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Research Article

Assessment of Soil Test Crop Response Based Fertilization on Nutrient Requirement, Nutrient Uptake and Nutrient Use Efficiency of Aerobic Rice

N Bhavya*, PK Basavaraja and R Krishna murthy

AICRP on STCR, Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, GKVK, Bengaluru – 560 065

Abstract

Studies on influence of soil test crop response based fertilization on nutrient requirement, nutrient uptake and nutrient use efficiency of aerobic rice was conducted during *Kharif* 2020 at Zonal Agricultural Research Station (ZARS), GKVK, Bengaluru. The experiment was laid out in RCBD comprising twelve treatments replicated thrice. The results revealed that significantly higher grain yield (68.85 q ha^{-1}) and straw yield (74.19 q ha^{-1}) of aerobic rice was recorded in treatment receiving fertilizer nutrients based on STCR inorganic approach for the targeted yield of 65 q ha^{-1} based on predicted soil test values. Similarly, the total uptake of nitrogen (176.73 kg ha^{-1}), phosphorus (25.95 kg ha^{-1}) and potassium (175.70 kg ha^{-1}) was higher in STCR target of 65 q ha^{-1} through inorganics based on predicted soil test values. The highest apparent recovery efficiency (ARE) and agronomic nutrient use efficiency (ANUE) of nitrogen (0.180 and 13.32 kg kg^{-1}) was recorded in STCR target of 65 q ha^{-1} through inorganics based on predicted soil test values. Similarly, ARE of phosphorus, potassium (0.132 and 0.053 kg kg^{-1} respectively) and ANUE of phosphorus (25.69 kg kg^{-1}) was higher in STCR target of 65 q ha^{-1} through inorganics based on actual soil test values.

Keywords: STCR, Aerobic rice, STL, PoP, Use efficiency

***Correspondence**
Author: N Bhavya
Email: bhavyanagraj.6@gmail.com

Introduction

Since inception of green revolution there has been a race for increasing cereal production using chemical fertilizers in India. Over the years, food grain production was increased by five times at the cost of 322 times increase in fertilizer consumption [1]. Staggering ‘net negative nutrient balance’ of 10 million tonnes has been reported in India [2] which is anticipated to reach 15 million tonnes by 2025. Such imbalance of fertilizer nutrient demand and supply of has raised problems of stagnant or declining crop productivity, deteriorating soil quality, multi-nutrient deficiencies and lower fertilizer use efficiency. Considering high cost of fertilizers and their adverse environmental implications, fertilizer recommendations based on soil test values, residual effect and yield targets becomes highly important. This can be achieved by following targeted yield approach involving integrated plant nutrition system (IPNS) for enhancing crop productivity, nutrient use efficiency as well as soil nutrient balance [3].

Targeted yield approach provides a scientific basis for balanced fertilization and balance between applied nutrients and soil available nutrients. Soil test crop response (STCR) based fertilizer prescription is gaining popularity among farming community due to its superiority over general blanket fertilizer recommendations. Field trials conducted in different agro- ecological zones with different cropping system revealed that the STCR based recommendations produced higher yields and maintain better nutrient status in contrast with blanket fertilizer recommendations [4].

Soil testing is a scientific tool to evaluate soil fertility by predicting the probability of getting a profitable crop response to recommended fertilizer application under specific soil-crop condition [5]. Though there are numerous soil testing laboratories in operation, in a vast country like India with millions of hectares of cultivated land, soil testing after each season and prior to the cultivation of each crop seems to be practically impossible for the want of time, money, labour and energy consuming and highly expensive which is neither economical nor environmental friendly [5]. Hence, the prediction of post-harvest soil test values (PHSTVs) using the pre-sowing soil test values, fertilizer doses and yield or uptake by the crop has much of practical significance.

With emerging water scarcity in many part of the world, the traditional way of lowland rice cultivation can no longer be sustained. Along with high water requirement, traditional system of rice production in long run leads to destruction of soil aggregates and reduction in macropore volumes [6]. Moreover, the lack of rainfall is a major production constraint in rainfed areas. Alternatives to the conventional flooded rice cultivation were developed worldwide to reduce water consumption and produce more rice with less water. Among different water saving strategies, "aerobic rice" is considered a promising cultivation system for water scarce areas. Keeping the above facts in view, the present investigation was conducted with an objective to study the influence of STCR based fertilizer recommendation on nutrient requirement, nutrient uptake and nutrient use efficiency by aerobic rice in comparison with other approaches of fertilizer recommendation.

