higher profitability and efficiency than the blanket fertilizer recommendation. To validate the FPEs for rice on the Kadambady soil series, validation experiments were conducted with rice variety TKM 13 on the Kadambady soil series at farmer's holdings in Melkondaiyar village of Tiruvallur district. A validation trial was conducted in Tiruvallur district with the following treatments.

Phase II (Validation Experiment)

No. of treatments : 10

T_1 : STCR-NPK alone – 5 t ha^{-1}

T_2 : STCR-NPK alone – 6 t ha^{-1}

T_3 : STCR-NPK alone – 7 t ha^{-1}

T_4 : STCR-IPNS – 5 t ha^{-1}

T_5 : STCR-IPNS – 6 t ha^{-1}

T_6 : STCR-IPNS – 7 t ha^{-1}

T_7 : Blanket recommendation at 100 % RDF

T_8 : Blanket + FYM at 12.5 t ha^{-1}

T_9 : Farmer's fertilization practice

T_{10} : Absolute control

Replications : 3

Design : Randomized Block Design (RBD)

Verification trial conducted on Kadambady soil series in farmers holding of Melkondaiyar village of Tiruvallur District during *samba* season (September 2021) with rice variety TKM 13. The experiment was laid out with 10 treatments in a RBD with three replications. The soil is low in available N (190 kg ha^{-1}), medium in available P (19 kg ha^{-1}), and available K (231 kg ha^{-1}). Based on the initial soil test values of available N, P & K and yield targets aimed, fertilizer doses were calculated and applied for STCR treatments. For IPNS treatments, 12.5 tonnes of FYM were applied basally and fertilizer N, P_2O_5, and K_2O doses were adjusted accordingly using the Refined FPEs of Kadambady soil series (Rabi) under yield target levels of 5, 6 and 7 t ha^{-1}. The details of fertilizer doses applied are furnished in (Table 3).

Table 3. The recommended doses of fertilizer nutrients applied for rice in Tiruvallur district

Trt. No.	Treatment details	FYM (t ha^{-1})	Nutrients added (kg ha^{-1})		
			FN	FP_2O_5	FK_2O
T_1	STCR-NPK alone -5 t ha^{-1}	0	98	40	39
T_2	STCR-NPK alone -6 t ha^{-1}	0	134	58	66
T_3	STCR-NPK alone -7 t ha^{-1}	0	170	76	75**
T_4	STCR-IPNS -5 t ha^{-1}	12.5	75*	25*	25*
T_5	STCR-IPNS -6 t ha^{-1}	12.5	99	42	36
T_6	STCR-IPNS -7 t ha^{-1}	12.5	134	60	63
T_7	Blanket 100% RDF	0	150	50	50
T_8	Blanket + FYM 12.5 t/ha	12.5	150	50	50
T_9	Farmer's fertilization practice	0	115	32	60
T_{10}	Absolute control	0	0	0	0

*Maintenance dose; **Maximum dose.

The crop was harvested in January 2022, and observations on grain and straw yield were recorded. Post-harvest soil samples and plant samples were collected for analysis. The details of grain yield, percentage achievement, and response ratio were computed.

Statistical analysis

The refinement experiment has been conducted with nine treatments and replicated thrice in RBD.

Results and Discussion

Refinement experiment

The effect of STCR-IPNS-based fertilizer application on the grain yield, nutrient uptake, and soil available nutrient content are given in (Table 4). Significant results are obtained from the verification trial based on the fertilizer recommendation arrived from the revised fertilizer prescription equation. Using the data on the grain yield, total uptake of N, P, and K, initial soil test values for available N, P, and K, and doses of fertilizer N, P_2O_5, K_2O, and FYM applied, the basic parameters *viz*., NR, Cs, Cf and Cfym were computed for the refinement of FPEs to suit Kadambady soil series for the desired yield target level of rice in Tiruvallur district.

