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Effect of Different Fertilizers and Approaches on Nutrient Use Efficiency and Economics of Aerobic Rice Under Rice-Cowpea Cropping Sequence in Ecological Conditions of Karnataka, India

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

[a] Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bangalore, Karnataka, India.
[b] AICRP on LTFE, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bangalore, Karnataka, India.
[c] Department of Crop Physiology, University of Agricultural Sciences, GKVK, Bangalore Karnataka -560065, India.
[d] AICRP for Dry land Agriculture, University of Agricultural Sciences, GKVK, Bangalore, Karnataka, India.
[e] Department of Soil Science and Agriculture Chemistry, College of Agriculture, Karekere, Hasan, Karnataka, India.
[f] Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, 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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**Corresponding author: Email: jayanthiuasb@gmail.com;*

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ABSTRACT

At the University of Agricultural Sciences, GKVK, Bengaluru, a field experiment was conducted in 2015-16 and 2016-17 to examine the impact of fertigation on the yield, nutrient usage efficiency, and economics of aerobic rice in an aerobic rice–cowpea cropping sequence. In a randomized block design, hybrid rice was tested in aerobic conditions with 16 treatments that were reproduced three times. The results indicated that significantly higher grain (62.98 q ha^{-1}) and straw (85.26 q ha^{-1}) yield of rice was recorded in 100% STCR dose through WSF at 8 DI. Similarly higher NRn (3.50 kg q^{-1}) and NRp (0.86 kg q^{-1}) of grain production in 100% STCR dose with WSF at 8 DI on contrary, higher NRk of 2.27 kg q^{-1} was noticed in 100% STCR with WSF at 4 DI. While higher AUE-N (32.51 kg kg^{-1}), AUE-P (65.02 kg kg^{-1}) and AUE-K (65.02 kg kg^{-1}) were recorded in 30% RDF with WSF at 8 DI. The higher ACRE-N (78.60 %) was recorded with 100% RDF with WSF at 8 DI and higher ACRE-P (44.40%) was recorded with 30% RDF with WSF at 8 DI. Notably higher ACRE-K (132.51%) was recorded in 30% STCR with WSF at 8 DI. However, supplement of 30% STCR dose with WSF at 8 DI obtained notably higher IUE-N (35.05 kg kg^{-1}), IUE-P (163.27 kg kg^{-1}) and IUE-K (60.11 kg kg^{-1}). Significantly higher PFP-N, P and K (261.23, 522.46 and 522.46, respectively) were recorded in 30% RDF with WSF at 8 DI. Among all treatments, 100% RDF through CF at 4 DI found significantly higher B: C ratio (2.74) during both years of pooled data.

Keywords: Agronomic use efficiency; apparent crop recovery efficiency; partial factor productivity; net returns; cost of cultivation; B: C ratio.

1. INTRODUCTION

A significant amount of water is used in the production of rice in India, where it is historically produced in standing water utilizing flood irrigation. Typical irrigation rates are 1200 mm ha^{-1} yr^{-1} on average, and in exceptionally dry years, they may surpass 1400-1500 mm [1]. India is a major contributor to the world's rice production, with an average productivity of 2.80 metric tons per hectare and a production output of 129.4 million metric tons [2]. The traditional method of puddled transplanted rice cultivation is in danger due to the depletion of water supplies and the increase in water expenses [3,4]. Surface and groundwater use has peaked in many areas, and sustainable agriculture will become more difficult in the future unless we embrace water-saving technologies. Enhancing water management is essential to growing rice sustainably. Numerous tactics are being actively sought in an effort to reduce the amount of water needed for rice production. These include switching to aerobic rice production and employing techniques like alternate soaking and drying under the system of rice intensification (SRI). Increased water productivity is required, and new research has shown that rice may also be cultivated in dry soils without flooding a process known as "aerobic rice." Since aerobic rice production uses less water than other water-saving technologies, it increases rice's water productivity and efficiency [5,6]. According to Adekoya *et al*. [7], fertigation is the most efficient method of providing nutrients to plant roots and significantly lowers environmental pollution risk. For example, drip fertigation in aerobic paddy fields results in a drop in methane gas emissions. Future green revolution and food security through energy and water security would benefit greatly from this. One of the most expensive agricultural inputs in the future will be fertilizer, and using the proper amount of fertilizer nutrients is essential for both environmental preservation and farm profitability. Therefore, fertilizer feeds the planet by feeding the soils, which in turn nourish the plants. Fertilizers will continue to be essential to the production of food grains if the world is to avoid starvation. According to FAO [8], the amount of mineral fertilizer nutrients used globally is predicted to rise from 175 million tons in 2015 to 199 million tons in 2030.

