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Nutrient use efficiency as influenced by fertigation of water soluble fertilizers in aerobic rice

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Abstract

A field experiment was carried out at ZARS, UAS, GKVK, Bengaluru to study the "Nutrient use efficiency as influenced by fertigation of water soluble fertilizers in aerobic rice" during *Kharif* 2015 and 2016. The present investigation includes 16 different treatment combinations replicated thrice with RCBD design where hybrid rice (KRH-4) was a test crop grown. The results indicated that, significantly higher grain and straw yield of rice were recorded with T_{14} treatment, which received the fertigation with 100% STCR dose through water soluble fertilizers (WSF) at 8 (8 times) days interval over soil application of 100% conventional fertilizers as per package of practice. Similarly, significantly higher NRn and NRp (3.50 and 0.86 mg kg^{-1}, respectively) were recorded in fertigation with 100% STCR dose through WSF at 8 days interval (T_{14}) and the treatment T_{11} recorded significantly higher NRk (2.27 mg kg^{-1}) for grain production of aerobic rice than conventional fertilizers treatments. Significantly higher AUE-N (67.05%) and AUE-K (140.99%) were recorded with fertigation with 30% STCR with WSF at 8 DI (T_{16}) and fertigation with 30% RDF with WSF at 8 DI (T_{10}) recorded significantly higher AUE-P of 131.73%. Significantly higher apparent crop recovery efficiency of N, P and K was recorded (78.60, 44.40 and 132.51 kg kg^{-1}) in fertigation with 100% RDF+WSF at 8 DI (T_8), 30% RDF with WSF at 8 DI through fertigation (T_{10}) and 30% STCR with WSF at 8 DI (T_{16}), respectively. Significantly higher internal utilization efficiencies of N (78.15%), P (352.11%) and K (129.43%) were noticed in T_{13}, T_2 and T_1, respectively. Fertigation with 30% RDF with WSF at 8 DI (T_{10}) recorded significantly higher partial factor productivity of N, P and K (261.23, 522.46 and 522.46, respectively) than other treatments. However, lower agronomic use efficiency-NPK (25.97%, 51.93% and 51.93%, respectively) was observed in soil application of 100% RDF with conventional fertilizer as per PoP (T_2) treatment. Similarly, lower apparent crop recovery efficiency of N and P (29.9 and 14.37 kg kg^{-1}, respectively) were observed with soil application of 100% RDF with conventional fertilizer (T_2). Similarly, lower ACRE-K (56.02 kg kg^{-1}) was observed in soil application of 100% RDF with conventional fertilizer at 8 DI (T_4).

Keywords: Fertigation, water soluble fertilizers, conventional fertilizers, Nutrient use efficiency and aerobic rice

Introduction

Rice is one of the input intensive crops in the world and input of nutrient contributes approximately 20-25% to the total production costs of rice. At present rice production alone consumes nearly 24.7 Mt of fertilizer ($N + P_2O_5 + K_2O$) which accounts for approximately 14.0 % of total global fertilizer consumption in a year. Scientists have predicted that a hike of at least 60% in rice yield is essential in order to ensure food and nutritional security of 9 billion populations that are expected to inhabit the globe by 2050. With increasing demand for food production, demand for nutrients is likely to increase further. Despite several decades of research the average recovery efficiency of N, P and K in rice is only 30-35%, 20-25% and 35-40%, respectively. At present, India imports 30% of nitrogenous, 70% of phosphatic and 100% of potassium fertilizer. Both N and P fertilizers are highly energy intensive and at the same time also have very low use efficiency. In addition, there are several drawbacks in the prevailing practices of nutrient management such as non-judicious blanket nutrient application, skewed NPK ratio, and nutrient mining etc., that pose severe threats to the productivity and sustainability of intensive rice production systems. At the same time inappropriate use of these nutrients has several socioeconomic and ecological consequences such as enhanced fertilizer cost, fossil fuel burning, greenhouse gas emission, pollution of water bodies etc. Therefore an appropriate nutrient management strategy apart from enhancing nutrient use efficiency, productivity and profitability should also aim at enhancing eco-efficiency and environmental sustainability.