Material and methods

A Field experiment entitled "Influence of soil test crop response based fertilization on nutrient requirement, nutrient uptake and nutrient use efficiency of aerobic rice" was conducted during *kharif* 2020 at Zonal Agricultural Research Station, university of agricultural sciences, GKVK, Bengaluru district located in Eastern Dry Zone of Karnataka (**Table 1**). The soil of the experimental site was red soil taxonomically belongs to Vijaypura soil series of great group *Kandic paleustalfs*. The soil of the experimental site was sandy loam in texture and acidic in reaction (pH 5.77). Electrical conductivity was 0.085 dSm^{-1} with organic carbon content of 4.44 g kg^{-1}. Available nitrogen was low (261.15 kg N ha^{-1}), phosphorus was high (98.55 kg P_2O_5 ha^{-1}) and potassium was medium (256.35 kg K_2O ha^{-1}). The experiment was laid out in randomized complete block design (RCBD) with twelve treatments comprising T_1: STCR through inorganics (65 q ha^{-1}) - Actual STV* (*Soil Test Value), T_2: STCR through inorganics (65 q ha^{-1}) - Predicted STV, T_3: STCR through integrated (65 q ha^{-1}) - Actual STV, T_4: STCR through integrated (65 q ha^{-1}) - Predicted STV, T_5: STCR through inorganics (55 q ha^{-1}) - Actual STV, T_6: STCR through inorganics (55 q ha^{-1}) - Predicted STV, T_7: STCR through integrated (55 q ha^{-1}) - Actual STV, T_8: STCR through integrated (55 q ha^{-1}) - Predicted STV, T_9: Package of practice, T_{10}: LMH (STL) - Actual STV, T_{11}: LMH (STL) - Predicted STV and T_{12}: Absolute control.

The following STCR fertilizer adjustment equation and post harvest soil test value prediction equations developed by AICRP on STCR, UAS, Bengaluru centre under *Alfisols* of Eastern Dry Zone of Karnataka was used for STCR treatments and to predicted the post harvest soil test value for the preceding crop of aerobic rice (dry chilli) which can be used as initial soil test value for the present investigation to prescribe the fertilizer dose. More details are regarding development of targeted yield equations and post harvest soil test value prediction equations are provided in Ph.D. thesis on "Development of targeted yield equation for aerobic rice and its evaluation on *Alfisols* of Eastern dry zone of Karnataka" [7] at the same experimental site.

Table 1 Post harvest soil test value prediction equation

Prediction equation	R^2 value
Inorganic approach	
PHN = 188.752 + 0.001** SN + 0.203 FN - 0.184 UN	0.610**
PHP = - 6.133 + 1.089** SP + 1.188** FP - 1.299* UP	0.965**
PHK = 5.075 + 1.138** SK + 1.275** FK - 0.249 UK	0.925**
IPNS approach	
PHN = 191.090** - 0.003 SN + 0.087** FP - 0.008 UN	0.442**
PHP = 7.325 + 0.721** SP + 1.167** FP + 2.515** UP	0.890**
PHK = 121.586** + 0.724** SK + 0.765** FP - 0.132 UK	0.907**
STCR- Inorganics (NPK alone) equation	
F.N. = 3.02879 T – 0.20314 STV-N	
F.P_2O_5. = 1.24589 T – 0.07368 STV - P_2O_5	
F.K_2O. = 1.51168 T – 0.22617 STV-K_2O	
STCR- IPNS (Integrated plant nutrient supply) equation	
F.N. = 2.89282 T – 0.20320 STV - N – 0.72978 OM	
F.P_2O_5.= 1.13206 T – 0.06960 STV - P_2O_5 – 0.48911 OM	
F.K_2O. = 1.50402 T – 0.21105 STV - K_2O – 0.42410 OM	

Using this fertilizer adjustment equations the quantity of fertilizer nutrients required with or without poultry manure for achieving the target of 65 and 55 q ha^{-1} grain yield of aerobic rice was worked out. The quantity of fertilizer nutrients (NPK) applied for each treatment is mentioned in **Table 2**.