Historically, the most popular technique for figuring out the ideal fertilizer dosages has been applying fertilizer based on recommendations from soil tests. This method is known as the "low-medium-high approach" and is frequently used in soil testing labs across the nation.

Nonetheless, the most suitable and scientific approach is the soil test crop response (STCR) targeted yield approach, which applies fertilizer by taking into account the crop's nutrient requirements, soil test results, and the contribution of nutrients from manures, fertilizers, and soil for particular yield targets [9]. Red gram, green gram, black gram, cowpea, moth bean, horse gram, peas, and other pulses are among the major crops farmed in India. The cowpea (*Vigna ungiculata* L.), a multipurpose grain legume that is widely grown in arid and semiarid tropical regions, is one of the most important arid legumes. It has been grown for human and animal sustenance in India since ancient times. When there is not enough water available to support a subsequent crop, fodder cowpea can be produced profitably as a summer crop in sandy loam rice fallow soils. According to Patidar and Mali [10], the inputs and subsequent crop have an impact on the component crop's reaction in a cropping system.

Because drip irrigation minimizes the soaking area by decreasing the active root zone, it allows for maximum water and nutrient efficiency. The cost of fertilizer and irrigation is decreased when fertilizer is added to drip irrigation. Fertigation also reduces the amount of nutrients lost due to leaching. When water-soluble fertilizer was applied to the soil instead of regular fertilizer, the concentration of accessible plant nutrients in the top layer was higher [11]. Compared to the conventional method, which involves applying fertilizers at a fixed dose with fewer splits, which may be the cause of more nutrient losses through various means, losses and fixation were minimal when applied in small quantities with a greater number of splits, which ultimately led to higher fertilizer use efficiency [12].

Utilizing water-soluble N sources with appropriate varieties, enhancing timing and application techniques, and better integrating the administration of basal N fertilizer without standing water are all ways to increase the efficiency of N utilization in rice [13]. Through trickle fertigation, nutrients can be applied directly to the area where active roots are highly concentrated. The efficiency of fertilizer use is likewise excellent because nutrients are applied to a small volume of soil. However, leaching, percolation, and volatilization can result in significant nutrient losses from traditional fertilization, particularly on light soils [14]. Accurately adjusting water and fertilizer inputs to match crop needs is another benefit of drip fertigation. Considering these factors, a study was conducted to assess the impacts of drip. Taking these points into account an investigation was carried out to evaluate the effects of drip fertigation on yield, nutrient use efficiency and economics of aerobic rice.

2. MATERIALS AND METHODS

Hybrid rice (KRH-4) was used as the test crop in this experiment, which involved sixteen treatments that were reproduced three times during *Kharif* 2015 and 2016. The investigation also examined the residual effects of these treatments on cowpea crop (KM-5), which was grown at ZARS, GKVK, Bangalore, throughout the summer seasons of 2016 and 2017. In an RCBD design, two years' worth of pooled data from an aerobic rice crop were gathered and examined. Treatments comprised 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 days interval, T_5:100% RDF-Water soluble fertilizers through fertigation at 4 days interval, T_6:50% RDF-Water soluble fertilizers through fertigation at 4 days interval, T_7:30% RDF-Water soluble fertilizers through fertigation at 4 days interval, T_8:100% RDF-Water soluble fertilizers through fertigation at 8 days interval, T_9:50% RDF-Water soluble fertilizers through fertigation at 8 days interval, T_{10}:30% RDF-Water soluble fertilizers through fertigation at 8 days interval, T_{11}:100% STCR-Water soluble fertilizers through fertigation at 4 days interval, T_{12}:50% STCR-Water soluble fertilizers through fertigation at 4 days interval, T_{13}:30% STCR-Water soluble fertilizers through fertigation at 4 days interval, T_{14}:100% STCR-Water soluble fertilizers through fertigation at 8 days intervals, T_{15}:50% STCR-Water soluble fertilizers through fertigation at 8 days intervals and T_{16}:30% STCR-Water soluble fertilizers through fertigation at 8 days intervals.