Voluminous research has been done to develop and optimize appropriate nutrient management strategy for rice and rice based systems in varying agro-ecological conditions. Most of the early researches focused on broad based blanket nutrient recommendations for similar agro-climatic region. However, these recommendations did not consider field-to-field variability of soil nutrient status which is often led to either excess or deficit nutrient application resulting in loss of nutrient, reduced yield poor nutrient response and low nutrient use efficiency. During past few years tremendous progress has been made in the nutrient management research in order to satisfy"4 R" criteria i.e. right dose, right time, right source and right place, required for enhancing nutrient use efficiency. Among the recent nutrient management practices, Fertigation is the scientific usage of micro-irrigation with water-soluble fertilizers and create a controlled nutrient release system resulting in significantly lower leaching losses of nutrients while meeting the water and nutrient requirements of crops throughout their growing stage, prevention of soil pollution and restoration of soil health. Drip irrigation facilitates maximal water and nutrient efficiency by reducing the active root zone, and thus minimizing the wetting area. Adding fertilizer to drip irrigation reduces the costs associated with irrigation and fertilizer application. Additionally, fertigation minimizes the losses of nutrients through leaching. Fertigation of water-soluble fertilizer had higher concentration of available plant nutrients in top layer over soil application of normal fertilizer (Hebbar *et al*., 2004) [12]. Losses and fixation was minimal when applied in small quantity with a more number of splits which ultimately resulted in higher fertilizer use efficiency compared to conventional method where application of fertilizers at a fixed dose with less number of splits which may attribute for more losses of nutrients through various means. Based on the above discussion the present study was conducted to know the how to increase the nutrient use efficiency in rice crop through fertigation of water soluble fertilizers in aerobic rice.

Materials and Methods

Experimental Details

The experiment was conducted with sixteen treatments replicated thrice times during *Kharif* 2015 and 2016 with hybrid rice (KRH-4) as a test crop and their residual effect on cowpea crop (KM-5) was grown during summer seasons of 2016 and 2017 at ZARS, GKVK, Bangalore. Two years pooled data of aerobic rice crop were collected and analyzed in RCBD design. Details of the treatments-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 in to the soil 15-20 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 expect 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 received 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.

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 soils were collected in each plot from both the years and analysis was done as per the standard procedures.

The initial soil of the experimental field was sandy clay loam in texture having a 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 in available secondary and DTPA extractable micronutrients contents (Table 1).

The quantity of fertilizers for STCR treatments (T_{11} to T_{16}) required for a yield of 80 q ha^{-1} were calculated (Table 2) by using STCR targeted yield equation developed at ZARS, V.C. Farm, Mandya (Prakash *et al*., 2007) [16] and it is as follows.

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 nitrogen (kg ha^{-1})

FP_2O_5 = Fertilizer phosphorus (kg ha^{-1})

FK_2O = Fertilizer potassium (kg ha^{-1})

OM=organic matter (kg ha^{-1})

SN, SP_2O_5 and SK_2O are initial available N, P_2O_5 and K_2O kg ha^{-1}, respectively.

Table 1: Initial soil physical and chemical properties of the experimental site

Sl. No.	Particulars	Value obtained
A	**Physical properties of soil**	
1	Course sand (%)	33.08
2	Fine sand (%)	36.13
3	Silt (%)	7.43
4	Clay (%)	23.56
5	Texture	Sandy clay loam
B	**Chemical properties of soil**	
1	pH (1:2.5)	6.72
2	Electrical conductivity (d S m^{-1})	0.08
3	OC (%)	0.48
4	CEC [cmol (p+) kg^{-1}]	8.12
5	Available N (kg ha^{-1})	212.59
6	Available P_2O_5 (kg ha^{-1})	21.98
7	Available K_2O (kg ha^{-1})	210.43
8	Exch.Ca [cmol (p^+) kg^{-1}]	3.96
9	Exch. Mg [cmol (p^+) kg^{-1}]	2.63
10	Available S (mg kg^{-1})	17.60
11	DTPA Zn (mg kg^{-1})	1.65
12	DTPA Fe (mg $kg^{-1)}$	18.28
13	DTPA Cu (mg kg^{-1})	0.61
14	DTPA Mn (mg kg^{-1})	23.91

Table 2: Quantity of NPK nutrients applied for different treatments through different approaches during 2015-16 and 2016-17

Sl. No.	Treatments	Quantity of NPK nutrients applied (kg ha^{-1})					
		2015-16			2016-17		
		N	P	K	N	P	K
1	T_1-Control	0.00	0.00	0.00	0.00	0.00	0.00
2	T_2-100% RDF-CF	125.00	62.50	62.50	125.00	62.50	62.50
3	T_3-100% RDF-CF 4 DI	125.00	62.50	62.50	125.00	62.50	62.50
4	T_4-100% RDF-CF 8 DI	125.00	62.50	62.50	125.00	62.50	62.50
5	T_5-100% RDF-WSF 4DI	125.00	62.50	62.50	125.00	62.50	62.50
6	T_6-50% RDF-WSF 4DI	62.50	31.25	31.25	62.50	31.25	31.25
7	T_7-30% RDF-WSF 4 DI	37.50	18.75	18.75	37.50	18.75	18.75
8	T_8-100% RDF-WSF 8 DI	125.00	62.50	62.50	125.00	62.50	62.50
9	T_9-50% RDF-WSF 8 DI	62.50	31.25	31.25	62.50	31.25	31.25
10	T_{10}-30% RDF-WSF 8 DI	37.50	18.75	18.75	37.50	18.75	18.75
11	T_{11}-100% STCR dose -WSF 4 DI	154.61	118.50	68.43	196.66	92.80	107.65
12	T_{12}-50% STCR dose -WSF 4 DI	76.74	58.60	38.21	106.15	52.54	58.36
13	T_{13}-30% STCR dose -WSF 4 DI	45.87	35.21	21.74	65.87	33.01	35.69
14	T_{14}-100% STCR dose -WSF 8 DI	148.08	116.71	71.71	200.73	93.99	110.45
15	T_{15}-50% STCR dose -WSF 8 DI	74.98	59.02	35.62	108.10	53.48	57.52
16	T_{16}-30% STCR dose -WSF 8 DI	44.23	34.84	20.35	66.72	33.00	35.82