After laying out the field plan soil samples were drawn from each treatment from experimental site. Based on the soil test values NPK fertilizers were applied in STCR and LMH approach. However in Package of Practice (PoP) recommended dose of poultry manure + NPK (100:50:50 kg NPK ha^{-1}) was applied. Fifty per cent of nitrogen recommended for each treatment was applied through urea and entire quantity of phosphorus through SSP (single super phosphate) and fifty per cent of potassium through MoP (muriate of potash) were supplied at the time of sowing as basal dose to each plot and remaining twenty five per cent of nitrogen and fifty per cent of potassium was applied at 30 days after sowing and the other twenty five per cent of N was applied at 60 DAS. At harvest random grain and straw samples were collected, dried, powdered and used for analysing the concentration of NPK by adopting the standard procedures outlined by [8]. Soil samples collected from the experimental plots after crop harvest were processed and analysed for available nitrogen, phosphorus and potassium by following standard procedures [8]. After analysing the major nutrient concentrations in grain and straw samples uptake of these nutrients by aerobic rice, nutrient requirement (NR), partial factor productivity (PFP), apparent recovery efficiency (ARE), agronomic nutrient use efficiency (ANUUE) and internal utilization efficiency (IUE) were computed by using the standard formulae shown below.

$$\text{NR (kg q}^{-1}\text{)} = \frac{\text{Nutrient uptake (NPK) by grain + Straw (kg ha}^{-1}\text{)}}{\text{Grain yield or any economic produce (q ha}^{-1}\text{)}}$$

$$\text{Uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%) x Biomass (kg ha}^{-1}\text{)}}{100}$$

$$\text{PFP (q kg}^{-1}\text{)} = \frac{\text{Yield obtained in treated plot (q ha}^{-1}\text{)}}{\text{Fertilizer nutrient applied (kg ha}^{-1}\text{)}}$$

$$\text{ARE (kg kg}^{-1}\text{)} = \frac{\text{Uptake in treated plot (kg ha}^{-1}\text{) - Uptake in control plot (kg ha}^{-1}\text{)}}{\text{Fertilizer nutrient applied (kg ha}^{-1}\text{) + Soil available nutrient (kg ha}^{-1}\text{)}}$$

$$\text{ANUE (kg kg}^{-1}\text{)} = \frac{\text{Grain yield in treated plot (kg ha}^{-1}\text{) – Grain yield in control plot (kg ha}^{-1}\text{)}}{\text{Fertilizer nutrient applied (kg ha}^{-1}\text{) + Soil available nutrient (kg ha}^{-1}\text{)}}$$

$$\text{IUE (kg kg}^{-1}\text{)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total uptake (kg N, P}_2\text{O}_5\text{ and K}_2\text{O ha}^{-1}\text{)}}$$

Table 2 Quantity of fertilizer nutrients and poultry manure applied through different approaches as per the treatments and soil test values

Treatments	**Soil test values**			**Poultry manure applied**	**Fertilizer nutrients applied**		
	N	**P_2O_5**	**K_2O**		**N**	**P_2O_5**	**K_2O**
	kg ha^{-1}			**t ha^{-1}**	**kg ha^{-1}**		
T_1	260.59	101.05	271.64	0	143.94	73.54	36.82
T_2	207.10	174.48	298.07	0	154.80	68.13	30.84
T_3	261.67	106.92	305.92	10	127.56	61.25	28.96
T_4	205.62	167.75	456.03	10	138.95	57.08	2.12
T_5	260.21	99.88	221.67	0	113.72	61.16	33.01
T_6	202.89	149.36	276.69	0	125.37	56.85	20.56
T_7	262.08	93.65	245.75	10	98.55	50.85	26.62
T_8	201.60	145.27	340.47	10	110.84	47.26	6.62
T_9	272.53	115.60	286.76	10	100.00	50.00	50.00
T_{10}	266.56	98.55	285.69	10	125.00	37.50	50.00
T_{11}	204.08	165.92	322.27	10	125.00	37.50	45.83
T_{12}	243.41	56.96	168.13	0	0.00	0.00	0.00