For hybrid rice, as per the package of practice the recommended dose of farm yard manure @ 10 t ha^{-1} was incorporated into the soil 20 days before sowing, $ZnSO_4$ @ 20 kg ha^{-1} and N, P_2O_5, K_2O @ 125:62.5:62.5 kg ha^{-1}, respectively were applied as per the treatments except for the absolute control treatment. For treatment T_2, where N was applied in three split doses *viz.*, 50% as basal, the remaining 50% nitrogen was top dressed in two equal splits during active tillering and before panicle initiation stage, 100% P nutrient was applied at the time of sowing and K was applied in two equal splits as basal and at active tillering stage through conventional fertilizers *viz*., urea, single super phosphate and muriate of potash, respectively. Basal dose of fertilizers were applied at the time of sowing @ 30%, 50% and 30% (N, P_2O_5 and K_2O, respectively) from T_3 to T_{16} treatments. For T_3 and T_4 treatments, in which the remaining 70%, 50% and 70% of N, P_2O_5 and K_2O, respectively were supplied through conventional fertilizers at 4 (15 times) and 8 (8 times) days interval of fertigation. Further, for the water soluble fertilizers treatments (*viz.*, T_5, T_6, T_7, T_{11}, T_{12} & T_{13} and T_8, T_9, T_{10}, T_{14}, T_{15} & T_{16}) the remaining 70%, 50% and 70% of N, P_2O_5 and K_2O, respectively were done through different grades of water soluble fertilizers *viz*., 19:19:19 (19 all), Mono Potassium Phosphate (MPP), Mono ammonium phosphate (MAP), Sulphate of Potash (SOP) and Calcium nitrate (CN) at 4 (15 times) and 8 (8 times) days interval of fertigation. The fertigation was done through ventury system starting from 20 days after sowing and continued up to 80 days after sowing or panicle initiation stage to each plot as per the treatments. Irrigation schedule was common for all the treatments. In both the years, after the harvest of the aerobic rice, land preparation was carried out, in summer season and cowpea was taken as a succeeding crop to check the residual effect of fertigation of 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 and cowpea, the soil samples were collected in each plot for each crop from both the years and analysis was done as per the standard procedures. The experimental field is located at 13° 15' N Latitude and 76° 15' E longitude with at elevation of 881.48 m above the mean sea level (MSL) and its texture is sandy clay loam and soil pH was neutral in reaction (6.72). and neutral in soil reaction (6.72). The initial fertility status of soil showed low OC (0.48%) content. And the soil was low in available N content, medium in available P_2O_5 and K_2O (212.59, 21.98 and 210.43 kg ha^{-1}, respectively) and sufficient amount of exch. Ca and Mg (3.96 and 2.63 [cmol (p$^+$) kg^{-1}], respectively) and available S (17.60 ppm) content in present in soil. DTPA extractable micronutrients *viz.,* (Fe-18.28, Zn-1.65, Mn-23.91and Cu-0.61 mg kg^{-1}) content in the soil was above critical levels.

Using the STCR targeted yield equation created at ZARS, V.C. Farm, Mandya [15], the amount of fertilizer needed for STCR treatments (T_{11} to T_{16}) for a yield of 80 q ha^{-1} was calculated (Table 1).

