

Impacts of long-term nutrient management based on soil test and crop response on soil health and yield sustainability in *TypicHaplustalf*

ABSTRACT

We studied the effect of soil test and crop response based long-term nutrient management on yield sustainability and soil health under rice- rice system in a *TypicHaplustalf*. The experiment was designed in randomized block design having five treatments, viz, control, 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-years mean data suggested that minimum yield was observed from control whereas highest was achieved in STCR-IPNS7 in both kharif as well as rabi 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 per ha 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 control.

Keywords: Soil test, crop response, sustainability, soil health

1. INTRODUCTION

One of the major challenges that India faced at present is to produce enough food, fodder, fibre and fuel for its growing population without compromising the need of the future generation. 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. Thus, massive quantity of chemical fertilizers is being pumped into the soil to replenish the nutrients removed by this nutrient exhaustive cropping systems. This can be observed from the fertilizer consumption (total N+P₂O₅+K₂O) that has grown from 69.8 thousand tonnes in 1950-51 to 29.796 million tonnes in 2021-22 with corresponding food grain output of 50.85 million tonnes to 305.6 million tonnes in India [1]. This chemical fertilizer contributes about 50% of the increase in country's food grain production [2]. Although this massive surge in fertilizers use allowed increase in the 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 carbon and yield stagnation[2;3]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. In order to prescribe precise dose of nutrient to crops, fertilizer application should be based on 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 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 combined use of soil and plant analysis [4]. It gives a real balance between applied nutrients and the available nutrients already present in the soil. This management practices are not only sustainable; it can also further improve crop yields and close the gap between actual and attainable yield [5]. The practice of nutrient application based on soil test and crop response for targeted yield using developed fertilizer adjustment equations for crops provides better option for balanced application of nutrients [4]. With 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 *TypicHaplustalf*.

2. MATERIAL 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 All India Coordinated Research Project on Soil Test Crop Response Correlation studies in rice-rice cropping system. The soil of the experimental field (Noyyal series *TypicHaplustalf*) 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 carbon 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 treatments were (i) Control (no organic and chemical fertilizers), (ii) Recommended dose of fertilizers (RDF), (iii) STCR-NPK alone for 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 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:

<i>Kharif</i>	<i>Rabi</i>
FN = 4.39 T – 0.52 SN – 0.80 ON	FN = 4.63 T – 0.56 SN – 0.90 ON
FP ₂ O ₅ = 2.22 T – 3.63 SP – 0.98 OP	FP ₂ O ₅ = 1.98 T – 3.18 SP – 0.99 OP
FK ₂ O = 2.44 T – 0.39 SK – 0.72 OK	FK ₂ O = 2.57 T – 0.42 SK – 0.67 OK

where FN, FP₂O₅ and FK₂O are amount of N, P₂O₅ and K₂O (kg ha⁻¹) fertilizer, respectively; SN, SP and SK are soil test value of available N, P₂O₅ and K₂O (kg ha⁻¹), respectively; ON, OP and OK is the amount of N, P₂O₅ and K₂O applied through organic sources, respectively; and T is target yield (q ha⁻¹).

The STCR based fertilizer prescription equations for a target yield was developed prior to initiation of the experiment. The kharif rice was sown during the first week of June while sowing of rabi was sown in the month of 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. Full dose of P and 25% of N and K were applied basally at the time of transplanting. Remaining N and K₂O 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.

Table 1: Soil test value (kg ha⁻¹) and quantity of fertilizer (kg ha⁻¹) added during the year of experimentation.

Treatments	SN	SP ₂ O ₅	SK ₂ O	FN	FP ₂ O ₅	FK ₂ O
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.

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 for the purpose of estimating 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 determined by Walkley and Black method [6]. Available N was analyzed by alkaline permanganate method [7], available P by Olsen method [8] and available K by ammonium acetate method [9]. The fresh soil samples collected at the maturity of rabi rice were immediately used for estimating biological properties. Urease activity in soils were analysed as per [10]. Phosphatase activity in soil was estimated by p-nitrophenyl phosphate incubation method [11]. Dehydrogenase activity in soil was estimated by incubating with triphenyl tetrazolium chloride (TTC) [12]. Soil microbial biomass carbon in soil was estimated by chloroform fumigation [13].

2.4 Data Analysis

All data were subjected to ANOVA [14] 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 mean yield of respective treatment, σ is the standard deviation and y_m is the maximum yield obtained during the period [15].

