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Budgeting of Primary Nutrients in Soil under Rice-cowpea Cropping Sequences in Alfisols

Jayanthi, T [a*], H. S. Latha [b], Savitha Madappa [c], Nunavath Umilsingh [d], H. R. Umesh [e] and Ashok. L. B [f]

[a] *Department of Soil Science & Agricultural Chemistry, UAS, GKVK, Bangalore, Karnataka, India.*
[b] *Department of Agronomy, AICRP for Dryland Agriculture, UAS, GKVK, Bangalore, Karnataka, India.*
[c] *Department of Crop Physiology, University of Agricultural Sciences, GKVK, Bangalore, Karnataka -560065, India.*
[d] *Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.*
[e] *Department of Soil Science & Agricultural Chemistry, AICRP on LTFE, UAS, GKVK, Bangalore, Karnataka, India.*
[f] *Department of Soil Science & Agriculture Chemistry, College of Agriculture, Karekere, Hassan, Karnataka, India.*

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

A field experiment was undertaken at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India to study the primary nutrients budgeting in rice-cowpea cropping system in an alfisols. Hybrid rice was tested under aerobic condition during *Kharif* 2015-16 and 2016-17 with 16

**Corresponding author: E-mail: jayanthiuasb@gmail.com;*

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treatments replicated thrice in randomized block design. Notably maximum grain (62.98 q ha^{-1}) and straw (85.26 q ha^{-1}) yield of rice was registered in treatment, which received 100% STCR dose through WSF at 8 DI. Rice has exhibited a notably higher total uptake of N, P, and K in the treatment with 100% STCR dose through WSF at 8 DI (220.68, 44.97, and 137.41 kg N, P, and K ha^{-1}, respectively). In fertigation with 100% RDF through WSF at 8 DI, a significantly greater seed yield (12.94 q ha^{-1}) and haulm yield (26.17 q ha^{-1}) of cowpea were observed. At 4 DI, 100% RDF through WSF showed a closely higher total uptake of N, P, and K by cowpea (68.94, 14.67, and 61.39 kg N, P, and K ha^{-1}, respectively). The maximum net positive balance (148.42 kg N ha^{-1}) was noticed in 100% RDF applied through WSF at 8 DI and minimum net positive balance 53.86 kg N ha^{-1} was recorded in 100% RDF-CF. During 2016-17, after the completion of second year residual crop cowpea, the maximum net positive balance (148.42 kg N ha^{-1}) was noticed in 100% RDF applied through WSF at 8 DI and minimum net positive balance 53.86 kg N ha^{-1} was recorded in 100% RDF-CF. The maximum net positive balance (38.27 kg $P_2O_5$$ha^{-1}$) was recorded in 100% STCR dose -WSF 8 DI and minimum net negative balance (15.70 kg P_2O_5 ha^{-1}) was recorded in 100% RDF-CF. The maximum net positive balance of potassium (98.27 kg K_2O ha^{-1}) was recorded in 100% RDF-WSF 4 DI and minimum net positive balance (24.61 kg K_2O ha^{-1}) was recorded in 100% RDF-CF 8 DI treatment.

Keywords: Fertigation; sol test crop response; water soluble fertilizer; conventional fertilizer; cowpea; soil properties.

1. INTRODUCTION

Nutrients like nitrogen, phosphorus, and potassium are essential for human life, but excessive amounts in the Earth's systems can result in environmental issues such as soil, water, and air pollution at local levels. With the increasing demand to feed the global population and rising concerns about nutrient pollution and climate change, managing nutrients sustainably has become a critical challenge for this century [1].

The extensive use of nutrients in agriculture, combined with other human activities, has significantly disrupted nutrient cycles in the Earth's system, particularly for key macronutrients like nitrogen (N) and phosphorus (P). As a result, there is a critical need to enhance nutrient management to provide nutritious food while minimizing harmful environmental effects. However, improving nutrient efficiency depends on the ability to measure and track the movement of nutrients within ecosystems and those that escape them, yet quantifying nutrient budgets remains challenging. A soil-plant nutrient budget, also referred to as a soil surface budget or nutrient balance, views the soil and plants as a single system, accounting for all nutrient inputs and outputs. In response to this challenge, growing research on nutrient budgets—focusing on nutrient inputs and outputs within a system—has significantly advanced our understanding of the complex nutrient cycles in human-natural systems. The aim of this paper is to assess the gain or loss of primary nutrients in the soil following a rice-cowpea cropping system in alfisols.

2. MATERIALS AND METHODS

The experiment was carried out using sixteen treatments, each replicated three times, during the Kharif seasons of 2015 and 2016, with hybrid rice (KRH-4) as the test crop. The residual effects on the subsequent cowpea crop (KM-5), grown during the summer seasons of 2016 and 2017, were also studied at ZARS, GKVK, Bangalore. Pooled data from two years of aerobic rice cultivation were collected and analyzed using a randomized complete block design (RCBD) [2].

Treatments consisted of T_1:Control (without NPK fertilizers), T_2:100% RDF-Conventional fertilizers through soil application as per PoP, T_3:100% RDF-Conventional fertilizers through fertigation at 4 days interval (DI), T_4:100% RDF-Conventional fertilizers through fertigation at 8 DI, T_5:100% RDF-Water soluble fertilizers through fertigation at 4 days interval, T_6:50% RDF-Water soluble fertilizers through fertigation at 4 DI, T_7:30% RDF-Water soluble fertilizers through fertigation at 4 DI, T_8:100% RDF-Water soluble fertilizers through fertigation at 8 DI, T_9:50% RDF-Water soluble fertilizers through fertigation at 8 DI, T_{10}:30% RDF-Water soluble fertilizers through fertigation at 8 DI, T_{11}:100% STCR-Water soluble fertilizers through fertigation at 4 days interval, T_{12}:50% STCR-Water soluble fertilizers through fertigation at 4 DI, T_{13}:30% STCR-Water soluble fertilizers through fertigation at 4 DI, T_{14}:100% STCR-Water soluble fertilizers through fertigation at 8 DI, T_{15}:50% STCR-Water soluble fertilizers through fertigation at 8 DI and T_{16}:30% STCR-Water soluble fertilizers through fertigation at 8 DI.