Table 1. Quantity of nutrients applied for various treatments via different approaches during 2015-16 and 2016-17

Treatments	Nutrients applied (kg ha^{-1})					
	2015-16			2016-17		
	N	P	K	N	P	K
T_1-Control	0.0	0.0	0.0	0.0	0.00	0.0
T_2-100% RDF-CF	125.0	62.5	62.5	125.0	62.5	62.5
T_3-100% RDF-CF 4 DI	125.0	62.5	62.5	125.0	62.5	62.5
T_4-100% RDF-CF 8 DI	125.0	62.5	62.5	125.0	62.5	62.5
T_5-100% RDF-WSF 4DI	125.0	62.5	62.5	125.0	62.5	62.5
T_6-50% RDF-WSF 4DI	62.5	31.2	31.2	62.5	31.3	31.2
T_7-30% RDF-WSF 4 DI	37.5	18.7	18.7	37.5	18.8	18.7
T_8-100% RDF-WSF 8 DI	125.0	62.5	62.5	125.0	62.5	62.5
T_9-50% RDF-WSF 8 DI	62.5	31.2	31.2	62.5	31.3	31.3
T_{10}-30% RDF-WSF 8 DI	37.5	18.7	18.7	37.5	18.8	18.8
T_{11}-100% STCR dose -WSF 4 DI	154.6	118.5	68.4	196.7	92.8	107.7
T_{12}-50% STCR dose -WSF 4 DI	76.7	58.6	38.2	106.2	52.5	58.4
T_{13}-30% STCR dose -WSF 4 DI	45.9	35.2	21.7	65.9	33.0	35.7
T_{14}-100% STCR dose -WSF 8 DI	148.1	116.7	71.7	200.7	93.9	110.5
T_{15}-50% STCR dose -WSF 8 DI	74.9	59.0	35.6	108.1	53.5	57.5
T_{16}-30% STCR dose -WSF 8 DI	44.2	34.8	20.3	66.7	33.0	35.8

FN =5.166 T- 0.799 SN x $KMnO_4$.N-9.67 x OM
FP_2O_5 =1.636 T- 0.256 SP_2O_5 x Olsen.P_2O_5-0.77 x OM
FK_2O =2.31T- 0.493 SK_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

3.1 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 significantly greater (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 increased nutrient uptake and a potential increase in yield in the STCR targeted yield strategy. Similar outcomes were stated by Raina *et al*. [16], Hebbar *et al.* [11], Anusha [17], Anitta [18], Tadesse *et al*. [19] and Pradeep Kumar and Parmanand [20].

3.2 Nutrient Requirement of N, P and K by Rice

NRn (3.50 kg q^{-1}) of aerobic rice grain production was noticeably increased in the 100% STCR dose with WSF at 8 DI. The NRp (0.86 kg q^{-1}) was noticeably higher in the treatment with 100% STCR dosage and WSF 8 DI. At 4 DI, 100% STCR with WSF showed a noticeably greater NRk of 2.27 kg q^{-1} (Table 2). Due to their complete solubility, availability, and efficiency, water-soluble fertilizers may have a higher nutrient uptake rate than traditional fertilizers in chilli crops [21].

3.3 Agronomic Use Efficiency (AUE)

In 30% RDF with WSF at 8 DI, AUE-N was noticeably greater (32.51 kg kg^{-1}). AUE-P was noticeably greater in 30% RDF with WSF at 8 DI (65.02 kg kg^{-1}). AUE-K was much greater at 65.02 kg kg^{-1} for the 30% RDF with WSF treatment at 8 DI (Table 3). The increased availability of nutrients to the plants close to the root zone may be the reason for the higher nutrient utilization efficiency under fertigation. According to Singandhupe *et al.* [22], the drip irrigation method's fertilizer use efficiency was enhanced by the frequent supply of nitrogen as urea, which was followed by the creation of NH4+, its longer-term adsorption on soil clay minerals, and the subsequent slow formation of nitrate nitrogen. Additionally, Dakshina Murthy *et al.* [23] described how incremental doses of the corresponding nutrients gradually boosted the agronomic efficiency of N, P, and K in rice.

