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Impacts of Long-Term Nutrient Management Based on Soil Test and Crop Response on Soil Health and Yield Sustainability in *Typic* Haplustalf

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

We studied the effect of soil tests and crop response-based long-term nutrient management on yield sustainability and soil health under rice-rice system in a *Typic* Haplustalf. The experiment was designed in randomized block design having five treatments, *viz*, control, the recommended dose of fertilizer (RDF), STCR–NPK for target yield of 6 t ha^{-1} for kharif rice and 5 t ha^{-1} for rabi rice (STCR–NPK6), STCR–NPK for 7 t ha^{-1} for kharif rice and 6 t ha^{-1} for rabi rice (STCR–NPK7), and STCR–IPNS for 7 t ha^{-1} for kharif rice and 6 t ha^{-1} for rabi rice (STCR–IPNS7), and these treatments were replicated thrice. The 10-year mean data suggested that minimum yield was observed from control whereas highest was achieved in STCR–IPNS7 in both kharif as well as rabi

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seasons. The highest sustainable yield index (SYI) was 0.93 in kharif and 0.77 in rabi rice was observed under STCR–IPNS7, and lowest in control. Soil fertility status revealed that disregard for external application of nutrients resulted in depletion of 108 kg N, 11.6 kg P, and 200 kg K ha^{-1} and intensity of nutrient depletion was lowest in STCR–IPNS followed by STCR–NPK7, STCR–NPK6, and RDF. The urease, phosphatase, and dehydrogenase activities and microbial biomass C were found to be higher in STCR–IPNS when compared with other nutrient management practices while minimum values were recorded in the control.

Keywords: Soil test; crop response; sustainability; soil health.

1. INTRODUCTION

The major challenges that India faces at present is to produce enough food, fodder, fiber and fuel for its growing population without compromising the needs of the future generation [1]. The goal to achieve food security led to the adoption of intensive cropping systems such as rice-rice, rice-wheat, maize-wheat, etc. which is heavily taxing the soil of its nutrients [2]. Thus, massive quantities of chemical fertilizers are being pumped into the soil to replenish the nutrients removed by these nutrient-exhaustive cropping systems. This can be observed from the fertilizer consumption (total $N+P_2O_5+K_2O$) that has grown from 69.8 thousand tons in 1950-51 to 29.796 million tons in 2021-22 with corresponding food grain output of 50.85 million tons to 305.6 million tons in India [3]. This chemical fertilizer contributes about 50% of the increase in the country's food grain production [4]. Although this massive surge in fertilizer use allowed an increase in food production, excessive and disproportionate use of chemical fertilizer without any organic input led to numerous problems such as nitrate pollution, soil acidity, heavy metal accumulation, eutrophication of waterbodies, deficiencies of secondary and micro-nutrients, emission of greenhouse gases, soil compaction, nutrient depletion, reduction in soil organic matter, loss of soil C and yield stagnation [4,5] which hampers the agricultural sustainability of the country.

To improve crop productivity as well as sustainability, judicious use of chemical fertilizer coupled with organic nutrient sources is vital. To prescribe a precise dose of nutrients to crops, fertilizer application should be based on the soil available nutrient level and the crop response anticipated. This provides fertilizer recommendations with caution by considering yield responses and targeted agronomic efficiencies along with the contribution of nutrients from both external (chemical and organic fertilizers) and indigenous (soil) sources. Not only this, recommendations based on soil test and crop response correlation (STCR) concept are more quantitative, accurate, and meaningful because of combined use of soil and plant analysis [6]. It gives a real balance between applied nutrients and the available nutrients already present in the soil. These management practices are not only sustainable; they can also further improve crop yields and close the gap between actual and attainable yields [7]. The practice of nutrient application based on soil tests and crop response for targeted yield using developed fertilizer adjustment equations for crops provides a better option for the balanced application of nutrients [6]. Against this backdrop, a study was initiated to assess the impacts of long-term nutrient management based on soil test and crop response on yield sustainability and soil health in a *Typic* Haplustalf.

2. MATERIALS AND METHODS

2.1 Site Description

The long-term experiment was initiated in 1998 at Wetland Farm of Tamil Nadu Agricultural University, Coimbatore as part of the All India Coordinated Research Project on Soil Test Crop Response Correlation studies in the rice-rice cropping system. The soil of the experimental field (Noyyal series *Typic* Haplustalf) was clay loam in texture, moderately alkaline in reaction (pH 8.2), and non-saline (EC 0.49 dS m^{-1}). The initial soil fertility status showed low available N (280 kg ha^{-1}), medium available P (20.2 kg ha^{-1}), and high available K (670 kg ha^{-1}) with 4.6 mg kg^{-1} organic C content. The available Zn (0.63 mg kg^{-1}) and Cu (0.33 mg kg^{-1}) were deficient but sufficient in available Mn (5.52 mg kg^{-1}) and Fe (11.3 mg kg^{-1}).