For hybrid rice, following the recommended practices, 10 t/ha of farmyard manure was incorporated into the soil 20 days prior to sowing. Additionally, $ZnSO_4$ was applied at 20 kg/ha, and nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) were applied at rates of 125:62.5:62.5 kg/ha, respectively, according to the treatment plans, except in the case of the absolute control. In treatment T_2, nitrogen was applied in three split doses: 50% as a basal application, and the remaining 50% was top-dressed in two equal parts during the active tillering stage and before panicle initiation. Phosphorus was fully applied at sowing, and potassium was split into two equal applications: one as basal and the other during active tillering, using conventional fertilizers such as urea, single superphosphate, and muriate of potash. The basal fertilizer doses were applied during sowing at 30%, 50%, and 30% for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), respectively, across treatments T_3 to T_{16}. For treatments T_3 and T_4, the remaining 70% of nitrogen, 50% of phosphorus, and 70% of potassium were provided through conventional fertilizers *via.,* fertigation at intervals of 4 days (15 times) and 8 days (8 times). For the treatments involving water-soluble fertilizers (T_5, T_6, T_7, T_{11}, T_{12} and T_{13}, and T_8, T_9, T_{10}, T_{14}, T_{15} and T_{16}), the remaining 70% of nitrogen, 50% of phosphorus, and 70% of potassium were applied through different grades of water-soluble fertilizers, such as 19:19:19 (all nutrients at 19%), Mono Potassium Phosphate (MPP), Mono Ammonium Phosphate (MAP), Sulphate of Potash (SOP), and Calcium Nitrate (CN), following fertigation at 4-day (15 times) and 8-day (8 times) intervals.

Fertigation was carried out using a venturi system, starting 20 days after sowing and continuing until 80 days after sowing or the panicle initiation stage, depending on the treatment. The irrigation schedule remained consistent across all treatments. In both years, following the harvest of aerobic rice, the land was prepared during the summer season, and cowpea was planted as the succeeding crop to assess the residual impact of fertigation with water-soluble fertilizers.

The initial soil samples were collected from each plot separately before conducting the experiment and soil samples were air dried, powdered, sieved and stored in plastic cover. And analysis was carried out for different physical and chemical properties as per standard procedures. Similarly, after the harvest of the aerobic rice, the soil samples were collected in each plot from both the years and analysis was done as per the standard procedures (Table 1).

The amount of fertilizers for STCR treatments (T_{11} to T_{16}) necessary to achieve a target yield of 80 q ha^{-1} was calculated (Table 2) using the STCR targeted yield equation developed at ZARS, V.C. Farm, Mandya [3], as detailed below.

Table 1. The physical-chemical properties of soil

Nutrient	Value	Remarks
Sandy clay loam		
Soil reaction (pH)	6.72	Neutral
OC (0.48%) content	OC (0.48%) content	Low
Available N	212.59 kg ha^{-1}	Low
Available P	21.98 kg ha^{-1}	Medium
Available K	210.43 kg ha^{-1}	Medium
Exchangeable Ca	3.96 cmol (p^+) kg^{-1}	-
Exchangeable Mg	2.63 cmol (p^+) kg^{-1}	-
Available S	17.60 ppm	-
DTPA extractable Fe	18.28 ppm	-
DTPA extractable Zn	1.65 ppm	-
DTPA extractable Mn	23.91 ppm	-
DTPA extractable Cu	0.61 ppm	-

Table 2. NPK nutrition application quantity for various treatments using various methods in 2015-16 and 2016-17

Treatments	Quantity of nutrients applied (kg/ha)					
	2015-16			2016-17		
	N	P	K	N	P	K
T_1-Control	0.00	0.00	0.00	0.00	0.00	0.00
T_2-100% RDF-CF	125.00	62.50	62.50	125.00	62.50	62.50
T_3-100% RDF-CF 4 DI	125.00	62.50	62.50	125.00	62.50	62.50
T_4-100% RDF-CF 8 DI	125.00	62.50	62.50	125.00	62.50	62.50
T_5-100% RDF-WSF 4DI	125.00	62.50	62.50	125.00	62.50	62.50
T_6-50% RDF-WSF 4DI	62.50	31.25	31.25	62.50	31.25	31.25
T_7-30% RDF-WSF 4 DI	37.50	18.75	18.75	37.50	18.75	18.75
T_8-100% RDF-WSF 8 DI	125.00	62.50	62.50	125.00	62.50	62.50
T_9-50% RDF-WSF 8 DI	62.50	31.25	31.25	62.50	31.25	31.25
T_{10}-30% RDF-WSF 8 DI	37.50	18.75	18.75	37.50	18.75	18.75
T_{11}-100% STCR dose -WSF 4 DI	154.61	118.50	68.43	196.66	92.80	107.65
T_{12}-50% STCR dose -WSF 4 DI	76.74	58.60	38.21	106.15	52.54	58.36
T_{13}-30% STCR dose -WSF 4 DI	45.87	35.21	21.74	65.87	33.01	35.69
T_{14}-100% STCR dose -WSF 8 DI	148.08	116.71	71.71	200.73	93.99	110.45
T_{15}-50% STCR dose -WSF 8 DI	74.98	59.02	35.62	108.10	53.48	57.52
T_{16}-30% STCR dose -WSF 8 DI	44.23	34.84	20.35	66.72	33.00	35.82

F-N =5.166 T- 0.799 S N x $KMnO_4$.N-9.67 x OM

F-P_2O_5 =1.636 T- 0.256 S P_2O_5 x Olsen.P_2O_5-0.77 x OM

F-K_2O =2.31T- 0.493 S K_2O x Amm.Ace.K_2O-1.14 x OM

Where,

T = Targeted yield (q ha^{-1}) *i.e*. 80 q ha^{-1}
FN = Fertilizer N (kg ha^{-1})
FP_2O_5 = Fertilizer P (kg ha^{-1})
FK_2O = Fertilizer K (kg ha^{-1})
OM= Organic manure (FYM) (kg ha^{-1})
S-N, S-P_2O_5 and S-K_2O are initial available N, P_2O_5 and K_2O kg ha^{-1}, respectively.