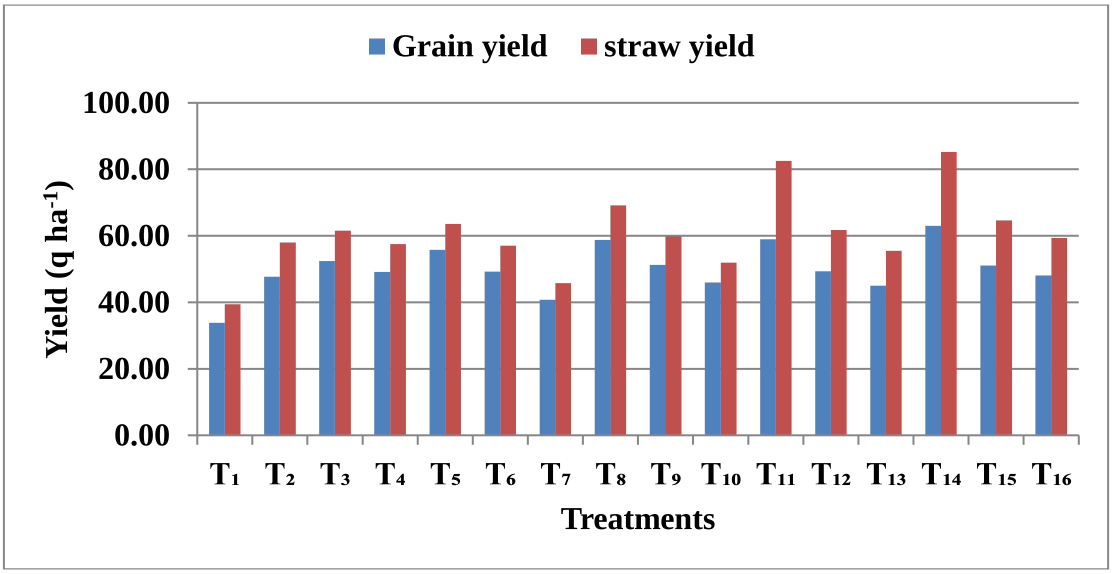

Fig. 1. Impact of various approaches, forms, doses and intervals of fertilizer application on grain and straw yield of aerobic rice under rice -cowpea cropping sequence

Table 2. Impact of various fertilizer application methods, types, dosages, and timings on the N, P, and K nutrient requirements of rice grain production in an aerobic rice-cowpea cropping sequence

Treatments	NR	PR	KR
		(kg q^{-1})	
T_1-Control	3.06	0.63	1.69
T_2-100% RDF-CF	2.97	0.63	1.95
T_3-100% RDF-CF 4 DI	3.14	0.64	1.97
T_4-100% RDF-CF 8 DI	3.22	0.67	1.87
T_5-100% RDF-WSF 4 DI	3.49	0.73	1.91
T_6-50% RDF-WSF 4 DI	2.94	0.64	1.76
T_7-30% RDF-WSF 4 DI	2.91	0.62	1.78
T_8-100% RDF-WSF 8 DI	3.43	0.73	1.94
T_9-50% RDF-WSF 8 DI	2.91	0.66	1.91
T_{10}-30% RDF-WSF 8 DI	2.89	0.65	1.74
T_{11}-100% STCR dose -WSF 4 DI	3.48	0.80	2.27
T_{12}-50% STCR dose -WSF 4 DI	2.92	0.67	1.81
T_{13}-30% STCR dose -WSF 4 DI	2.88	0.66	1.90
T_{14}-100% STCR dose -WSF 8 DI	3.50	0.86	2.24
T_{15}-50% STCR dose -WSF 8 DI	3.03	0.73	1.89
T_{16}-30% STCR dose -WSF 8 DI	2.92	0.72	1.87
S Em ±	0.16	0.04	0.14
CD at 5%	0.45	0.11	0.39

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

Table 3. Impact of various fertilizer application methods, types, dosages, and timings on the Agronomic use efficiency and Apparent crop recovery efficiency of aerobic rice under rice-cowpea cropping sequence