Results and Discussion

Grain and straw yield

Significantly higher grain yield (**Table 3**) of 68.85 q ha^{-1} was recorded with the application of nutrients based on STCR approach for the targeted yield of 65 q ha^{-1} through inorganic based on predicted soil test values (T_2) compared to treatment T_8 (60.14 q ha^{-1}) [STCR integrated (55 q ha^{-1}) - Predicted STV], T_7 (57.55 q ha^{-1}) [STCR integrated (55 q ha^{-1}) - Actual STV], T_9 (53.25 q ha^{-1}) (Package of practice), T_{11} (49.15 q ha^{-1}) (LMH - predicted STV), T_{10} (48.76 q ha^{-1}) (LMH - Actual STV), and T_{12} (20.66 q ha^{-1}) (Absolute control). However, it was on par with treatments receiving fertilizers through STCR inorganic approach for the targeted yield of 65 q ha^{-1} based on actual soil test values (T_1:

65.50 q ha^{-1}); STCR integrated approach for the targeted yield of 65 q ha^{-1} based on predicted soil test values (T_4: 63.79 q ha^{-1}) and actual test values (T_3: 61.70 q ha^{-1}); STCR inorganic approach for the targeted yield of 55 q ha^{-1} for predicted soil test values (T_6: 62.96 q ha^{-1}) and actual soil test values (T_5: 61.58 q ha^{-1}). Similarly, Significantly higher straw yield (74.19 q ha^{-1}) was registered under the treatment T_2 [STCR inorganics (65 q ha^{-1}) - Predicted STV] compared to STCR integrated approach where the fertilizers were applied by considering actual soil test values for the targeted yield of 55 q ha^{-1} (T_7: 59.67 q ha^{-1}), POP (T_9: 53.43 q ha^{-1}), LMH approach for predicted (T_{11}: 47.33 q ha^{-1}) and actual (T_{10}: 46.72 q ha^{-1}) soil test values but it was on par with other STCR treated plots *viz.*, STCR integrated (65 q ha^{-1}) - Predicted STV (T_4: 73.38 q ha^{-1}), STCR inorganics (55 q ha^{-1}) - Predicted STV (T_6: 71.47 q ha^{-1}), STCR inorganics (65 q ha^{-1}) - Actual STV (T_1: 67.05 q ha^{-1}), STCR integrated (65 q ha^{-1}) - Actual STV (T_3: 66.04 q ha^{-1}), STCR inorganics (55 q ha^{-1}) - Actual STV (T_5: 63.05 q ha^{-1}), and STCR integrated (55 q ha^{-1}) - Predicted STV (T_8: 61.76 q ha^{-1}). However, significantly lowest straw yield was reported from absolute control plots (T_{12}: 19.73 q ha^{-1}).

The higher yield in STCR treatments could be attributed to the ability of targeted yield approaches to satisfy the nutrient demand of crop more efficiently. These findings are in close accordance with those reported by Kumar and Paramananda, 2018 [9] who opined that application of fertilizers based on STCR approach at critical physiological phases would have supported for better assimilation of photosynthates towards grain. Increase in grain yield can also be attributed to favorable effect in accelerating the growth and yield parameters. Higher grain and biomass yield with STCR nutrient management strategies over RDF or LMH approach of nutrient management clearly indicated the benefit of judicious and balanced nutrient management in rice. Lowest grains and straw yield in control plots was due to the continuous removal of nutrients from the soil without addition of any external inputs[10].

Nutrient uptake

Nitrogen uptake

Significantly higher nitrogen uptake by grain (90.79 kg ha^{-1}) was observed in treatment STCR target 65 q ha^{-1} through inorganics based on predicted soil test values compared to all other treatment except STCR target 65 q ha^{-1} through inorganics based on actual soil test values (T_1: 89.38 kg ha^{-1}), STCR target 65 q ha^{-1} through integrated approach based on predicted (T_4: 83.63 kg ha^{-11}) soil test values, STCR target 55 q ha^{-1} through inorganic based on predicted (T_6: 82.29 kg ha^{-1}) and actual (T_5: 82.02 kg ha^{-1}) soil test values and they were significantly superior over rest of the treatments (Table 3). Lower nitrogen uptake by grain was recorded in absolute control (T_{12}: 25.48 kg ha^{-1}). Significantly higher uptake of nitrogen (85.94 kg ha^{-1}) by rice straw was recorded in treatment T_2 [STCR inorganics (65 q ha^{-1}) - Predicted STV] compared to treatments T_7 [STCR integrated (55 q ha^{-1}) - Actual STV] (66.47 kg ha^{-1}), T_9 (Package of practice) (56.21 kg ha^{-1}), T_{11} (LMH- predicted STV) (51.02 kg ha^{-1}), T_{10} (LMH- Actual STV) (48.00 kg ha^{-1}) and T_{12} (Absolute control) (22.37 kg ha^{-1}). While it was on par with the remaining treatments. Similarly, the total uptake of nitrogen by aerobic rice crop was significantly higher (176.73 kg ha^{-1}) in treatment receiving NPK fertilizers alone *i.e.*, without poultry manure for a targeted yield of 65 q ha^{-1} through predicted soil test values (T_2) compared to all other treatments except treatment T_6 (162.21 kg ha^{-1}), T_1 (161.94 kg ha^{-1}) and T_3 (159.71 kg ha^{-1}). Whereas significantly lower uptake (47.85 kg ha^{-1}) was noticed in absolute control (T_{12}). Higher uptake of nitrogen was recorded through inorganic approach compared to integrated where NPK fertilizers were applied along with poultry manure at 10 t ha^{-1} and the uptake was higher with the application of fertilizers based on predicted soil test values compared to actual soil test values.