Results and Discussion

Grain and Straw Yield

The grain and straw yield of rice as influenced by drip fertigation levels, approaches, forms of fertilizers and intervals of fertigation. The results of the present study indicated that the treatment with 100% STCR dose through WSF at 8 days interval (DI) of fertigation recorded significantly higher grain and straw yield (62.98 and 85.26 q ha^{-1}, respectively) of aerobic rice (Table 3and Figure1) compared to soil application of 100% conventional fertilizers as per pop (T_2) followed by treatments which received the conventional fertilizers through fertigation (T_3 & T_4) and also control treatment (T_1). This increase in the yield of rice under drip irrigation might be due to efficient utilization of water and higher absorption of nutrients by the crop with maintenance of excellent soil-water-air relationship with higher oxygen concentration in the root zone (Sharma *et al*., 2013) [22]. Babu *et al*. (2018) [4] has reported that the escalated yield in drip fertigation than soil application was because of constant nutrient availability during the entire crop growth period. Further it may be ascribed to its complete solubility of water soluble fertilizers and enhanced availability of nutrients near effective root zone than conventional fertilizers. This may be resulted in more uptake of nutrients and intern higher yield in STCR targeted yield approach than soil application of conventional fertilizers. Similar findings were stated by Rain *et al*. (2011) [17]; Tadesse *et al*. (2013) [25]. Pradeep Kumar and Parmanand (2018) [14] recorded higher yield under STCR approach which differed significantly with recommended dose of fertilizer and farmer's fertilizer practice. The higher grain and stover yield of aerobic rice might be due to addition of exact quantity of NPK fertilizers through STCR approach compared to blanket recommendation or RDF reported by Vidyavathi *et al.* (2012) [29].

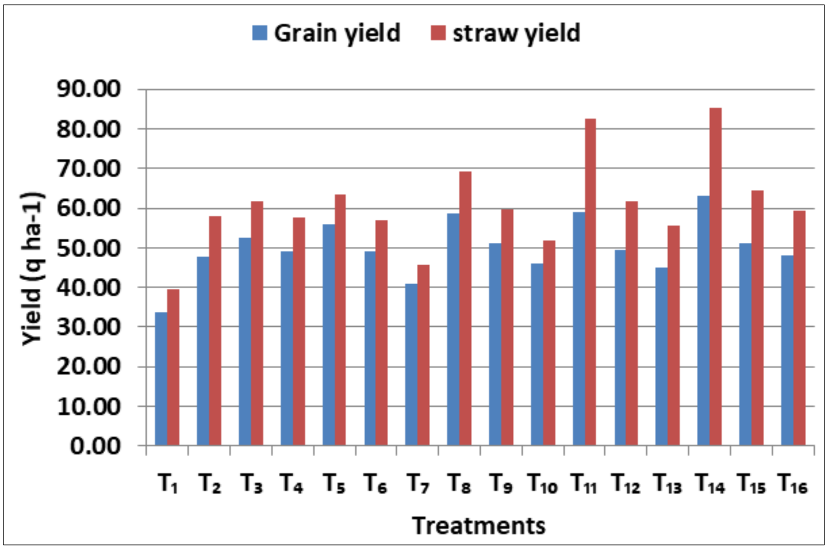

Fig 1: Effect of different approaches, forms, doses and intervals of fertilizer application on grain and straw yield of rice under aerobic rice - cowpea cropping sequence

N, P and K nutrient requirement by rice under aerobic rice-cowpea cropping system

Nutrient requirement of Nitrogen (NRn)

Nutrient requirement of nitrogen (NRn) by grains of aerobic rice during 2015, 2016 and pooled data showed significant difference between the 16 treatments imposed with different approaches, forms, doses and intervals of fertilizer application Table 3. Pooled data indicated that, significantly higher NRn (3.50 mg kg^{-1}) of aerobic rice grain production in 100% STCR dose with WSF at 8 DI (T_{14}) treatment. However, significantly lower NRn of 2.88 mg kg^{-1} was noticed in 30% STCR dose with water soluble fertilizer at 4 DI (T_{13}).