3. RESULTS AND DISCUSSION

3.1 Crop Yield and Sustainability

Long-term grain yield scenario of the past 10 years shows that maximum was achieved from STCR-IPNS7 in both the cropping seasons, and 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. Highest mean grain yield in both kharif (6935 kg ha⁻¹) and rabi (6312 kg ha⁻¹) was achieved in highest yield target. The improvement in grain yield using STCR based integrated fertilizer recommendations with organics may be attributed to balance supply of nutrients from soil and improvement in physical, chemical and biological properties of soil [16;17]. In all the years of experimentation, the target yield was achieved with $\pm 10\%$ deviation which is considered acceptable for all STCR experiments.

The sustainable yield index (SYI) is a quantitative measure to assess sustainability of an agricultural practice [15]. The SYI under control is 0.77 for kharif rice and 0.53 for rabi rice in control, which is the lowest among all treatments (Table 2). Highest SYI (0.93 for kharif rabi and 0.77 for rabi) was observed under STCR-IPNS7 systems. The result suggests that absence of chemical and organic fertilizers (control) is least sustainable whereas the presence of organics in addition to chemical fertilizers improve the sustainability of the system. The SYI showed that kharif system could sustain higher crop productivity than the rabi system. Chemical fertilizers application as per *ad hoc* recommendation is more

sustainable than control. Combination of organic and inorganic fertilizers is considered an effective solution to maintain the sustainability of crop ecosystems [18].

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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).

Treatments	Kharif										y _m *	σ	ȳ	SYI
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022				
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				
Treatments	Rabi										y _m	σ	ȳ	SYI
	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-10	2021-22	2022-23				
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 ȳ is mean yield of respective treatment.

3.2 Nutrient Balance

Perusal of data showed significantly higher soil organic carbon, available N, P and K in those plots receiving combined chemical and organic fertilizers as per STCR based nutrient management since the commencement of the experiment in both kharif and rabi season (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. Absence of nutrient input led to serious soil organic carbon depletion from its initial status. Continuous application of FYM alone or in combination with fertilizers increased the SOC in soil than fertilizer alone and control. Ghosh and Singh [19] also found that the treatments where fertilizers were applied showed higher soil organic carbon 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.* [20] reported that combinations of organic and inorganic nitrogen are likely to increase achievable yields and improve soil fertility. Long-term application of nutrients led to build up of soil P levels. Sharma *et al.* [4] reported significantly increase in available P in organic and integrated treatments over 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 lesser in case of plots receiving chemical fertilizers and organics. Thakare and Wake [21] also observed that increasing levels of the organic manures significantly increased the nutrients availability in soil over control.

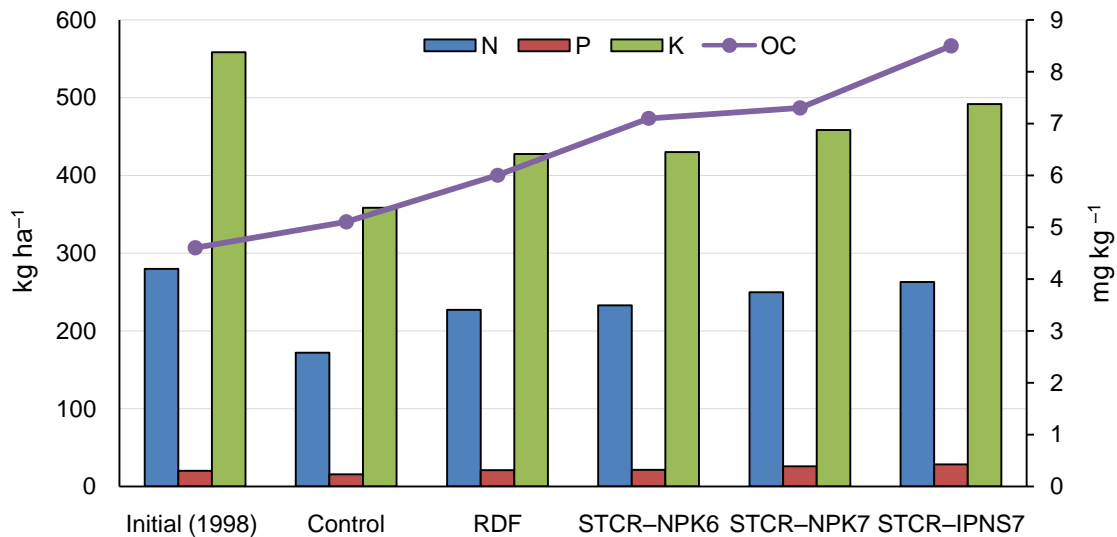


Fig. 1. Effect of treatments on soil nutrient balance compared with initial levels.