Phosphorus uptake

Significantly higher phosphorus uptake by grain (T_2: 15.08 kg ha^{-1}) was recorded with treatment (T_2) receiving fertilizer nutrients through STCR approach of nutrient recommendation for the targeted yield of 65 q ha^{-1} based on predicted soil test values compared to package of practice (T_9: 11.88 kg ha^{-1}), LMH approach of fertilizer recommendation using predicted (T_{11}: 11.41 kg ha^{-1}) and actual soil test vales (T_{10}: 11.01 kg ha^{-1}) and absolute control (T_2: 4.91 kg ha^{-1}) (Table 3). However, other STCR treated plots were on par with treatment T_2. Similarly, the higher total uptake of phosphorus was recorded in treatment T_2 [STCR inorganics (65 q ha^{-1}) - Predicted STV] (25.95 kg ha^{-1}) which was superior over POP and LMH approach and control plot. However, significantly lower uptake was recorded in absolute control (T_{12}) (7.63 kg ha^{-1}). The uptake was higher in grain compared straw and similarly higher uptake higher uptake was recorded in all the inorganic approaches with predicted soil test values compared to integrated and actual soil test values.

Potassium uptake

Significantly higher (22.04 kg ha^{-1}) potassium uptake was recorded in treatment receiving NPK fertilizers alone for the targeted yield of 65 q ha^{-1} through STCR inorganic approach based on predicted soil test values and it was on par with treatments receiving fertilizers through STCR inorganics for the targeted yield of 65 q ha^{-1} based on actual soil test values (21.21 kg ha^{-1}) (T_1), STCR target 55 q ha^{-1} through inorganics based on predicted soil test values (19.21 kg ha^{-1}) (T_6) and STCR targeted yield of 65 q ha^{-1} through integrated approach based on predicted soil test values (19.13 kg ha^{-1}) (T_4) (Table 3). Whereas, significantly lower value was recorded in absolute control (T_{12}: 6.67 kg ha^{-1}). Significantly higher uptake of potassium by rice straw was recorded in treatment T_2 [STCR inorganics (65 q ha^{-1}) - Predicted STV] (153.66 kg ha^{-1}) compared to all other treatments except T_1 (151.91 kg ha^{-1}), T_4 (151.72 kg ha^{-1}), T_3 (147.09 kg ha^{-1}) and T_6 (133.82 kg ha^{-1}). Total uptake of potassium followed the same trend as that of straw.

Higher uptake of nutrients was recorded through inorganic approach compared to integrated where NPK fertilizers were applied along with poultry manure at 10 t ha^{-1} and the uptake was higher with the application of fertilizers based on predicted soil test values compared to actual soil test values. Application of increased NPK levels with and without poultry manure based on soil test values for the targeted yield of rice recorded significantly higher uptake of nitrogen, phosphorus and potassium by grain and straw of rice over that of LMH approach and package of practice could be attributed to higher yield of aerobic rice and higher application of fertilizer doses that enables the higher availability of nutrients in the vicinity of rice root thereby proliferous growth of root system under balanced application leads to ease in absorption of nitrogen, phosphorus and potassium resulted in higher uptake. Similar findings were reported by Basavaraja *et al.,* (2017) [11] who concluded that significantly higher NPK uptake was recorded in STCR-targeted yield with IPNS approach (30 q ha^{-1}) in finger millet crop which was on par with package of practice (POP) approach. They also reported that the increased NPK uptake under POP and STCR-targeted (30 q ha^{-1}) with purely inorganic approach could be due to application of required quantity of nutrients through inorganic fertilizers in STCR. Similarly, in general, the higher uptake and the availability of these nutrients were due to higher availability and high dry matter production.