3. RESULTS AND DISCUSSION

Grain and straw yield of aerobic rice: When rice was fertigated with 100% STCR dose using water soluble fertilizers at 8 DI, treatment yields of grain (62.98 q ha^{-1}) and straw (85.26 q ha^{-1}) were much higher (Fig. 1). This might be explained by the full solubility of WSF and increased nutrient availability close to the effective root zone, which led to improved nutrient uptake and a potential increase in yield in the STCR targeted yield strategy. Similar outcomes were stated by Raina et al. [4]; Hebbar et al. [5] and Anusha [6]; Anitta [7], Tadesse et al. [8] and Pradeep Kumar and Parmanand [9] and Umilsingh et al. [10].

Total uptake of major nutrients by aerobic rice: The treatment with 100% STCR dose through water soluble fertilizers at 8 DI has recorded significantly higher total uptake N, P and K by rice (220.68, 44.97 and 137.41 kg N, P and K ha^{-1}, respectively) and data presented in Table 3. This could be because the rice root zone has been more evenly distributed with regular supplies of the readily soluble form of NPK nutrients combined with irrigation water in fertigation treatments, which led to a higher availability of nutrients in the soil for plant uptake in drip fertigation with WSF through STCR approach than soil application of conventional fertilizers. Similar data were obtained by Hebbar et al. [5] in tomato crop and Raina et al. [4] in apricot.

Seed yield and haulm yield of cowpea: The results of the 8 DI treatment's 100% RDF fertigation with water soluble fertilizers showed a noticeably greater haulm and seed production (12.94 and 26.17 q ha^{-1}, respectively) (Fig. 2). This may be the result of applying a higher dose (100%) of NPK fertilizer using an RDF or STCR approach to an aerobic rice crop that was planted before cowpeas were planted. This may have left more residual NPK nutrients in the soil, which improved root nodulation and nitrogen fixation. It may also have helped maintain soil fertility by utilizing infinite atmospheric nitrogen through biological nitrogen fixation. Production of an elevated level of yield structure may be caused by an increased level of biomass accumulation as well as an efficient translocation and absorption of photosynthates to the reproductive parts as a result of an appropriate supply of nutrients. The current study's findings are consistent with those published by Gawain and Pawar [11]; Saeid et al. [12].

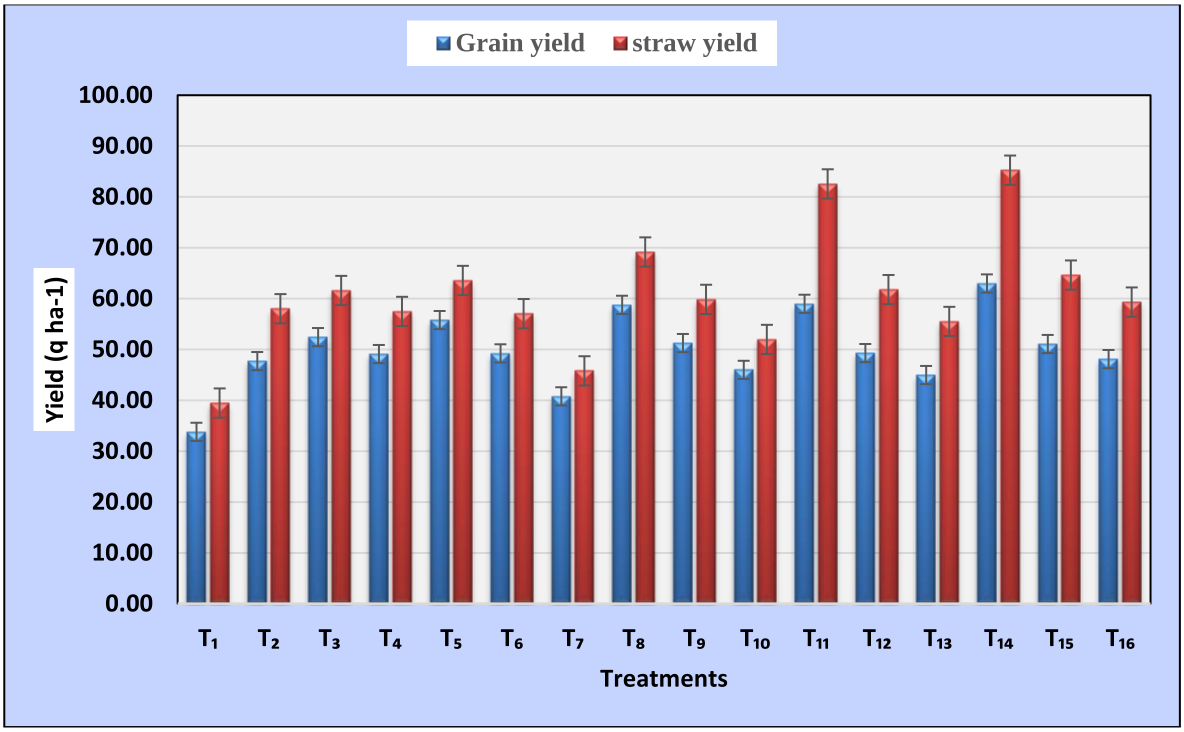

Fig. 1. Impact of various fertilizer treatment methods, forms, dosages, and intervals on the grain and straw production of aerobic rice grown in an aerobic rice-cowpea cropping sequence

Table 3. Impact of various fertilizer administration methods, forms, dosages, and intervals on rice's overall uptake of N, P, and K in an aerobic rice-cowpea cropping cycle