Nutrient requirement of phosphorus (NRp)

Significant difference was observed between the 16 treatments investigated in the present study with respect to nutrient requirement of phosphorus (NRp) by aerobic rice grain and data is presented in Table 3. Among the different treatments, T_{14} has recorded significantly higher NRp (0.86 mg kg^{-1}) than other treatments except T_{11} (0.80 mg kg^{-1}), which was statistically on par. The treatment received 30% RDF with WSF 4 DI (T_7) treatment has noticed significantly lower NRp of 0.62 mg kg^{-1} than all other treatments.

Nutrient requirement of potassium (NRk)

Nutrient requirement of potassium (NRk) by aerobic rice grain was found significant differences between the 16 treatments as influenced by different approaches, forms, doses and intervals of fertilizer application. Among different treatments, significantly higher NRk of 2.27 mg kg^{-1} was noticed in 100% STCR with WSF at 4 DI (T_{11}) over other treatments but, it was statistically on par with T_2, T_3, T_5, T_8, T_9, T_{13}, T_{14} and T_{15} treatments (Table 3). However, control without fertilizer application (T_1) treatment has recorded significantly lower NRk of 0.69 mg kg^{-1} than all other treatments.

The present study results revealed that the higher NPK requirement for rice grain production was recorded in treatment which received 100% NPK applied through STCR approach with WSF than soil application of 100% conventional fertilizers as per PoP. The higher NPK requirement might be due to more utilization of easily soluble nutrients through WSF by the crop to produce the higher yield in 100% STCR dose with WSF treated plot than 100% RDF with conventional fertilizers.

Further, among the two sources of fertilizers applied, water soluble fertilizers treated plots have showed higher NR-npk by rice grain than soil application of conventional fertilizers treated plots this might be due to more uptake of nutrients with water soluble fertilizers because of their complete solubility, availability and efficiency as compared to conventional fertilizers in chilli crop (Veeranna, 2000) [28]. Tanmoy *et al.* (2021b) [26] concluded that the nutrients response (NR) were maximum through SSNM approach due to optimization of nutrients in the rice–rice–pulse cropping system for a target yield of rice and need-based S and Zn application for higher productivity.

Similarly, present study results are in corroborated with finding of Prakash *et al.* (2021) [15] concluded that the nutrient requirement of rice increased linearly with the increase in nutrient applied. Similar results were also reported by Saeid and Manochehr (2010) [20] and Basavaraj *et al.* (2016) [5]. Higher nutrient requirement might be due to higher utilization of nutrients by the crop and balanced nutrient application like nitrogen as both basal and split, and P_2O_5 and K_2O as basal only. Higher uptake of nutrients also the reason for higher nutrient requirement (Yadav, 2003) [31].

Agronomic use efficiency (AUE) of N, P and K by aerobic

Agronomic use efficiency (AUE) is calculated in units of yield increase per unit of nutrient applied. It is more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return. It is one of the complex forms of NUE expressions and is most commonly defined as the difference in yield in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied. Agronomic use efficiency (AUE) in aerobic rice crop as influenced by different approaches, forms, doses and intervals of fertilizer application is presented in Table 4 and Figure 2.

Agronomic use efficiency of nitrogen (AUE-N)

Significantly higher (67.05%) agronomic use efficiency of nitrogen (AUE-N) was recorded in 30% STCR with WSF at 8 DI (T_{16}). However, lower agronomic use efficiency-N

(25.97%) was observed in soil application of 100% RDF with conventional fertilizer as per POP (T_2) and data is presented in Table 4 and Figure 2.

Agronomic use efficiency of phosphorous (AUE-P)

Totally 16 treatments were accommodated in the present investigation, where significantly higher (131.73%) agronomic use efficiency of phosphorous (AUE-P) in 30% RDF with WSF at 8 DI (T_{10}). However, lower AUE-P was (Table 4 and Figure 2) observed (51.93%) in soil application of 100% RDF with conventional fertilizer as per PoP (T_2).

Agronomic use efficiency of potassium (AUE-K)

The treatment 30% STCR with WSF at 8DI (T_{16}) has recorded significantly higher agronomic use efficiency of K (AUE-K) of 140.99%. However, lower AUE-K was observed in soil application of 100% RDF with conventional fertilizer as per P_OP (T_2) with 51.93% and data is presented in Table 4 and Figure 2.

Drip fertigation scheduling at favourable moisture regimes is generally registered higher use efficiency (N, P and K) as compared to direct soil application of nutrients was observed in the present investigation. This was attributed to better availability of moisture and nutrients throughout the crop growth stages in drip fertigation system leading to better uptake of nutrients, production of higher dry matter and in turn increased the economical yield besides reduced loss of nutrients through leaching especially N and K. The availability of right amount of water at right time resulted in improved nutrient uptake with lesser losses of nutrients. Such findings were also reported by Raina *et al*. (2011) [17] in apricot and Rekha (2014) [19] in aerobic rice.