Table 3 Uptake of major nutrients by aerobic rice grain, straw and total uptake as influenced by different approaches of nutrient application

Treatments	**Grain yield**	**Straw yield**	**Nitrogen Uptake**			**Phosphorus Uptake**			**Potassium Uptake**		
	(q ha^{-1})		**Grain (kg ha^{-1})**	**Straw**	**Total**	**Grain**	**Straw**	**Total**	**Grain**	**Straw**	**Total**
T_1	65.50	67.05	89.38	72.56	161.94	14.85	9.52	24.37	21.21	151.91	173.12
T_2	68.85	74.19	90.79	85.94	176.73	15.08	10.87	25.95	22.04	153.66	175.70
T_3	61.70	66.04	80.03	71.46	151.50	14.05	9.47	23.51	18.57	147.09	165.66
T_4	63.79	73.38	83.63	76.08	159.71	14.71	9.73	24.44	19.13	151.72	170.85
T_5	61.58	63.05	82.02	68.88	150.90	13.74	9.84	23.58	18.60	131.48	150.08
T_6	62.96	71.47	82.29	79.91	162.21	13.93	10.52	24.45	19.21	133.82	153.03
T_7	57.55	59.67	77.27	66.47	143.73	13.26	8.71	21.97	18.09	123.82	141.91
T_8	60.14	61.76	78.11	68.07	146.17	13.70	8.77	22.47	18.21	122.97	141.18
T_9	53.25	53.43	70.40	56.21	126.61	11.88	6.65	18.53	16.93	127.79	144.71
T_{10}	48.76	46.72	62.37	48.00	110.37	11.07	5.82	16.89	15.11	105.66	120.77
T_{11}	49.15	47.33	63.17	51.02	114.19	11.41	6.35	17.76	16.33	114.30	130.63
T_{12}	20.66	19.73	25.48	22.37	47.85	4.91	2.73	7.63	6.67	36.96	43.63
S.Em. ±	2.88	4.24	3.65	6.42	8.38	0.74	0.98	1.38	1.04	7.55	8.16
C.D. @ 5%	8.39	12.42	10.71	18.83	24.57	2.18	2.89	4.06	3.05	22.13	23.92

Nutrient requirement

Nitrogen, phosphorus and potassium requirement by rice grain did not showed significant difference between the treatments imposed due to different approaches fertilizer application (**Table 4**). However, numerically higher N requirement (2.580 kg q^{-1}) and P_2O_5 requirement (0.891 kg q^{-1}) for rice grain production was recorded in treatment receiving fertilizer nutrient through STCR inorganic approach based on predicted soil test values for the targeted yield of 55 q ha^{-1} (T_6) whereas lower N and P_2O_5 requirement was recorded in LMH approach through actual soil test values (2.249 kg q^{-1} and 0.794 kg q^{-1} respectively). Similarly, higher K_2O requirement (3.288 kg q^{-1}) for rice grain production was recorded in treatment receiving fertilizer nutrient through package of practice (T_9) followed by STCR target of 65 q ha^{-1} through integrated approach based on actual soil test values (T_3: 3.244 kg q^{-1}) whereas lower K_2O requirement was recorded in absolute control (T_{12}: 2.536 kg q^{-1}). Higher nitrogen and phosphorus requirement might be due to more utilization of nutrients by the crop for higher yield in STCR approach and higher potassium requirement in POP might be attributed to application of higher dose of potassium fertilizers thereby increase in the availability of nutrient for plant uptake.