Treatments	Total uptake (kg/ha)		
	N	P	K
T_1-Control	102.99	18.53	54.58
T_2-100% RDF-CF	140.45	27.14	89.30
T_3-100% RDF-CF 4 DI	162.62	29.75	98.22
T_4-100% RDF-CF 8 DI	157.09	27.31	90.30
T_5-100% RDF-WSF 4 DI	194.06	41.18	127.50
T_6-50% RDF-WSF 4 DI	144.61	31.17	77.45
T_7-30% RDF-WSF 4 DI	118.13	26.14	59.53
T_8-100% RDF-WSF 8 DI	201.24	42.15	126.67
T_9-50% RDF-WSF 8 DI	148.86	31.03	80.33
T_{10}-30% RDF-WSF 8 DI	131.38	28.46	60.85
T_{11}-100% STCR dose -WSF 4 DI	205.45	43.15	131.50
T_{12}-50% STCR dose -WSF 4 DI	143.77	31.80	81.44
T_{13}-30% STCR dose -WSF 4 DI	128.68	27.47	61.66
T_{14}-100% STCR dose -WSF 8 DI	220.68	44.97	137.41
T_{15}-50% STCR dose -WSF 8 DI	154.89	32.80	80.23
T_{16}-30% STCR dose -WSF 8 DI	139.52	29.84	65.32
SEm ±	**007.42**	**01.56**	**02.24**
CD at 5%	**020.98**	**04.40**	**06.35**

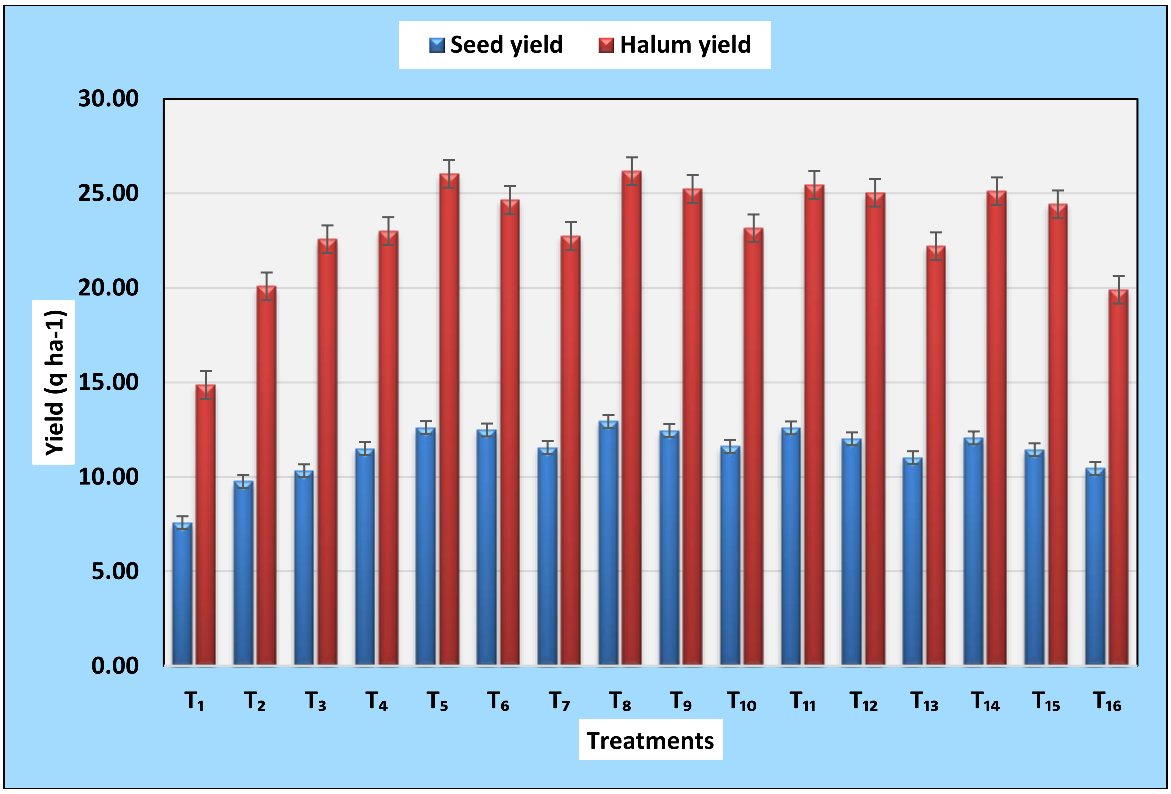

Fig. 2. Impact of water-soluble fertilizer fertigation on cowpea seed and haulm output in a rice-cowpea cropping sequence

Table 4. The impact of varying methods, types, amounts, and timing of fertilizer administration on the overall uptake of nitrogen, phosphorus, and potassium by cowpea in an aerobic rice-cowpea cropping cycle

Treatments	**Total uptake (kg ha^{-1})**		
	N	**P**	**K**
T_1-Control	34.73	7.94	32.55
T_2-100% RDF-CF	49.25	11.40	44.36
T_3-100% RDF-CF 4 DI	51.89	12.79	49.62
T_4-100% RDF-CF 8 DI	53.88	12.41	51.61
T_5-100% RDF-WSF 4 DI	68.94	14.67	61.39
T_6-50% RDF-WSF 4 DI	61.62	13.28	55.51
T_7-30% RDF-WSF 4 DI	53.26	12.00	50.79
T_8-100% RDF-WSF 8 DI	67.07	14.65	60.03
T_9-50% RDF-WSF 8 DI	61.96	12.64	54.81
T_{10}-30% RDF-WSF 8 DI	55.31	11.54	49.42
T_{11}-100% STCR dose -WSF 4 DI	65.86	14.09	56.31
T_{12}-50% STCR dose -WSF 4 DI	57.78	12.56	53.49
T_{13}-30% STCR dose -WSF 4 DI	51.40	11.49	49.26
T_{14}-100% STCR dose -WSF 8 DI	61.76	13.67	55.91
T_{15}-50% STCR dose -WSF 8 DI	54.51	12.24	51.90
T_{16}-30% STCR dose -WSF 8 DI	46.76	10.48	44.18
SEm ±	**2.42**	**0.43**	**2.73**
CD at 5%	**6.83**	**1.23**	**7.70**