Refinement of FPEs in Tiruvallur district

Basic parameters

Basic parameters	N	P_2O_5	K_2O
Nutrient requirement (kg q^{-1})	1.76	0.93	1.93
Percent contribution of nutrients from soil	20.82	58.19	24.96
Percent contribution of nutrients from fertilizers	48.76	51.66	71.20
Percent contribution of nutrients from FYM	42.81	20.13	47.61

Refined fertilizer prescription equations for rice (*var. TKM 13*) on Kadambady soil series in Tiruvallur district

Making use of the basic parameters *viz*., NR, Cs, Cf and Cfym, the FPEs were developed under NPK alone and IPNS (Eqn. 8–13).

STCR-NPK alone	STCR-IPNS (NPK+FYM)
FN = 3.59 T - 0. 43 SN Eqn. 8	FN = 3.59 T - 0. 43 SN - 0.88 ON Eqn. 9
FP_2O_5 = 1.79 T - 2.58 SP Eqn. 10	FP_2O_5 = 1.79 T - 2.58 SP - 0.89 OP Eqn. 11
FK_2O = 2.72 T - 0.42 SK Eqn. 12	FK_2O = 2.72 T - 0.42 SK – 0.81 OK Eqn. 13

Where, FN, FP_2O_5, and FK_2O are fertilizer N, P_2O_5, and K_2O in kg ha^{-1}, respectively; T is the grain yield target in q ha^{-1} and SN, SP, and SK respectively are alkaline $KMnO_4$–N, Olsen–P and NH_4OAc –K in kg ha^{-1}; ON, OP and OK are quantities of N, P, and K in Kg ha^{-1}supplied through FYM.

A ready reckoner of fertilizer doses (nomograms) was formulated for desired yield targets of rice *var*. TKM 13 for a range of soil test values under STCR -NPK alone and STCR-IPNS (NPK + FYM at 12.5 t ha^{-1}) (Table 5).

Table 4. Experimental data for refinement of fertilizer prescription equations for rice (*var.TKM 13*) in Kadambady soil series at Tiruvallur district (Mean of three replications)

Treatment details	Grain Yield	Straw yield	UN	UP	UK	SN	SP	SK	FN	FP_2O_5	FK_2O	FYM (t ha^{-1})
	(kg ha-1)											
T_1 STCR-NPK alone - 5 t ha^{-1}	4549	6680	85.72	19.67	73.77	257	45.0	273	70	42	40	0
T_2 STCR-NPK alone – 6 t ha^{-1}	5298	7423	87.57	21.54	76.18	255	45.0	271	119	62	69	0
T_3 STCR-NPK alone – 7 t ha^{-1}	5932	7988	90.24	23.42	79.29	255	43.5	268	168	83	97	0
T_4 STCR-IPNS - 5 t ha^{-1}	4719	6784	92.87	20.58	75.48	257	45.0	269	35	24	12	12.5
T_5 STCR-IPNS -6 t ha^{-1}	5499	7620	95.09	23.14	78.09	256	45.0	268	84	44	41	12.5
T_6 STCR-IPNS -7 t ha^{-1}	6231	8410	96.61	25.14	80.08	256	45.8	270	133	65	70	12.5
T_7 FYM at 6.25 t ha^{-1} alone	3535	5145	63.61	13.67	66.47	255	43.5	268	-	-	-	6.25
T_8 FYM at 12.5 t ha^{-1} alone	3882	5804	72.77	16.89	72.48	256	45.0	271	-	-	-	12.5
T_9 Absolute control	2904	4746	52.74	9.50	55.16	253	37.4	267	0	0	0	0
Mean	4728	6733	81.91	19.28	73.00	256	43.9	270				

Table 5. Soil test-based fertilizer doses for desired yield targets of rice (*var.* TKM 13) under STCR-NPK alone and STCR-IPNS.