Partial factor productivity

The partial factor productivity of nitrogen was significantly higher (0.584 q kg^{-1}) in treatment T_7 [STCR integrated (55 q ha^{-1}) - Actual STV] compared to all other treatments except treatments T_8 [STCR integrated (55 q ha^{-1}) - Predicted STV] (0.543 q kg^{-1}), T_5 [STCR inorganics (55 q ha^{-1}) - Actual STV] (0.542 q kg^{-1}) and T_{10} (LMH - Actual STV) (0.533 q kg^{-1}) which were on par (Table 4). The partial factor productivity of P_2O_5 was significantly higher (1.311 q kg^{-1}) in treatment T_{11} (LMH - predicted STV) compared to all other treatments except treatments T_{10} (LMH - Actual STV) (1.300 q kg^{-1}), T_8 [STCR integrated (55 q ha^{-1}) - predicted STV] (1.275 q kg^{-1}), T_7 [STCR integrated (55 q ha^{-1}) - Actual STV] (1.132 q kg^{-1}) and T_4 [STCR integrated (65 q ha^{-1}) - Predicted STV] (1.118 q kg^{-1}) which were on par. Similarly, The partial factor productivity of K_2O was significantly higher (9.962 q kg^{-1}) in treatment T_4 [STCR integrated (65 q ha^{-1}) - Predicted STV] compared treatments T_{11} (LMH - predicted STV) (1.073 q kg^{-1}), T_9 (Package of practice) (1.065 q kg^{-1}) and T_{10} (LMH - actual STV) (0.975 q kg^{-1}) whereas the remaining treatments were on par. The partial factor productivity of nitrogen was significantly higher in treatment T_7 [STCR integrated (55 q ha^{-1}) - Actual STV] which might be due to to higher yield obtained with respect to lower application rate of nitrogen (98.55 kg ha^{-1}). Similarly, the partial factor productivity of P_2O_5 was significantly higher in treatment T_{11} (LMH - predicted STV) and K_2O in T_4 [STCR integrated (65 q ha^{-1}) - Predicted STV] which is also attributed to the application of lower dose of fertilizer compared to other treatments. The finding of the present study was supported by Sampath and Srinivas (2017) [14] who reported that higher PFP was positively correlated with higher yield obtained and lower dose of applied fertilizers in case of rice crop.

Table 4 Nutrient requirement (NR) and Partial factor productivity (PFP) of N, P_2O_5 and K_2O as influenced by different approaches of nutrient application

Treatments	NR			PFP		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	kg q^{-1}			q kg^{-1}		
T_1	2.475	0.852	3.170	0.455	0.891	1.789
T_2	2.568	0.864	3.064	0.445	1.011	2.254
T_3	2.460	0.878	3.244	0.485	1.006	2.225
T_4	2.503	0.877	3.214	0.459	1.118	9.962
T_5	2.459	0.876	2.931	0.542	1.007	1.877
T_6	2.580	0.891	2.924	0.502	1.108	3.084
T_7	2.502	0.876	2.958	0.584	1.132	2.201
T_8	2.442	0.854	2.815	0.543	1.275	2.160
T_9	2.378	0.801	3.288	0.533	1.065	1.065
T_{10}	2.249	0.794	2.975	0.390	1.300	0.975
T_{11}	2.328	0.820	3.198	0.393	1.311	1.073
T_{12}	2.316	0.848	2.536	-	-	-
S.Em. ±	0.121	0.042	0.164	0.026	0.068	3.010
C.D. @ 5 %	NS	NS	NS	0.077	0.200	8.878