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizers, CF: Conventional fertilizers, DI: Days interval, NS: Non significant

Table 5. Nitrogen balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice-cowpea cropping system (2015-16)

Treatments	Initial Available N (kg ha^{-1})	Addition of N through fertilizer (kg ha^{-1})	Total N (kg ha^{-1})	Crop uptake of N (kg ha^{-1})	Expected balance N (kg ha^{-1})	Actual available N (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	202.25	0.00	202.25	141.28	60.97	106.12	45.15
T_2-100% RDF-CF	206.73	125.00	331.73	186.88	146.00	132.33	-12.52
T_3-100% RDF-CF 4 DI	210.91	125.00	335.91	218.70	117.21	140.33	23.12
T_4-100% RDF-CF 8 DI	207.44	125.00	332.44	211.75	120.69	139.33	18.65
T_5-100% RDF-WSF 4 DI	201.60	125.00	326.60	269.35	57.25	145.67	88.42
T_6-50% RDF-WSF 4 DI	203.00	62.50	265.50	214.93	50.57	123.39	72.83
T_7-30% RDF-WSF 4 DI	225.87	37.50	263.37	175.32	88.05	126.52	38.47
T_8-100% RDF-WSF 8 DI	205.80	125.00	330.80	273.21	57.59	130.33	72.74
T_9-50% RDF-WSF 8 DI	208.13	62.50	270.63	223.08	47.55	113.40	65.85
T_{10}-30% RDF-WSF 8 DI	214.03	37.50	251.53	192.24	59.29	111.26	51.98
T_{11}-100% STCR dose -WSF 4 DI	202.72	154.61	357.33	276.00	81.33	150.08	68.76
T_{12}-50% STCR dose -WSF 4 DI	204.12	76.74	280.86	206.30	74.57	130.52	55.95
T_{13}-30% STCR dose -WSF 4 DI	204.84	45.87	250.71	184.28	66.43	121.40	54.97
T_{14}-100% STCR dose -WSF 8 DI	210.89	148.08	358.97	289.23	69.74	145.00	75.26
T_{15}-50% STCR dose -WSF 8 DI	208.53	74.98	283.51	213.99	69.52	125.64	56.12
T_{16}-30% STCR dose -WSF 8 DI	211.68	44.23	255.91	191.21	64.70	117.86	53.16

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Table 6. Nitrogen balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice-cowpea cropping system (2016-17)

Treatments	Initial available N (kg ha^{-1})	Addition of N through fertilizer (kg ha^{-1})	Total N (kg ha^{-1})	Crop uptake of N (kg ha^{-1})	Expected balance N (kg ha^{-1})	Actual available N (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	106.12	0.00	106.12	134.16	-28.04	77.67	105.70
T_2-100% RDF-CF	132.33	125.00	257.33	192.52	64.81	118.67	53.86
T_3-100% RDF-CF 4 DI	140.33	125.00	265.33	210.32	55.02	128.00	72.98
T_4-100% RDF-CF 8 DI	139.33	125.00	264.33	210.19	54.14	121.13	66.98
T_5-100% RDF-WSF 4 DI	145.67	125.00	270.67	256.65	14.02	128.33	114.31
T_6-50% RDF-WSF 4 DI	123.39	62.50	185.89	197.53	-11.63	102.00	113.63
T_7-30% RDF-WSF 4 DI	126.52	37.50	164.02	167.45	-3.42	105.80	109.22
T_8-100% RDF-WSF 8 DI	130.33	125.00	255.33	263.42	-8.09	140.33	148.42
T_9-50% RDF-WSF 8 DI	113.40	62.50	175.90	198.54	-22.65	105.00	127.65
T_{10}-30% RDF-WSF 8 DI	111.26	37.50	148.76	181.13	-32.37	97.85	130.22
T_{11}-100% STCR dose -WSF 4 DI	150.08	196.66	346.75	266.62	80.13	142.67	62.54
T_{12}-50% STCR dose -WSF 4 DI	130.52	106.15	236.67	196.80	39.87	130.06	90.20
T_{13}-30% STCR dose -WSF 4 DI	121.40	65.87	187.28	175.87	11.41	109.33	97.93
T_{14}-100% STCR dose -WSF 8 DI	145.00	200.73	345.73	275.65	70.08	138.48	68.40
T_{15}-50% STCR dose -WSF 8 DI	125.64	108.10	233.74	204.82	28.92	120.91	91.99
T_{16}-30% STCR dose -WSF 8 DI	117.86	66.72	184.58	181.35	3.23	101.60	98.37

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Table 7. Phosphorous balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice- cowpea cropping system (2015-16)