In this present study, higher use efficiency of nutrients under fertigation might be ascribed to increase the availability of nutrients to the plants directly near the root zone but, lower nutrient use efficiency in soil application of fertilizers might be due to reduced nutrient uptake associated with reduced moisture availability and less solubility of nutrients. Similar results were observed by Gururaj (2013) and Anusha (2015) [2] in rice crop.

Singandhupe *et al*. (2003) [23] revealed that, in drip irrigation method, frequent application of nitrogen as urea followed by the formation of NH_4^+, its adsorption on soil clay minerals for a longer period followed by a gradual formation of nitrate nitrogen increased fertilizer use efficiency. In case of surface irrigation, more depletion of available soil moisture till the next irrigation reduced the N availability to plants. Further, between the two sources of fertilizers conventional and water soluble fertilizers, more uptake of nutrients with water soluble fertilizers because of their complete solubility, availability and efficiency as compared to conventional fertilizers, similar results were observed by Veeranna *et al.* (2000) [28] in chilli crop. This increased use efficiency of nitrogen, phosphorus and potassium is due to higher availability of these nutrients in soil. This is may be due to excess application of nutrients resulted in losses, fixation and converted into non-exchangeable form of nutrients in the soil leads to lesser availability of nutrients during crop growth period under conventional fertilizer treatments.

Similarly, Chakravorti and Samantaray (2006) [8] revealed that the application of organic manures resulted in increase the activity of beneficial microbes and colonization of mycorrhizal fungi, which play an important role in mobilization of nutrients in soil, thereby leading to better availability of nutrients and facilitating the uptake of NPK nutrients by plants resulting in high nutrient use efficiency. Similar finding were noticed in the present investigation.

Tanmoy *et al*. (2021b) [26] results clearly showed that crop nutrition through an ample dose of chemical fertilizers was beneficial for improving productivity and nutrient use efficiency. The low response of crops to nitrogenous fertilizers was due to various nitrogen loss mechanisms, namely, ammonia volatilization, leaching, and denitrification. A similar finding was also reported by Singh and Bansal (2010) and Xu *et al*. (2014) [30]. The nitrogen use efficiency gradually decreases with increase in N application rates (Saeid and Manochehr, 2010 [20] and Basavaraj *et al.*, 2016) [5]. Higher PUE may be due to application of lower dose of phosphorous nutrient. Similarly, higher K use efficiency may be due to lower rate of K nutrient application.

Recently, Bijay *et al.* (2015) [6] found the high nitrogen use efficiency of transplanted rice can be achieved by applying a balanced amount of N fertilizer at transplanting, enough N fertilizer at active tillering stage, and an optical sensor-guided N fertilizer dose at tillering and panicle initiation stages of rice. Similar results have been reported by Anamul and Moynul (2016) [1]. Selvi *et al.* (2003) [21] observed greater phosphorus use efficiency in rice at lower dose of P_2O_5 and K_2O level. Dakshina Murthy *et al.* (2015) [9] also explained Agronomic efficiency of N, P and K was progressively increased in rice with incremental doses of respective nutrients.

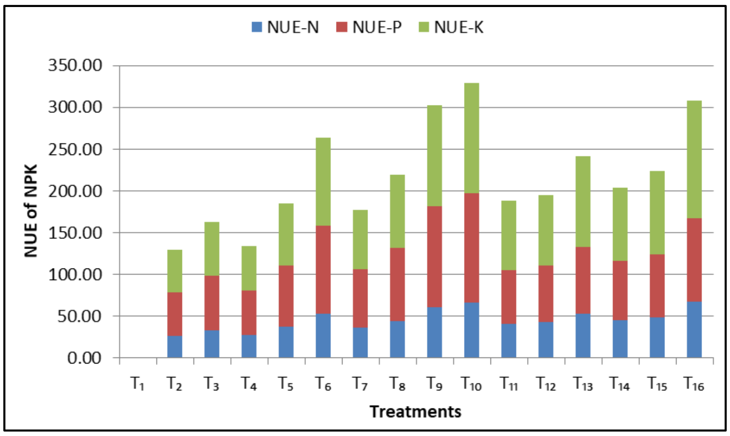

Fig 2: Use efficiency of N, P and K in aerobic rice as influenced by different forms of fertilizers in aerobic rice under aerobic rice-cowpea cropping sequence.