Yield target 6.0 t ha^{-1}								
Initial STV			STCR-NPK alone			STCR-IPNS		
SN	SP	SK	FN	FP_2O_5	FK_2O	FN	FP_2O_5	FK_2O
220	22	240	121	51	62	81	31	30
240	24	260	112	45	54	72	25	22
Yield target 7.0 t ha^{-1}								
220	22	240	157	69	90	117	49	58
240	24	260	148	63	81	108	43	49

The recommendations from the refinement experiment were verified by conducting the verification trial and demonstrated in the farmer's field by conducting on-farm trials and the results were achieved at 90%. From the ready reckoner table, it has been inferred that when NPK alone was applied, for a soil test value of 220 kg $KMnO_4$-N ha^{-1}, the doses of fertilizer N required for desired yield targets of 6 and 7 t ha^{-1} were 121 and 157 kg ha^{-1} respectively. When FYM at 12.5 t ha^{-1} was applied along with NPK, the required fertilizer N doses were 81 and 117 kg ha^{-1} with 33.06% and 25.48% reduction in fertilizer doses over NPK alone respectively for the same yield target and soil test values. In the case of P fertilization, when NPK alone was applied, for a soil test value of 22 kg ha^{-1} of Olsen-P, the doses of fertilizer P_2O_5 required for desired yield targets of 6 and 7 t ha^{-1} were 51 and 69 kg ha^{-1} respectively. When NPK was applied along with FYM at 12.5 t ha^{-1}, the doses were 31 and 49 kg ha^{-1} with a percent reduction of 39.22 and 28.99 respectively over NPK alone. Concerning K fertilization, when NPK alone was applied, for a soil test value of 240 kg of $NH4_OAc$-K ha^{-1}, the doses of fertilizer K_2O required for desired yield targets of 6 and 7 t ha^{-1} were 62 and 90 kg ha^{-1} respectively. When NPK was applied along with FYM at 12.5 t ha^{-1}, the doses were 30 and 58 kg ha^{-1} with a percent reduction of 51.61 and 35.56 respectively over NPK alone (Table 5).

Using the FPEs under IPNS, the extent of saving of inorganic fertilizers was computed. The results showed that the application of FYM at 12.5 t ha^{-1} with a manurial composition of N: 0.48 %, P: 0.23%, K: 0.42 % and moisture: 24% contributed fertilizer N, P_2O_5 and K_2O at 40:20:32 kg ha^{-1}.

Verification trial

At Melkondaiyar village, from the test verification trials, the highest mean grain yield of rice was recorded with STCR-IPNS 7 t ha^{-1} (6.74 t ha^{-1}) followed by STCR-NPK 7 t ha^{-1} (6.51 t ha^{-1}). The increase in grain yield owing to the STCR approach might be due to the balanced application of nutrients which is based on soil analysis and takes into account the amount of nutrients removed by the crops, initial levels of soil fertility, efficiency of nutrients present in the soil and added through the fertilizers. Further, the addition of FYM increased the rice yield which might be due to the direct effect of decomposition and mineralization of various nutrients from FYM and indirectly due to the rhizosphere effect in increasing the microbial activity and its impact on the available nutrient content (20). Similar outcomes were also reported by (21) in direct-seeded rice, (22) in rice, (23) in foxtail millet, and (24) in onion under different conditions.

The increase of yield in STCR-IPNS - 7 t ha^{-1} was 41.5% over blanket (100% RDF alone), 24.8% over blanket + FYM at 12.5 t ha^{-1}, and 56.7% over farmer's practice. The highest response ratio was recorded in STCR-IPNS 7 t ha^{-1} (11.82 kg kg^{-1}) followed by STCR-IPNS 6 t ha^{-1} (11.29 kg kg^{-1}). The increase in RR due to STCR-IPNS-7 t ha^{-1} was 4.54, 1.98, and 5.25 kg kg^{-1} respectively over the blanket (100% RDF alone), blanket + FYM at 12.5 t ha^{-1}, and farmer's practice. Farmer's practice recorded a lower yield and response ratio as compared to blanket and STCR treatments. Fertilizer response is described as a functional relationship between the increase in crop yield and fertilizer nutrients added. The relatively higher RR recorded under STCR and IPNS treatments when compared to blanket might be due to a balanced supply of nutrients from fertilizer, efficient utilization of applied fertilizer nutrients in the presence of organic sources, and the synergistic effect of the conjoint addition of various sources of nutrients (25). Similar outcomes were also reported by (26–28). Post-harvest soil nutrient availability is also maintained by adopting STCR-