Treatments	Initial available P_2O_5 (kg ha^{-1})	Addition of P_2O_5 through fertilizer (kg ha^{-1})	Total P_2O_5 (kg ha^{-1})	Crop uptake of P_2O_5 (kg ha^{-1})	Expected balance P_2O_5 (kg ha^{-1})	Actual available P_2O_5 (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	25.81	0.00	25.81	26.70	-0.89	19.67	20.56
T_2-100% RDF-CF	20.43	62.50	82.93	39.52	43.41	59.33	15.92
T_3-100% RDF-CF 4 DI	17.56	62.50	80.06	42.58	37.48	74.43	36.95
T_4-100% RDF-CF 8 DI	21.51	62.50	84.01	39.10	44.91	63.15	18.24
T_5-100% RDF-WSF 4 DI	20.79	62.50	83.29	55.16	28.13	64.42	36.29
T_6-50% RDF-WSF 4 DI	21.15	31.25	52.40	45.85	6.55	42.65	36.10
T_7-30% RDF-WSF 4 DI	22.23	18.75	40.98	38.04	2.94	36.91	33.97
T_8-100% RDF-WSF 8 DI	20.79	62.50	83.29	55.98	27.31	63.39	36.09
T_9-50% RDF-WSF 8 DI	20.79	31.25	52.04	45.18	6.86	40.93	34.07
T_{10}-30% RDF-WSF 8 DI	23.30	18.75	42.05	40.20	1.85	33.52	31.67
T_{11}-100% STCR dose -WSF 4 DI	18.28	118.50	136.78	57.96	78.82	118.67	39.84
T_{12}-50% STCR dose -WSF 4 DI	23.38	58.60	81.97	45.33	36.64	70.69	34.05
T_{13}-30% STCR dose -WSF 4 DI	22.77	35.21	57.97	39.81	18.16	51.38	33.22
T_{14}-100% STCR dose -WSF 8 DI	25.26	116.71	141.98	60.23	81.74	114.04	32.29
T_{15}-50% STCR dose -WSF 8 DI	20.07	59.02	79.09	45.41	33.68	63.37	29.69
T_{16}-30% STCR dose -WSF 8 DI	27.52	34.84	62.36	40.56	21.80	51.52	29.72

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Table 8. Phosphorous balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice-cowpea cropping system (2016-17)

Treatments	Initial available P_2O_5 (kg ha^{-1})	Addition of P_2O_5 through fertilizer (kg ha^{-1})	Total P_2O_5 (kg ha^{-1})	Crop uptake of P_2O_5 (kg ha^{-1})	Expected balance P_2O_5 (kg ha^{-1})	Actual available P_2O_5 (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	19.67	0.00	20.16	26.24	-6.08	13.67	19.75
T_2-100% RDF-CF	59.33	62.50	117.59	37.56	80.03	64.33	-15.70
T_3-100% RDF-CF 4 DI	74.43	62.50	127.84	42.49	85.36	76.67	-8.69
T_4-100% RDF-CF 8 DI	63.15	62.50	124.74	40.35	84.39	79.33	-5.06
T_5-100% RDF-WSF 4 DI	64.42	62.50	121.92	56.53	65.39	83.54	18.15
T_6-50% RDF-WSF 4 DI	42.65	31.25	68.90	43.07	25.83	43.50	17.67
T_7-30% RDF-WSF 4 DI	36.91	18.75	50.66	38.25	12.41	37.67	25.25
T_8-100% RDF-WSF 8 DI	63.39	62.50	120.89	57.61	63.29	80.77	17.48
T_9-50% RDF-WSF 8 DI	40.93	31.25	67.18	42.15	25.03	41.67	16.64
T_{10}-30% RDF-WSF 8 DI	33.52	18.75	47.27	39.80	7.47	36.84	29.37
T_{11}-100% STCR dose -WSF 4 DI	118.67	92.80	152.97	56.52	96.45	126.67	30.21
T_{12}-50% STCR dose -WSF 4 DI	70.69	52.54	96.83	43.39	53.44	69.33	15.89
T_{13}-30% STCR dose -WSF 4 DI	51.38	33.01	67.64	38.11	29.54	54.85	25.31
T_{14}-100% STCR dose -WSF 8 DI	114.04	93.99	149.52	57.05	92.47	130.75	38.27
T_{15}-50% STCR dose -WSF 8 DI	63.37	53.48	90.95	44.68	46.27	71.43	25.16
T_{16}-30% STCR dose -WSF 8 DI	51.52	33.00	69.14	40.09	29.05	52.43	23.38

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Table 9. Potassium balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice-cowpea cropping system (2015-16)

Treatments	Initial available K_2O (kg ha^{-1})	Addition of K_2O through fertilizer (kg ha^{-1})	Total K_2O (kg ha^{-1})	Crop uptake of K_2O (kg ha^{-1})	Expected balance K_2O (kg ha^{-1})	Actual available K_2O (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	212.40	0.00	212.40	89.43	122.97	97.85	-25.12
T_2-100% RDF-CF	203.79	62.50	266.29	139.93	126.36	107.67	-18.69
T_3-100% RDF-CF 4 DI	193.33	62.50	255.83	151.25	104.59	120.00	15.41
T_4-100% RDF-CF 8 DI	223.60	62.50	286.10	142.91	143.19	124.49	-18.70
T_5-100% RDF-WSF 4 DI	234.13	62.50	296.63	189.22	107.41	126.79	19.38
T_6-50% RDF-WSF 4 DI	195.60	31.25	226.85	133.80	93.05	108.14	15.09
T_7-30% RDF-WSF 4 DI	211.80	18.75	230.55	112.45	118.10	106.95	-11.15
T_8-100% RDF-WSF 8 DI	224.60	62.50	287.10	189.32	97.78	129.00	31.22
T_9-50% RDF-WSF 8 DI	217.80	31.25	249.05	138.04	111.01	120.20	9.20
T_{10}-30% RDF-WSF 8 DI	210.33	18.75	229.08	112.63	116.45	112.33	-4.12
T_{11}-100% STCR dose -WSF 4 DI	212.48	68.43	280.92	189.85	91.06	133.10	42.04
T_{12}-50% STCR dose -WSF 4 DI	196.33	38.21	234.54	138.17	96.37	114.75	18.38
T_{13}-30% STCR dose -WSF 4 DI	204.32	21.74	226.06	112.58	113.48	110.17	-3.31
T_{14}-100% STCR dose -WSF 8 DI	205.85	71.71	277.56	193.20	84.36	127.43	43.06
T_{15}-50% STCR dose -WSF 8 DI	206.80	35.62	242.42	134.62	107.80	118.15	10.35
T_{16}-30% STCR dose -WSF 8 DI	213.67	20.35	234.02	112.27	121.75	109.29	-12.46

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Table 10. Potassium balance in soil as influenced by different approaches, forms, doses and intervals of fertilizer application on rice under aerobic rice-cowpea cropping system (2016-17)