Treatments	AUE-N	AUE-P	AUE-K	ACRE-N	ACRE-P	ACRE-K
		(kg kg^{-1})			(%)	
T_1-Control	0.00	0.00	0.00	0	0	0
T_2-100% RDF-CF	11.13	11.13	11.13	29.97	14.37	56.45
T_3-100% RDF-CF 4 DI	14.90	14.90	14.90	47.70	20.13	73.13
T_4-100% RDF-CF 8 DI	12.24	12.24	12.24	43.28	18.84	56.02
T_5-100% RDF-WSF 4 DI	17.58	17.58	17.58	72.85	30.82	78.88
T_6-50% RDF-WSF 4 DI	24.69	24.69	24.69	66.59	33.13	95.19
T_7-30% RDF-WSF 4 DI	18.61	18.61	18.61	40.36	20.72	81.12
T_8-100% RDF-WSF 8 DI	19.98	19.98	19.98	78.60	34.64	91.19
T_9-50% RDF-WSF 8 DI	27.93	27.93	27.93	73.39	39.78	131.44
T_{10}-30% RDF-WSF 8 DI	32.51	32.51	32.51	75.70	44.40	119.91
T_{11}-100% STCR dose -WSF 4 DI	14.53	14.53	14.53	59.18	24.68	90.57
T_{12}-50% STCR dose -WSF 4 DI	17.08	17.08	17.08	45.58	21.70	72.87
T_{13}-30% STCR dose -WSF 4 DI	20.61	20.61	20.61	48.23	25.14	110.90
T_{14}-100% STCR dose -WSF 8 DI	17.08	17.08	17.08	69.51	31.31	96.02
T_{15}-50% STCR dose -WSF 8 DI	19.27	19.27	19.27	58.72	28.90	93.09
T_{16}-30% STCR dose -WSF 8 DI	26.80	26.80	26.80	69.82	39.82	132.51
SEm ±	5.20	5.20	5.20	9.15	6.31	14.63
CD at 5%	14.70	14.70	14.70	ACRE-N	ACRE-P	ACRE-K

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

3.4 Apparent Crop Recovery Efficiency (ACRE)

Table 3 displays the data for the treatment with 100% RDF+WSF at 8 DI by fertigation, which had the greater ACRE-N (78.60%). At 8 DI, a noticeably greater ACRE-P (44.40%) was noted in 30% RDF with WSF. At 8 DI, 30% STCR with WSF showed a noticeably higher ACRE-K (132.51%) (Table 3). This might be the result of increased nutrient availability and the crop's simultaneous uptake of higher N, P, and K levels. This demonstrates the potential for higher levels of the corresponding nutrients and demonstrates that the recovery efficiency of the incremental dosages is good at early increments. These findings closely match those of Patel and Upadyay [24]. WSF applied at lower doses showed a higher ACRE-P than WSF applied at higher doses with conventional fertilizers. This could be because the soil has more P available due to the supply of P from completely soluble form from water-soluble fertilizers and from FYM mineralization.

3.5 Internal Utilization Efficiency

At 8 DI, a 30% STCR dosage with WSF markedly increased IUE-N in aerobic rice (35.05 kg kg^{-1}). At 4 DI of fertigation, the 30% RDF treatment using water-soluble fertilizers showed a noticeably higher IUE-P (163.27 kg kg^{-1}). Table 4 shows a considerably greater IUE-K for the control treatment (60.11 kg kg^{-1}). In comparison to other treatments, Prakash *et al.* [25] found that the utilization efficiency of N, P, and K was higher when no nutrient was provided (43.04%, 207.66%, and 41.22%, respectively). Rice's usage efficiency dropped when fertilizer levels rose (Table 4).

3.6 Partial Factor Productivity

At 8 DI, 30% RDF with WSF had a significantly greater PFP-N (261.23) than the other treatments. In aerobic rice, the 30% RDF with WSF treatment at 8 DI was shown to have a considerably larger PFP-P (522.46) than the other treatments (Table 4). At 8 DI, 30% RDF with WSF showed a significantly greater PFP-K (522.46) than the other treatments (Table 4). This enhanced PFP in the current study was brought about by balanced nutrient application, improved nutrient uptake and use of native nutrients, and an increase in the crop's ability to absorb applied nutrients and use them to produce grain [26]. This could be because split NPK application timed to crop demand improved NPK partial factor productivity, recovery efficiency, and agronomic efficiency. More nutrients available to plants resulted in the highest fertilizer nutrient recovery [27].