IPNS fertilizer recommendations. STCR-IPNS treatments recorded a higher percent achievement and response ratio among all the treatments (Table 6).

Table 6. Results of test verification trial at Melkondaiyar village, Tiruvallur district

Trt. No.	Treatments	Grain yield(kg ha^{-1})	Per-cent Achiev ement	Re-sponse Ratio (kg kg^{-1})	BCR
T_2	STCR-NPK alone -6 t ha^{-1}	5750	95.83	10.86	2.13
T_3	STCR-NPK alone -7 t ha^{-1}	6510	93.00	11.11	2.32
T_4	STCR-IPNS -5 t ha^{-1}	4940	98.80	11.26	1.89
T_5	STCR-IPNS -6 t ha^{-1}	5860	97.67	11.29	2.16
T_6	STCR-IPNS -7 t ha^{-1}	6740	96.29	11.82	2.33
T_7	Blanket 100% RDF	4760	-	7.28	1.80
T_8	Blanket + FYM 12.5 t/ha	5400	-	9.84	1.87
T_9	Farmer's fertilization practice	4300	-	6.57	1.66
T_{10}	Absolute control	2941	-	-	1.30

Post-harvest soil nutrient availability

The results of validation experiments on post-harvest soil nutrient availability in Tiruvallur district are given in (Fig. 1).

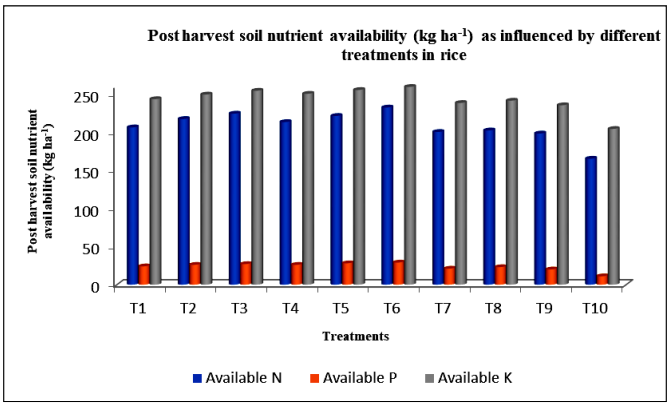

Fig. 1. Results of validation experiment on post-harvest soil nutrient availability (kg ha^{-1}) in Tiruvallur district.

The results on $KMnO_4$-N, Olsen-P, and NH_4OAc-K indicated the build-up and maintenance of soil fertility due to soil test-based fertilizer recommendation under IPNS and there was depletion in absolute control as compared to initial soil available N, P, and K. Despite higher removal of nutrients, the fertility status was maintained at a higher level in IPNS as compared to NPK alone. This might be attributed to the prevention of losses of nutrients under IPNS, even after meeting the crop needs. A combination of organic manure and chemical fertilizers would be quite promising not only in providing greater stability in production but also in maintaining better soil fertility. The higher BCR was mainly due to the higher yield compared to the farmer's fertilizer practice and indicates that the farmer's income could be enhanced by practicing the STCR approach of fertilizer recommendation (22). This is in line with the findings of (12).

Salient findings

- FPEs on Kadambady soil series have been developed through refinement of existing FPEs for rice and ready reckoner of fertilizer doses were computed for the desired yield target of rice *(var. TKM 13)*
- Refined FPEs on Kadambady soil series in Tiruvallur district.