Treatments	Initial available K_2O (kg ha^{-1})	Addition of K_2O through fertilizer (kg ha^{-1})	Total K_2O (kg ha^{-1})	Crop uptake of K_2O (kg ha^{-1})	Expected balance K_2O (kg ha^{-1})	Actual available K_2O (kg ha^{-1})	Net gain (+) or Net loss (-) (kg ha^{-1})
T_1-Control	97.85	0.00	104.78	84.85	19.93	63.00	43.07
T_2-100% RDF-CF	107.67	62.50	200.53	127.38	73.15	100.67	27.51
T_3-100% RDF-CF 4 DI	120.00	62.50	171.79	144.43	27.36	110.51	83.15
T_4-100% RDF-CF 8 DI	124.49	62.50	228.60	140.91	87.69	112.30	24.61
T_5-100% RDF-WSF 4 DI	126.79	62.50	211.62	188.56	23.07	121.34	98.27
T_6-50% RDF-WSF 4 DI	108.14	31.25	139.39	132.12	7.27	100.00	92.73
T_7-30% RDF-WSF 4 DI	106.95	18.75	137.96	108.18	29.78	92.35	62.56
T_8-100% RDF-WSF 8 DI	129.00	62.50	201.65	184.08	17.57	107.08	89.50
T_9-50% RDF-WSF 8 DI	120.20	31.25	151.45	132.25	19.20	95.33	76.13
T_{10}-30% RDF-WSF 8 DI	112.33	18.75	139.54	107.91	31.63	90.90	59.27
T_{11}-100% STCR dose -WSF 4 DI	133.10	107.65	237.73	185.77	51.96	127.24	75.28
T_{12}-50% STCR dose -WSF 4 DI	114.75	58.36	173.11	131.70	41.40	92.89	51.49
T_{13}-30% STCR dose -WSF 4 DI	110.17	35.69	142.79	109.25	33.54	97.61	64.07
T_{14}-100% STCR dose -WSF 8 DI	127.43	110.45	236.34	193.45	42.90	123.89	80.99
T_{15}-50% STCR dose -WSF 8 DI	118.15	57.52	175.67	129.65	46.01	104.04	58.03
T_{16}-30% STCR dose -WSF 8 DI	109.29	35.82	145.71	106.71	39.00	107.67	68.66

RDF: Recommended dose of fertilizer, STCR: Soil test crop response, WSF: Water soluble fertilizer, CF: Conventional fertilizers, DI: Days of interval, NS: Non significant

Total uptake of major nutrients by cowpea: At 4 DI, cowpeas absorbed significantly more N, P, and K overall (68.94, 14.67, and 61.39 kg N, P, and K ha^{-1}, respectively) when grown in 100% RDF using water-soluble fertilizers (Table 4). The higher biomass output along with increased availability of leftover nitrogen, phosphorous, and potassium in the soil following rice crop harvest may be the cause of the cowpea crop's increased uptake of N, P, and K. The enhanced nutrient intake was further linked to the improved cowpea growth and yield performance. Similar results were also noted by Dinesh [13], who stated that the application of organic manure provides the first crop with roughly one-third of the total N and half of the total P, with the remaining N and P being available to the subsequent crop as a residual effect.

Balance sheet of available NPK in soil as influenced by different approaches, forms, doses and intervals of fertilizer application under rice-cowpea cropping system (2015-16 and 2016-17): Prior to the seeding of aerobic rice, the initial nutrient status (NPK) of the soil was assessed and documented. The total amount of nutrients in the soil includes the nutrients that were added through chemical fertilizers. Following the harvest of both the rice and cowpea crops, the amount of nutrients removed by them was measured. Each season's expected balance, actual balance, and net gain/loss of nutrients were computed independently.

N balance sheet: Table 5 displays the initial available N in the soil for each of the 16 treatments in 2015–16, which ranged from 201.60 to 225.87 kg N ha^{-1}. Maximum nitrogen uptake (289.23 kg N ha^{-1}) by aerobic rice and cowpea combined from the soil was noted in the treatment when 100% NPK was administered via STCR with WSF at 8 DI. When no fertilizers or FYM were given, the control treatment showed the lowest uptake (141.28 kg N ha^{-1}). However, the real balance in the 100% STCR dose -WSF 4 DI was greater (150.08 kg N ha^{-1}), whereas the control group showed a lower value (106.12 kg N ha^{-1}). The maximum net positive balance (88.42 kg N ha^{-1}) was recorded in 100% RDF-WSF 4 DI, but net negative balance (-12.52 kg N ha^{-1}) was found in 100% RDF-CF, 100% RDF was applied through regular fertilizer as per package of practice.

In 2016-17, the initial available N content in soil varied from 106.12 to 150.08 kg N ha^{-1} between the 16 treatments in the present investigation (Table 6). Aerobic rice and cowpea showed a greater uptake of nitrogen (275.65 kg N ha^{-1}) in the soil in the treatment when 100% NPK was treated using an STCR technique and WSF at 8 DI. With no fertilizer and FYM applied, the control treatment had the lowest uptake (134.16 kg N ha^{-1}). The real N balance, however, was found to be lower in the control (77.67 kg N ha^{-1}) and higher (142.67 kg N ha^{-1}) in the 100% STCR dosage -WSF 4 DI. The maximum net positive balance (148.42 kg N ha^{-1}) was noticed in 100% RDF applied through WSF at 8 DI and minimum net positive balance 53.86 kg N ha^{-1} was recorded in 100% RDF-CF.