3.3 Soil Biological Parameters

Different treatment led to significant changes in the urease, phosphatase, dehydrogenase and microbial biomass carbon in the soil. Compared to control plots, RDF significantly improved the urease, dehydrogenase and microbial biomass carbon by 33.5, 43.1 and 73.7%, respectively. Maximum biological activities were observed in STCR treatment with highest target yield (STCR-IPNS7). Compared to the RDF, this treatment improved the soil urease, phosphatase, dehydrogenase activity and microbial biomass carbon 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 [22;23]

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

Treatments	Urease (mgNH 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

4. CONCLUSION

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

CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

REFERENCES

1. FAI. 2022. Fertilisers Statistics 2021-22. The Fertilisers Association of India. New Delhi.
2. Shukla AK, Behera SK, Chaudhari SK, Singh G. Fertilizer use in Indian agriculture and its impact on human health and environment. *Ind J Fertil.* 2022;18:218-37.
3. Kumar D, Sinha NK, Haokip IC, Kumar J, Wanjari RH, Verma S, Mohanty M, Jayaraman S, Elanchezhian R, Mishra R. Impact of Fertilizer Consumption on Soil Health and Environmental Quality in India. *Ind J Fertil.* 2022;18(10):992-1005.
4. Sharma VK, Pandey RN, Sharma BM. Studies on long term impact of STCR based integrated fertilizer use on pearl millet (*Pennisetum glaucum*)-wheat (*Triticum aestivum*) cropping system in semi-arid condition of India. *J Environ Biol.* 2016;36(1):241.
5. Penuelas J, Coello F, Sardans J. A better use of fertilizers is needed for global food security and environmental sustainability. *Agric Food Secur.* 2023;12(1):5.
6. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29-38.
7. Subbaiah BV, Asija GL. A rapid procedure for estimation of available nitrogen in soil. *Curr. Sci.* 1956;25:259-60.

8. Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorous in soils by extraction with sodium bicarbonate. Circular US Dept. of Agriculture, Washington, DC.
9. Hanway JJ, Heidel H. Soil Analysis Methods as Used in Iowa State College (Agricultural Bulletin No. 57). Iowa State College, Iowa. 1952:1-3.
10. Casida Jr LE, Klein DA, Santoro T. Soil dehydrogenase activity. *Soil Sci.* 1964;98(6):371-6.
11. Tabatabai MA. Use of p-nitro-phenyl phosphate for assay of soil phosphatase activity. *Soil Biol Biochem.* 1972;4:479-87.
12. Tabatabai MA, Bremner JM. Assay of urease activity in soils. *Soil Biol Biochem.* 1972;4(4):479-87.
13. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. *Soil Biol Biochem.* 1987;19(6):703-7.
14. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John Wiley & Sons; 1984.
15. Wanjari RH, Singh MV, Ghosh PK. Sustainable yield index: An approach to evaluate the sustainability of long-term intensive cropping systems in India. *J Sustain Agric.* 2004;24(4):39-56.
16. Rani M, Goyal V, Dey P, Malik K, Yadav R. Soil test based balanced fertilization (10 years) for improving soil nutrient status and use efficiency under pearl millet-wheat cropping system. *Int J Plant Prod.* 2022;16(4):723-39.
17. Shreenivas BV, Ravi MV, Latha HS. Effect of nutrient management approaches on the quality of soil and crops, sustainability of yield in maize-chickpea sequential cropping system. *Int J Agric Sci.* 2017;13(2):353-9.
18. Gentile R, Vanlauwe B, Chivenge P, Six J. Interactive effects from combining fertilizer and organic residue inputs on nitrogen transformations. *Soil Biol Biochem.* 2008;40(9):2375-84.
19. Ghosh BN, Singh RD. Effect of conjoint use of farmyard manure and nitrogen on rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system in Uttaranchal mid-hill soils. *Indian J Agric Sci.* 2003;73(12):680-3.
20. Yang L, Bian X, Yang R, Zhou C, Tang B. Assessment of organic amendments for improving coastal saline soil. *Land Degrad Dev.* 2018;29(9):3204-11.
21. Thakare R, Wake A. Soil microbial population and nutrients availability influenced by graded levels of organic manures under organically grown rainfed pearl millet in vertisol. *J Agroecol Nat Resour Manag.* 2015;2(1):1-5.
22. Li J, Rao M. Field evaluation of crop yield as affected by nonuniformity of sprinkler-applied water and fertilizers. *Agric Water Manag.* 2003;59(1):1-3.
23. Zhou Z, Zhang S, Jiang N, Xiu W, Zhao J, Yang D. Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Front Environ Sci.* 2022;10:2292.