Table 4. Impact of various fertilizer application methods, types, dosages, and timings on the internal utilization efficiency and partial factor productivity of aerobic rice under rice-cowpea cropping sequence

Treatments	IUE-N	IUE-P	IUE-K	PFP-N	PFP-P	PFP-K
		(kg kg^{-1})				
T_1-Control	32.92	161.42	60.11	0	0	0
T_2-100% RDF-CF	33.96	158.43	52.11	84.58	169.15	169.15
T_3-100% RDF-CF 4 DI	32.31	156.61	51.29	91.23	182.45	182.45
T_4-100% RDF-CF 8 DI	31.23	150.87	53.83	85.26	170.53	170.53
T_5-100% RDF-WSF 4 DI	28.75	139.55	52.76	95.47	190.95	190.95
T_6-50% RDF-WSF 4 DI	34.09	156.88	57.08	170.04	340.09	340.09
T_7-30% RDF-WSF 4 DI	34.55	163.27	56.89	230.86	461.72	461.72
T_8-100% RDF-WSF 8 DI	29.29	138.53	51.76	102.36	204.71	204.71
T_9-50% RDF-WSF 8 DI	34.42	152.86	52.65	177.77	355.54	355.54
T_{10}-30% RDF-WSF 8 DI	35.05	156.47	58.22	261.23	522.46	522.46
T_{11}-100% STCR dose -WSF 4 DI	28.82	126.23	45.50	82.41	134.95	171.95
T_{12}-50% STCR dose -WSF 4 DI	34.34	149.43	55.25	126.03	199.93	243.34
T_{13}-30% STCR dose -WSF 4 DI	34.99	152.49	53.33	188.77	294.18	380.34
T_{14}-100% STCR dose -WSF 8 DI	28.66	117.85	45.68	87.69	141.55	172.56
T_{15}-50% STCR dose -WSF 8 DI	33.18	137.37	52.99	131.64	205.87	266.59
T_{16}-30% STCR dose -WSF 8 DI	34.44	139.37	54.20	204.90	316.24	423.92
SEm ±	1.71	7.88	3.44	05.78	10.24	14.19
CD at 5%	4.85	22.29	9.71	16.33	28.96	40.12

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

More AE and RE were observed in wheat when the recommended dose of N was applied in 3-split doses as opposed to 2-split doses [28].

3.7 Cost of cultivation

The treatment that received 100% RDF with WSF at 4 DI had a significantly greater cost of cultivation (₹ 76, 861 ha^{-1}) than the other treatments, with the exception of 100% RDF with WSF at 8 DI, which was statistically comparable (₹ 76,361 ha^{-1}) (Table 5). However, the control plot showed a reduced cultivation cost (₹ 27,990 ha^{-1}).

3.8 Gross Returns

Although 100% STCR with WSF at 8 DI had much greater gross returns (₹ 1,38,753 ha^{-1}) than other treatments, it was statistically comparable to 100% STCR dosage WSF 4 DI (₹ 1,30,350 ha^{-1}) and 100% RDF-WSF 8 DI (₹ 1,27,935 ha^{-1}). However, Table 5 shows that the control plot had a lower gross return (₹ 73,522 ha^{-1}).

3.9 Net Returns

The current study included 16 distinct treatment combinations; however, the 100% RDF with conventional fertilizer at 4 DI yielded considerably greater net returns of ₹ 72,484 ha^{-1} than the other treatments (Table 5). However, 30% RDF with WSF at 4 DI treatment showed a reduced net return of ₹ 40,104 ha^{-1}.

3.10 Benefit Cost Ratio (B: C ratio)

With the exception of Control, 100% RDF-CF, and 100% RDF-CF 4 DI, which were statistically equivalent, the B: C ratio (2.74) was considerably higher in the 100% RDF with conventional fertilizer at 4 DI in the current study (Table 5). However, in 100% RDF with WSF at 4 DI plot, a lower B:C ratio (1.58) was observed.