Apparent crop recovery efficiency (ACRE) of N, P and K by aerobic

Apparent crop recovery efficiency-N (ACRE-N)

Apparent crop recovery efficiency is most commonly defined as the difference in uptake in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied. Apparent recovery of NPK in aerobic rice crop as influenced by different approaches, forms, doses and intervals of fertilizer application is presented in Table 4.

Apparent crop recovery efficiency of nitrogen (ACRE-N) ranged from 29.97 to 78.60 kg kg^{-1}. The higher apparent crop recovery efficiency of nitrogen was recorded in treatment T_8 (78.60 kg kg^{-1}) with 100% RDF+WSF at 8 days interval (DI) through fertigation. Lower ACRE-N (29.9 kg kg^{-1}) was observed in soil application of 100% RDF with conventional fertilizer (T_2) and data is presented in Table 4.

Apparent crop recovery efficiency-P (ACRE-P)

The data pertaining to apparent crop recovery efficiency of phosphorus (ACRE-P) ranged from 14.37 to 44.40 kg kg^{-1} is presented in Table 91. Significantly higher apparent crop recovery efficiency of phosphorus (44.40 kg kg^{-1}) was recorded in 30% RDF with WSF at 8 DI through fertigation (T_{10}). However, lower ACRE-P (14.37 kg kg^{-1}) was observed in soil application of 100% RDF with conventional fertilizer (T_2).

Apparent crop recovery efficiency-K (ACRE-K)

Apparent crop recovery efficiency of potassium (ACRE-K) ranged from 56.45 to 132.51 kg kg^{-1} and data is depicted in Table 4. Significantly higher apparent crop recovery efficiency of potassium (132.51 kg kg^{-1}) was recorded in 30% STCR with WSF at 8 DI (T_{16}). However, lower ACRE-K (56.02 kg kg^{-1}) was observed in soil application of 100% RDF with conventional fertilizer at 8 DI (T_4) treatment.

The increased apparent crop recovery efficiency of N was recorded in treatment received water soluble fertilizers with 100% RDF or STCR approach at 8 DI. Similar results were observed by Ashim *et al.* (2021) who concluded that apparent nitrogen recovery values in rice under integrated plant nutrition, irrespective of crop culture, was significantly higher when compared to absolute control and 100% RDF. The highest ANR value was achieved under integrated use of chemical fertilizer, brown manuring, vermicompost, and application of *Azospirillum brasilense* due to efficient use of applied nutrients without losses.

The increased apparent crop recovery efficiency of phosphorus was noticed in WSF applied as compared with conventional fertilizers which might be due to higher availability of P nutrient in soil through supply of P from completely soluble form from the water soluble fertilizers also supply of P from mineralization of FYM.

This higher ACRE-K was observed in WSF applied through RDF or STCR approach compared to conventional fertilizer treated plots, this might be due to efficient utilization of added K from WSF along with FYM might have helped in better availability of nutrients. This may be due to better availability of nutrients and concomitant utilization by the crop with incremental levels of N, P and K. This is an indication of the fact that recovery efficiency of the incremental doses is good at initial increments and shows the scope for increased levels of respective nutrients. These results are in close agreement with those of Upadhyay and Patel (1992) [27].

Internal Utilization Efficiency (IUE)

Internal Utilization Efficiency of Nitrogen –N (IUE-N)

Significantly higher internal utilization efficiency of nitrogen (IUE-N) in aerobic rice (78.15%) was recorded in 30% STCR dose with WSF at 4 DI (T_{13}) than other treatments except T_1,T_2,T_3,T_6,T_7,T_9,T_{10},T_{11},T_{12},T_{15} and T_{16} , which were statistically on par (Table 5). The lower IUE-N (61.66%) was observed in 100% RDF with WSF at 4 DI (T_5).

Internal Utilization Efficiency of phosphorous-P (IUE-P)

In aerobic rice, 100% RDF through conventional fertilizers application as per POP (T_2) was recorded significantly higher (352.11%) internal utilization efficiency of phosphorous (IUE-P) than other treatments except T_1,T_3,T_4,T_6,T_7,T_9,T_{10},T_{12} and T_{13}, which were statistically on par (Table 92). The lower IUE-P (275.70%) was observed in 100% STCR dose with water soluble fertilizer at 8 DI (T_{14}).

Internal Utilization Efficiency of Potassium (IUE-K)

The control (T_1) treatment was recorded significantly higher (129.43%) internal utilization efficiency of potassium (IUE-K) than other treatments except T_6, T_7, T_{10}, T_{12}, T_{13}, T_{15} and T_{16}, which were statistically on par (Table 5). The lower IUE-K (106.86%) was observed in 100% STCR dose through WSF at 8 DI (T_{14}).

In the present investigation, higher utilization efficiency of NPK was observed in lower fertilizer doses or no fertilizers received treatments than highr doses. Similar results were recorded by Prakash *et al*. (2021) [15] the utilization efficiency of N, P and K was higher with no nutrient applied (43.04%, 207.66% and 41.22%, respectively) than other treatments. Increase in levels decreased the utilization efficiency in rice.