STCR-NPK alone	STCR-IPNS (NPK+FYM)
FN = 3.59 T - 0. 43 SN Eqn. 14	FN = 3.59 T - 0. 43 SN - 0.88 ON Eqn. 15
FP_2O_5 = 1.79 T - 2.58 SP Eqn. 16	FP_2O_5 = 1.79 T - 2.58 SP - 0.89 OP Eqn. 17
FK_20 = 2.72 T - 0.42 SK Eqn. 18	FK_20 = 2.72 T - 0.42 SK – 0.81 OK Eqn. 19

- From the test verification trials conducted at farmer's holdings, the highest mean grain yield of rice was recorded with STCR-IPNS 7 t ha^{-1} (6.74 t ha^{-1}) followed by STCR-NPK 7 t ha^{-1} (6.51 t ha^{-1}).
- Increase of yield in STCR-IPNS - 7 t ha^{-1} was 41.5% over blanket (100% RDF alone), 24.8% over blanket + FYM at 12.5 t ha^{-1}, and 56.7% over farmer's practice.
- Highest response ratio was recorded in STCR-IPNS 7 t ha^{-1} (11.82 kg kg^{-1}) followed by STCR-IPNS 6 t ha^{-1} (11.29 kg kg^{-1}).
- Increase in RR due to STCR-IPNS-7 t ha^{-1} was 4.54, 1.98 and 5.25 kg kg^{-1} respectively over blanket (100% RDF alone), blanket + FYM at 12.5 t ha^{-1} and farmer's practice.
- Compared to conventional methods that rely solely on inorganic fertilizers for nutrient supply, STCR-IPNS incorporates FYM at12.5 t ha^{-1}, which not only provides essential nutrients but also enhances the microbial activity and promotes nutrient cycling which enhances the availability of nutrients thereby increasing the productivity of the crop.
- Farmer's practice recorded a relatively lower yield and response ratio as compared to blanket and STCR treatments.
- Post-harvest soil nutrient availability is also maintained by adopting STCR-IPNS fertilizer recommendations.
- STCR - IPNS treatments recorded the higher percent achievement and response ratio among all the treatments.

Conclusion

Soil Test Crop Response-based fertilizer prescriptions under the Integrated Plant Nutrition System (STCR-IPNS for 7 t ha^{-1}) can be recommended to the farmers for achieving the aimed yield target (6.74 t ha^{-1}), higher response ratio (11.82 kg kg^{-1}), and BCR (2.33). Application of fertilizer N, P_2O_5 and K_2O based on initial soil test values with FYM

at12.5 t ha^{-1} (with a manurial composition of N: 0.48 %, P: 0.23%, K: 0.42 % and moisture: 24%) contributed fertilizer N, P_2O_5 and K_2O at 40:20:32 kg ha^{-1} and the dose can be reduced from the recommended dose of fertilizers. Hence, STCR-IPNS based fertilizer recommendations can be suggested at policy level for achieving higher yield, response ratio and BCR for rice on Kadambady soil series and allied soil series, especially in Tiruvallur district of North Eastern agro climatic zone of Tamil Nadu with fertilizer saving and maintenance of soil fertility.

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Authors' contributions

The conceptualization of the study was carried out by SS and RS, while the methodology was developed by SS, SM and RS. Resources were provided by SS, SM, VA and RS. Data collection efforts were handled by SS and VA and the investigation was conducted by SS and VA. Formal analysis was performed by SS and VA. The original draft of the manuscript was written by SS with visualization contributions from SM. Supervision of the study was undertaken by SS, SM, VA and RS. All authors reviewed and approved the final version of the paper.

Compliance with ethical standards

Conflict of interest: The authors declare no conflicts of interest.

Ethical issues: None

Declaration of generative AI and AI assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT to correct grammatical mistakes and language editing. After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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