2.2 Treatment Details

Five treatments were imposed in three replications in Randomized Block Design. The

Table 1. Soil test value (kg ha^{-1}) and quantity of fertilizer (kg ha^{-1}) added during the year of experimentation

Treatments	SN	SP_2O_5	SK_2O	FN	FP_2O_5	FK_2O
Control	165	14.1	430	0	0	0
RDF	229	21.3	506	150	50	50
STCR-NPK6	233	22.1	509	101	29	25*
STCR-NPK7	246	26.4	545	140	35	25*
STCR-IPNS7	268	29.9	568	88	25*	25*

*** IPNS: NPK+FYM @12.5 t ha^{-1}; * maintenance dose (50% of blanket) and for IPNS plots, FYM @ 12.5 t ha^{-1} and Azospirillum and Phosphobacteria each @ 2 kg ha^{-1}*

treatments were (i) Control (no organic and chemical fertilizers), (ii) Recommended dose of fertilizers (RDF), (ii) STCR-NPK alone for a target yield of 6 t ha^{-1} for kharif rice and 5 t ha^{-1} for rabi rice (STCR-NPK6), (iv) STCR-NPK alone for a target yield of 7 t ha^{-1} for kharif rice and 6 t ha^{-1} for rabi rice (STCR-NPK7), and (v) STCR - IPNS for target yield of 7 t ha^{-1} for kharif rice and 6 t ha^{-1} for rabi rice (STCR-IPNS7). The fertilizer doses were calculated based on the available nutrient status of initial soil samples using the fertilizer prescription equations as furnished below:

Kharif	*Rabi*
FN = 4.39 T – 0.52 SN – 0.80 ON	FN = 4.63 T – 0.56 SN – 0.90 ON
FP_2O_5 = 2.22 T – 3.63 SP – 0.98 OP	FP_2O_5 = 1.98 T – 3.18 SP – 0.99 OP
FK_2O = 2.44 T – 0.39 SK – 0.72 OK	FK_2O = 2.57 T– 0.42 SK – 0.67 OK

where FN, FP_2O_5, and FK_2O are the amount of N, P_2O_5, and K_2O (kg ha^{-1}) fertilizer, respectively; SN, SP, and SK are soil test values of available N, P_2O_5, and K_2O (kg ha^{-1}), respectively; ON, OP and OK is the amount of N, P_2O_5 and K_2O applied through organic sources, respectively; and T is target yield (q ha^{-1}).

The STCR-based fertilizer prescription equations for a target yield were developed before the initiation of the experiment. The kharif rice was sown during the first week of June while sowing of rabi was sown in November. The soil test values and the quantity of fertilizers required are presented in Table 1. The N was supplied through Urea and DAP, P through DAP, and K through MOP. The full dose of P and 25% of N and K were applied basally at the time of transplanting. The remaining N and K_2O were applied in three equal splits *viz*., active tillering, panicle initiation, and heading stages, and routine agronomic practices (irrigation, weeding, etc.) were carried out periodically.

2.3 Sample Collection and Analysis

The grain yield data was taken at the time of each harvest. Grain yield data obtained for the last 10 years (from 2013 to 2023) was used to estimate SYI to reduce variability in climate and variety. After the harvest of rabi crop in 2022-23, soil samples were collected and analyzed for different parameters. Organic C was determined by the Walkley and Black method [8]. Available N was analyzed by the alkaline permanganate method [9], available P by the Olsen method [10], and available K by the ammonium acetate method [11]. The fresh soil samples collected at the maturity of rabi rice were immediately used for estimating biological properties. Urease activity in soils was analyzed as per [12]. Phosphatase activity in soil was estimated by p-nitrophenyl phosphate incubation method [13]. Dehydrogenase activity in soil was estimated by incubating with triphenyl tetrazolium chloride (TTC) [14]. Soil microbial biomass C in soil was estimated by chloroform fumigation [15].

2.4 Data Analysis

All data were subjected to ANOVA [16] using R Software (Version 4.2.3). The sustainable yield index (SYI) is estimated by SYI = $(\bar{y}-\sigma)/y_m$, where $\bar{y}$ is the mean yield of the respective treatment, σ is the standard deviation and y_m is the maximum yield obtained during the period [17].