Partial Factor Productivity (PFP)

Partial factor productivity is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system (Fatehjeet *et al*., 2015) [10]. Partial factor productivity (PFP) is a production efficiency expression, calculated in units of crop yield per unit of nutrient applied. It explains how productive rice cropping system in comparison to its nutrient input applied.

Partial Factor Productivity of N (PFP-N)

In aerobic rice, significantly higher (261.23) partial factor productivity of N (PFP-N) was recorded in 30% RDF with WSF at 8 DI (T_{10}) than other treatments (Table 93). The lower PFP-N (82.41) was observed in 100% STCR dose through WSF at 4 DI (T_{11}).

Partial Factor Productivity of P (PFP-P)

The treatment with 30% RDF with WSF at 8 DI (T_{10}) was recorded significantly higher (522.46) partial factor productivity of P (PFP-P) in aerobic rice than other treatments

(Table 5). The lower PFP-P (134.95) was observed in 100% STCR dose through WSF at 4 DI (T_{11}).

Partial Factor Productivity of K (PFP-K)

Significantly higher partial factor productivity of K (PFP-K) was noticed (522.46) in 30% RDF with WSF at 8 DI (T_{10}) than other remaining treatments (Table 5). The lower PFP-K (169.15) was observed in 100% RDF with conventional fertilizers as per POP (T_2).

This increased PFP in the present investigation due to balanced application of nutrients, increased nutrient uptake and utilization of indigenous nutrients, and by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain (Singh *et al*., 2008) [24].

Nedunchezhiyan *et al*. (2018) [13] concluded that AE, RE and PFP increased with fertigation duration and attained maximum when fertigation was given up to 170 days after planting. Fertigation of water soluble fertilizers, viz. N, P_2O_5, K_2O 120-60-120 kg/ha in 40 split doses at 4 days interval (N, P_2O_5, K_2O: 3-1.5-3 kg/ha/dose) or 50 split doses at 3 days interval (N, P_2O_5, K_2O:2.4-1.2-2.4 kg/ha/dose) can be recommended for more productivity, quality and nutrient-uptake use efficiency of elephant-foot yam. This may be due to synchronizing split NPK application with crop demand enhanced AE, RE and PFP of NPK. Maximum fertilizer nutrient recovery was attained when more nutrients were available to plants (Cassman *et al*., 2002) [7]. Application of recommended dose of N in 3-split doses resulted in more AE and RE than 2-split doses in wheat (Ratanoo *et al*. 2016) [18].

Conclusion

Significantly higher grain and straw yield of rice were recorded with T_{14} treatment, which received the fertigation with 100% STCR dose through water soluble fertilizers (WSF) at 8 (8 times) days interval followed by T_{11}, T_8 and T_5 treatments over soil application of 100% conventional fertilizers as per package of practice (T_2). However, significantly higher agronomic use efficiency of N, P and K was recorded in treatemnts received fertilizer at lower dose (30% dose) than higher doses, irrespective of approaches and fertigation intervals.

Table 3: Effect of fertigation of graded levels of water soluble fertilizers through STCR approach on grain, straw yield and N, P and K requirement by rice under aerobic rice-cowpea cropping sequence

Treatments	Grain yield	Straw yield	Nitrogen requirement	Phosphorus requirement	Potassium requirement
	(q ha^{-1})			(mg kg^{-1})	
T_1-Control	33.80	39.46	3.06	0.63	1.69
T_2-100% RDF-CF	47.71	58.01	2.97	0.63	1.95
T_3-100% RDF-CF 4 DI	52.43	61.60	3.14	0.64	1.97
T_4-100% RDF-CF 8 DI	49.10	57.48	3.22	0.67	1.87
T_5-100% RDF-WSF 4DI	55.78	63.57	3.49	0.73	1.91
T_6-50% RDF-WSF 4DI	49.23	57.04	2.94	0.64	1.76
T_7-30% RDF-WSF 4 DI	40.78	45.79	2.91	0.62	1.78
T_8-100% RDF-WSF 8 DI	58.78	69.17	3.43	0.73	1.94
T_9-50% RDF-WSF 8 DI	51.26	59.85	2.91	0.66	1.91
T_{10}-30% RDF-WSF 8 DI	45.99	51.97	2.89	0.65	1.74
T_{11}-100% STCR dose -WSF 4 DI	58.98	82.56	3.48	0.80	2.27
T_{12}-50% STCR dose -WSF 4 DI	49.29	61.77	2.92	0.67	1.81
T_{13}-30% STCR dose -WSF 4 DI	44.97	55.51	2.88	0.66	1.90
T_{14}-100% STCR dose -WSF 8 DI	62.98	85.26	3.50	0.86	2.24
T_{15}-50% STCR dose -WSF 8 DI	51.07	64.63	3.03	0.73	1.89
T_{16}-30% STCR dose -WSF 8 DI	48.11	59.32	2.92	0.72	1.87
SEm ±	2.74	3.30	0.16	0.04	0.14
CD at 5%	7.74	9.33	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 4: Effect of different approaches, forms, doses and intervals of fertilizer application on agronomic use efficiency of N, P and K and apparent crop recovery efficiency in rice under aerobic rice-cowpea cropping sequence.