According to Kavitha *et al*. [29], even though WSF plots produced better yields, the benefit-to-cost ratio was worse, mostly because drip-fertilized tomatoes require expensive specific fertilizers. When compared to drip irrigation with 100% RDF soil application, the fertigated plots yielded a greater yield and gross income because of the higher uptake and higher nutrient usage efficiency of expensive fertilizers, which resulted in a very small change in the B: C ratio. As a result, the higher costs for the water-soluble fertilizers were fairly offset by the higher income. Veeranna [21] found similar outcomes, with 80% of the soluble fertilizers achieving higher yields with lower B: C ratios as a result of higher WSF pricing.

Table 5. Impact of various fertilizer application methods, types, dosages, and timings on economics of aerobic rice under rice-cowpea cropping sequence

Treatments	Cost of cultivation (Rs.)	Gross returns (Rs.)	Net returns (Rs.)	B: C ratio
T_1-Control	27990.00	73522.33	45532.33	2.63
T_2-100% RDF-CF	40919.10	104121.50	63202.40	2.54
T_3-100% RDF-CF 4 DI	41619.10	114103.33	72484.23	2.74
T_4-100% RDF-CF 8 DI	41119.10	106821.75	65702.65	2.60
T_5-100% RDF-WSF 4 DI	76861.20	121088.33	44227.13	1.58
T_6-50% RDF-WSF 4 DI	56480.60	107023.17	50542.56	1.90
T_7-30% RDF-WSF 4 DI	48328.36	88432.08	40103.72	1.83
T_8-100% RDF-WSF 8 DI	76361.20	127935.00	51573.80	1.68
T_9-50% RDF-WSF 8 DI	55980.60	111490.83	55510.23	1.99
T_{10}-30% RDF-WSF 8 DI	47828.36	99781.92	51953.56	2.09
T_{11}-100% STCR dose -WSF 4 DI	75007.38	130349.92	55342.54	1.75
T_{12}-50% STCR dose -WSF 4 DI	56662.46	107836.00	51173.54	1.91
T_{13}-30% STCR dose -WSF 4 DI	48587.96	98262.67	49674.70	2.03
T_{14}-100% STCR dose -WSF 8 DI	74664.32	138752.83	64088.51	1.87
T_{15}-50% STCR dose -WSF 8 DI	56031.39	111828.33	55796.94	2.01
T_{16}-30% STCR dose -WSF 8 DI	47956.64	105114.67	57158.03	2.20
SEm ±	255.39	5464.96	5444.40	0.11
CD at 5%	721.98	15449.29	15391.18	0.32

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

According to Tahmina *et al*. [30], the rice yield, nutrient uptake, and subsequent use efficiency, as well as the concentrations of organic carbon, were all considerably impacted by the combined application of organic and inorganic fertilizers. In rice cultivation, there were notable variations in the recovery, agronomic, and physiological efficiency of N, P, and K between treatments. In comparison to the RD and farmers' practices, the nitrogen recovery efficiency (RE) was found to be significantly greater in the treatments that included both organic and inorganic fertilizers (56-58%).

4. CONCLUSION

Under the conditions of this investigation, it can be recommended by cultivate, higher grain and straw yield, NRn, NRp was recorded in 100% STCR dose+WSF at 8 DI on contrary higher NRk was noticed in 100% STCR with WSF at 4 DI. While higher AUE-N, AUE-P and AUE-K were recorded in 30% RDF with WSF at 8 DI. The higher ACRE-N, ACRE-P and ACRE-K was recorded with 100% RDF, 30% RDF and 30% STCR, respectively with WSF at 8 DI. However, supplement of 30% STCR dose with WSF at 8 DI obtained notably higher IUE-N, IUE-P and IUE-K. Significantly higher PFP-N, P and K were recorded in 30% RDF with WSF at 8 DI. Higher B: C ratio was obtained with 100% RDF through CF at 4 DI.

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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