3. RESULTS AND DISCUSSION

3.1 Crop Yield and Sustainability

The long-term grain yield scenario of the past 10 years shows that the maximum was achieved from STCR-IPNS7 in both the cropping seasons and the lowest was achieved from the control treatment (Table 2). On average, the increase in grain yield of rice over control treatment in RDF, STCR-NPK6, STCR-NPK7, and STCR-IPNS7 over control was 124, 129, 175, and 184%, respectively for kharif crop; and 95.4, 97.7, 135 and 144%, respectively for rabi crop. The highest mean grain yield in both kharif (6935 kg ha^{-1}) and rabi (6312 kg ha^{-1}) was achieved in the highest yield target. The improvement in grain yield using STCR-based integrated fertilizer recommendations with organics may be attributed to a balance supply of nutrients from soil and improvement in physical, chemical, and biological properties of soil [18,19]. In all the years of experimentation, the target yield was achieved with ±10% deviation which is considered acceptable for all STCR experiments.

The sustainable yield index (SYI) is a quantitative measure to assess the sustainability of an agricultural practice [17]. The SYI is 0.77 for kharif rice and 0.53 for rabi rice in control, which is the lowest among all treatments (Table 2). The highest SYI (0.93 for kharif rabi and 0.77 for rabi) was observed under STCR-IPNS7. The result suggests that the absence of chemical and organic fertilizers (in control) is not sustainable whereas the presence of organics in addition to chemical fertilizers improves the sustainability of the system. While the SYI of RDF and STCR-NPK6 are comparable in kharif season, SYI of STCR-NPK6 is higher in rabi. In general, STCR based treatments are more sustainable than RDF and control treatments while sole chemical fertilizer application as per *ad hoc* recommendation (RDF) is more sustainable than control. A combination of organic and inorganic fertilizers is considered an effective solution to maintain the sustainability of crop ecosystems [20].

3.2 Nutrient Balance

Perusal of data showed significant higher soil organic carbon, available N, P, and K in plots receiving combined chemical and organic fertilizers as per STCR-based nutrient management since the commencement of the experiment (Fig. 1). Compared to control, there was 51.5, 79.3, 84.3 and 114% increase in SOC under RDF, STCR-NPK6, STCR-NPK7 and STCR-IPNS7, respectively. The absence of nutrient input led to serious soil organic C depletion. Continuous application of FYM alone or in combination with fertilizers increased the SOC in soil than fertilizer alone and control. Ghosh and Singh [21] also found that the treatments where fertilizers were applied showed higher SOC than control due to greater yield and associated greater amount of organic input to the soil. Application of chemical fertilizer with organics improved the available N by 35.5 to 52.9% over control although the initial N fertility level could not be attained. Yang et al. [22] reported that combinations of organic and inorganic nutreints are likely to increase yields and improve soil fertility. Long-term application of nutrients led to the build-up of soil P levels. Sharma et al. [6] reported a significant increase in available P in organic and integrated treatments after 10 years of continuous application of FYM @15 t ha^{-1} in kharif and rabi season under pearl millet-wheat cropping system Available K decreased significantly from its initial value of 558 kg ha^{-1} in the year 1997 to 358 kg ha^{-1} in the year 2023 in control. The decrease was slightly less in the case of plots receiving chemical fertilizers and organics. Thakare and Wake [23] also observed that increasing levels of organic manures significantly increased the nutrient availability in soil over control.

3.3 Soil Biological Parameters

Different treatments led to significant changes in the urease, phosphatase, dehydrogenase, and microbial biomass C in the soil. Compared to control plots, RDF significantly improved the urease, dehydrogenase, and microbial biomass C by 33.5, 43.1 and 73.7%, respectively. Maximum biological activities were observed in STCR treatment with the highest target yield (STCR–IPNS7). Compared to the RDF, this treatment improved the soil urease, phosphatase, dehydrogenase activity, and microbial biomass C by 38.0, 37.2, 52.2, and 38.7%, respectively. Previous studies have also shown that fertilization management and incorporation of organic matter can affect soil enzyme activity [24,25].

Table 2. Average grain yield (kg ha^{-1}) of different crops after 28 cropping cycles of long-term experiments in India (2012-13 to 2022-23)