Treatments	AUE-N	AUE-P	AUE-K	ACRE-N	ACRE-P	ACRE-K
		(%)			(%)	
T_1-Control	0.00	0.00	0.00	0	0	0
T_2-100% RDF-CF	25.97	51.93	51.93	29.97	14.37	56.45
T_3-100% RDF-CF 4 DI	32.62	65.23	65.23	47.70	20.13	73.13
T_4-100% RDF-CF 8 DI	26.65	53.31	53.31	43.28	18.84	56.02
T_5-100% RDF-WSF 4 DI	36.87	73.73	73.73	72.85	30.82	78.88
T_6-50% RDF-WSF 4 DI	52.82	105.65	105.65	66.59	33.13	95.19
T_7-30% RDF-WSF 4 DI	35.50	71.00	71.00	40.36	20.72	81.12
T_8-100% RDF-WSF 8 DI	43.75	87.50	87.50	78.60	34.64	91.19
T_9-50% RDF-WSF 8 DI	60.55	121.10	121.10	73.39	39.78	131.44
T_{10}-30% RDF-WSF 8 DI	65.87	131.73	131.73	75.70	44.40	119.91
T_{11}-100% STCR dose -WSF 4 DI	40.03	64.60	83.91	59.18	24.68	90.57
T_{12}-50% STCR dose -WSF 4 DI	43.11	67.85	83.76	45.58	21.70	72.87
T_{13}-30% STCR dose -WSF 4 DI	53.22	79.20	108.68	48.23	25.14	110.90

T_{14}-100% STCR dose -WSF 8 DI	44.67	71.16	88.11	69.51	31.31	96.02
T_{15}-50% STCR dose -WSF 8 DI	48.75	75.35	99.38	58.72	28.90	93.09
T_{16}-30% STCR dose -WSF 8 DI	67.05	100.18	140.99	69.82	39.82	132.51
SEm ±	9.20	18.34	19.04	9.15	6.31	14.63
CD at 5%	26.00	51.85	53.84	25.86	17.85	41.37

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

Table 5: Effect of different approaches, forms, doses and intervals of fertilizer application on internal utilization efficiency of N, P and K and partial factor of productivity of rice under aerobic rice-cowpea cropping sequence.

Treatments	IUE-N	IUE-P	IUE-K	PFP-N	PFP-P	PFP-K
		(%)				
T_1-Control	71.29	347.77	129.43	0	0	0
T_2-100% RDF-CF	75.36	352.11	115.29	84.58	169.15	169.15
T_3-100% RDF-CF 4 DI	70.30	342.32	111.52	91.23	182.45	182.45
T_4-100% RDF-CF 8 DI	67.82	328.46	116.68	85.26	170.53	170.53
T_5-100% RDF-WSF 4 DI	61.66	297.38	113.09	95.47	190.95	190.95
T_6-50% RDF-WSF 4 DI	73.60	338.80	123.19	170.04	340.09	340.09
T_7-30% RDF-WSF 4 DI	73.52	347.73	120.60	230.86	461.72	461.72
T_8-100% RDF-WSF 8 DI	63.93	300.83	112.96	102.36	204.71	204.71
T_9-50% RDF-WSF 8 DI	74.76	331.61	114.13	177.77	355.54	355.54
T_{10}-30% RDF-WSF 8 DI	74.75	333.21	123.92	261.23	522.46	522.46
T_{11}-100% STCR dose -WSF 4 DI	69.48	302.01	107.88	82.41	134.95	171.95
T_{12}-50% STCR dose -WSF 4 DI	77.35	336.45	124.37	126.03	199.93	243.34
T_{13}-30% STCR dose -WSF 4 DI	78.15	340.12	118.33	188.77	294.18	380.34
T_{14}-100% STCR dose -WSF 8 DI	67.57	275.70	106.86	87.69	141.55	172.56
T_{15}-50% STCR dose -WSF 8 DI	75.29	310.68	119.89	131.64	205.87	266.59
T_{16}-30% STCR dose -WSF 8 DI	76.98	311.52	120.76	204.90	316.24	423.92
SEm ±	3.38	13.27	4.26	5.78	10.24	14.19
CD at 5%	9.55	37.52	12.03	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 significance

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