P balance sheet: The initial available P_2O_5 content in soil varied from 17.56 to 27.52 kg P_2O_5 ha^{-1} during 2015-16 and furnished in Table 7. When 100% NPK was administered using STCR with WSF at 8 DI, aerobic rice and cowpeas jointly absorbed the most phosphorus from the soil (60.23 kg P_2O_5 ha^{-1}). With no fertilizer and FYM applied, the control treatment had the lowest absorption (26.70 kg P_2O_5 ha^{-1}). The real phosphorus balance, however, was seen to be lower in the control (19.67 kg P_2O_5 ha^{-1}) and greater (118.67 kg P_2O_5 ha^{-1}) in the 100% STCR dosage -WSF 4 DI. In 100% STCR dosage -WSF 4 DI, the maximum net positive balance (39.84 kg P_2O_5 ha^{-1}) was greater than in 100% RDF-CF, with the lowest net positive balance (15.92 kg P_2O_5 ha^{-1}) being recorded.

The initial available P_2O_5 in soil varied between 19.67 and 118.67 kg P_2O_5 ha^{-1} in 2016–17 across the four treatments (Table 8). Maximum phosphorus uptake (57.61 kg P_2O_5 ha^{-1}) by aerobic rice and cowpea combined from the soil was noted in the treatment that received 100% NPK applied using RDF with WSF at 8 DI. With no fertilizer and FYM applied, the control treatment had the lowest absorption (26.24 kg P_2O_5 ha^{-1}). The maximum net positive balance (38.27 kg ha^{-1}) was recorded in 100% STCR dose -WSF 8 DI, and the minimum net negative balance (15.70 kg P_2O_5 ha^{-1}) was recorded in 100% RDF-CF. However, the actual balance was higher (130.75 kg P_2O_5 ha^{-1}) in 100% STCR dose -WSF 4 DI and lower value (13.67 kg P_2O_5 ha^{-1}) was observed in the control.

K balance sheet: The initial available K_2O in soil varied between 193.33 and 234.13 kg K_2O ha^{-1} in 2015–16 (Table 9). In 100% NPK administered using STCR with WSF at 8 DI, higher potassium uptake by aerobic rice and cowpea combined (193.20 kg K_2O ha^{-1}) from the soil was observed. With no fertilizer and FYM applied, the control treatment had the lowest absorption (89.43 kg K_2O ha^{-1}). Nevertheless, at 100% STCR dose -WSF 4 DI, the real balance was higher (133.10 kg K_2O ha^{-1}) and the control showed a lower value (97.85 kg K_2O ha^{-1}). The net positive balance (43.06 kg K_2O ha^{-1}) was higher in 100% STCR dose -WSF 8 DI and maximum net negative balance (25.12 kg K_2O ha^{-1}) was recorded in control treatment.

Table 10 displays the initial available K_2O in soil for each of the 16 treatments, which ranged from 97.85 to 133.10 kg K_2O ha^{-1} in 2016-17. The maximum potassium uptake (193.45 kg K_2O ha^{-1}) by aerobic rice and cowpea combined from the soil was observed in 100% NPK applied using STCR with WSF at 8 DI. The treatment with no fertilizer and FYM applied, known as the control treatment, had the lowest uptake (84.85 kg K_2O ha^{-1}). However, actual balance of K was higher (127.24 kg K_2O ha^{-1}) in 100% STCR dose -WSF 4 DI and lower value (63.00 kg K_2O ha^{-1}) was noticed in control and maximum net positive balance of potassium (98.27 kg K_2O ha^{-1}) was recorded in 100% RDF-WSF 4 DI and minimum net positive balance (24.61 kg K_2O ha^{-1}) was recorded in 100% RDF-CF 8 DI treatment.

Balanced nutrient management in cropping systems which can maintain the good soil health, thereby minimizing environmental pollution, is a cost-effective and environmentally friendly approach to target agricultural sustainability. Tanmoy et al. [14] concluded the application of ample doses of recommended nutrients is essential to maintain a positive nutrient balance. The rice-legume systems, which has the opportunity to replenish a portion of the nutrients (more specifically N) through biological N fixation and nutrient recycling. The control treatment (no fertilizer application) yielded less with the least nutrient uptake and omission of any nutrient, as well as a control treatment, resulted in a negative nutrient balance, which is synonymous with depletion of soil fertility. A cost-effective and environmentally beneficial way to attain agricultural sustainability is through balanced nutrient management in cropping systems, which promotes healthy soil and lowers environmental pollution. Applying the required nutritional doses in sufficient amounts is essential to preserving a good nutrient balance, according to Tanmoy et al. [14]. One benefit of rice-legume systems is that they recycle resources and use biological nitrogen fixation to replenish some nutrients, especially nitrogen. The treatment that did not apply fertilizer had the lowest yields and the least amount of nitrogen uptake. In addition, a negative nutrient balance a sign of declining soil fertility was produced by the lack of any nutrient or control treatment. According to Senthivelu et al. [15], FYM @ 12.5 t ha^{-1} and 100% inorganic recommended NPK (112.5:37.5:37.5 kg ha^{-1}) alone showed significantly higher amounts of nutrient uptake, post-harvest nutrient availability, and positive balance of NPK. Net negative nutrient balance was seen in the control treatment. According to Ajeet et al. [16], applying fertilizer and increasing irrigation levels to cauliflower at the same time may be a sustainable way to improve soil fertility and nutrient balance. By lowering nutrient loss in the soil and increasing nutrient availability during the cropping season, drip fertigation's nutrient supply allowed for increased uptake of NPK and maintained the soil's nutritional status. According to Bhavya et al. [17], the STCR method of fertilizer application, in particular when combined with the IPNS approach, is more appropriate for achieving a greater yield as well as a more effective and balanced use of fertilizer nutrients, which results in a higher positive balance of applied main nutrients in the soil. Since FYM was administered to every plot in the current investigation, every treatment aside from the control recorded a positive balance. Singh et al. [18] cited similar results.

4. CONCLUSION

It is possible to draw the conclusion that, given the circumstances of this study, it is advised to cultivate cowpea plants at 100% STCR dose using water soluble fertilizer at 8 DI in order to obtain superior effects on seed output and nutrient uptake. Similarly, fertigation with 100% RDF through WSF at 8 DI increased the production of seeds in cowpeas, and at 4 DI, cowpeas absorbed 100% RDF through WSF.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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