Kharif														
Treatments	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**y_m***	**σ**	**$\bar{y}$**	**SYI**
Control	2928c	2475c	2350c	2300b	2380c	2320c	2450d	2340c	2450	2360c	2928	183	2435	0.77
RDF	5812b	5690b	4650b	5460c	5510b	5400b	5560c	5490b	5490	5600b	5812	311	5466	0.89
STCR-NPK6	5910b	5780b	4720b	5580c	5644b	5580b	5720c	5630b	5570	5660b	5910	320	5579	0.89
STCR-NPK7	6861a	6860a	5875a	6790b	6730a	6620a	6900b	6840a	6720	6800a	6900	301	6700	0.93
STCR-IPNS7	7040a	7060a	6120a	7025a	6986a	7020a	7160a	7040a	6870	7030a	7160	295	6935	0.93
Mean	5094	4980	4288	4862	4878	4826	4968	4893	4854	4912				
S. Em ±	134	194	132	134	125	194	146	166	134	134				
C.D. at 5%	439	948	649	655	614	633	717	815	658	439				
Rabi														
Treatments	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**	**2019-10**	**2021-22**	**2022-23**	**y_m**	**σ**	**$\bar{y}$**	**SYI**
Control	3931c	2500c	2600c	2450c	2410c	2415c	2280c	2400c	2360c	2420c	3931	483	2577	0.53
RDF	6500b	4515b	5060b	5660b	4800b	4920b	4785b	4675b	4695b	4750b	6500	602	5036	0.68
STCR-NPK6	6417b	4630b	5258b	5750b	4870b	4935b	4800b	4760b	4740b	4790b	6417	569	5095	0.71
STCR-NPK7	7278a	5680a	6080a	6860a	5915a	5782a	5810a	5790a	5725a	5800a	7278	546	6072	0.76
STCR-IPNS7	7458a	5960a	6424a	7080a	6205a	5890a	6090a	6050a	5920a	6040a	7458	535	6312	0.77
Mean	6317	4657	5084	5560	4840	4788	4753	4735	4688	4760	6317			
S. Em ±	137	160	137	134	139	115	132	138	139	206				
C.D. at 5%	672	782	677	655	680	377	433	450	454	673				

**y_m is the maximum yield obtained during the period, σ is the standard deviation and $\bar{y}$ is mean yield of respective treatment. The values with different letters in a column are significantly different ($p < 0.05$)*

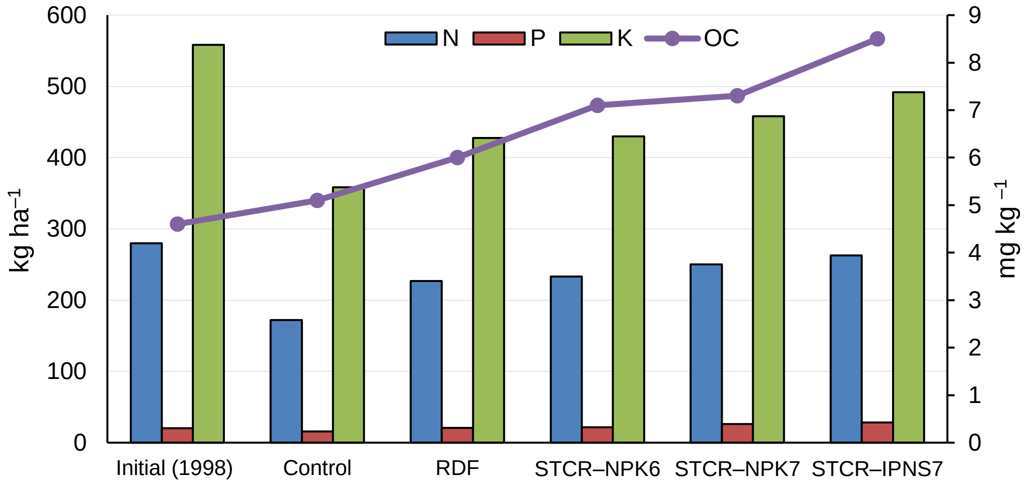

Fig. 1. Effect of treatments on soil nutrient balance compared with initial levels

Table 3. Effect of varying nutrient management practices on soil biological properties

Treatments	Urease (mg NH_4-N g^{-1} hr^{-1})	Phosphatase (mg PNP g^{-1} hr^{-1})	Dehydrogenase (mg TPF g^{-1} day^{-1})	MBC (mg kg^{-1})
Control	12.8c	35.5c	17.4c	101.7d
RDF	17.1b	40.3bc	24.9b	176.7c
STCR–NPK6	18.8b	44.6b	26.4b	198.8bc
STCR–NPK7	20.4ab	48.4ab	28.3b	229.1ab
STCR–IPNS7	23.6a	55.3a	37.9a	254.6c
Mean	18.5	44.8	25.3	192.2
S. Em ±	1.17	1.73	1.18	9.99
C.D. at 5%	3.83	8.4	3.85	48.8

The values with different letters in a column are significantly different ($p < 0.05$)

4. CONCLUSION

The long-term crop yield scenario and SYI suggest that target yield-based IPNS is a more holistic approach to nutrient management compared to chemical-based or no-nutrient applications. Soil test-based IPNS could retard soil nutrient depletion, and improve soil biological properties vis-à-vis ensuring balance nutrient application thereby sustaining the cropping system. Thus, the STCR-IPNS mode of nutrient management is considered as a more sustainable approach than sole chemical-based nutrient application.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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