Apparent recovery efficiency and Agronomic nutrient use efficiency

The apparent recovery efficiency and agronomic nutrient use efficiency of nitrogen differed significantly due to application of fertilizer nutrients based on actual and predicted soil test values and were ranging from 0.094 kg kg^{-1} to 0.180 kg kg^{-1} with respect to ARE and 7.16 kg kg^{-1} to 13.32 kg kg^{-1} with respect to ANUE (**Table 5**). Significantly higher ARE (0.180 kg kg^{-1}) and ANUE (13.32 kg kg^{-1}) of nitrogen was recorded in STCR inorganic approach for the targeted yield of 65 q ha^{-1} based on predicted soil test values compared to POP, LMH approach through actual soil test values and LMH approach through predicted soil test values. Similarly, significantly higher apparent recovery efficiency (0.132 kg kg^{-1}) and agronomic nutrient use efficiency (25.69 kg kg^{-1}) of phosphorus was recorded in STCR target of 65 q ha^{-1} through inorganic fertilizers based on actual soil test values (T_1) compared to treatment receiving fertilizer nutrients through LMH approach through predicted soil test values (T_{11}) (14.44 kg kg^{-1}) but the remaining treatments were found on par. The ARE and ANUE was higher in inorganic approach compared to integrated at higher target but it was higher in integrated approach compared to inorganics at lower target and with actual soil test values compared to predicted soil test values. But, no significant difference was observed between inorganic and integrated approach and between predicted and actual soil test values. The apparent recovery efficiency of potassium was significantly higher (0.053 kg kg^{-1}) in treatment T_1 compared to all other treatments except with treatment T_5 (0.050 kg kg^{-1}), T_2 (0.049 kg kg^{-1}), T_6 (0.047 kg kg^{-1}) and T_7 (0.047 kg kg^{-1}) which were on par. Whereas, significantly lower value was recorded in LMH approach through actual test values (T_{11}: 0.028 kg kg^{-1}). Similarly, Similarly, ANUE of potassium was significantly higher (16.06 kg kg^{-1}) in STCR target 55 q ha^{-1} based on actual soil test values (T_5) compared to all other treatments except treatment T_2 (14.66 kg kg^{-1}), T_1 (14.59 kg kg^{-1}), T_6 (14.25 kg kg^{-1}) and T_7 (13.54 kg kg^{-1}). Significantly lower ANUE (7.91 kg kg^{-1}) was recorded in treatment T_{11} (LMH- Predicted STV). The higher ARE and ANUE of nitrogen in STCR target of 65 q ha^{-1} through inorganics based on predicted soil test values can be attributed to higher uptake and yield due to application of higher dose of nitrogen fertilizer compared to other treatments. However, higher ARE and ANUE of phosphorus was recorded in STCR target 65 q ha^{-1} through inorganics based on actual soil test values. This can also be attributed to application of higher dose of phosphatic fertilizers compared to other treatments. Even though higher dose of potassium fertilizer was applied in LMH approach and package of practice, ARE and ANUE was recorded higher in STCR treated plots which indicates the effective utilization of applied and soil available nutrients in STCR approach. Similarly, Prakash *et al.* (2021)[12] reported that use efficiency of in N, P and K was progressively increased in rice with incremental doses of respective nutrients 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 higher grain yield. Basavaraja *et al.* (2016) [13] reported that NPK uptake and nutrient use efficiency in aerobic paddy was significantly higher in the treatment where nutrients were applied through STCR integrated approach for a yield target of 75 q ha^{-1}. There was no significant difference between actual and predicted soil test value based fertilizer application with respect to recovery efficiency or nutrient use efficiency which indicates that predicted soil test values could also be used to prescribe the fertilizer dose so that the added nutrient can be used efficiently by the crops.

Table 5 Apparent recovery efficiency (ARE), Agronomic nutrient use efficiency (ANUE) and Internal utilisation efficiency (IUE) of N, P_2O_5 and K_2O as influenced by different approaches of nutrient application

Treatments	ARE			ANUE			IUE		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(kg kg^{-1})								
T_1	0.158	0.132	0.053	11.08	25.69	14.59	40.48	117.52	31.56
T_2	0.180	0.096	0.049	13.32	19.87	14.66	38.99	116.10	32.71
T_3	0.150	0.124	0.040	10.67	24.26	12.05	40.13	112.80	30.58
T_4	0.165	0.087	0.030	12.23	18.77	9.25	39.44	112.39	30.69
T_5	0.151	0.126	0.050	10.94	25.44	16.06	41.18	115.23	34.59
T_6	0.163	0.098	0.047	12.88	20.57	14.25	39.12	113.95	34.37
T_7	0.144	0.131	0.047	10.59	25.53	13.54	40.18	115.02	33.90
T_8	0.159	0.099	0.038	12.63	20.54	11.48	41.24	117.20	35.54
T_9	0.121	0.097	0.034	8.76	19.93	9.63	42.05	125.21	30.99
T_{10}	0.093	0.107	0.028	7.16	21.22	8.35	43.69	125.92	33.65
T_{11}	0.094	0.076	0.029	8.66	14.44	7.91	42.99	122.45	31.42
T_{12}	-	-	-	-	-	-	43.19	118.29	39.53
S.Em. ±	0.015	0.013	0.004	0.91	2.34	0.92	1.90	5.52	1.70
C.D. @ 5 %	0.044	0.039	0.011	2.74	6.92	2.72	NS	NS	4.98

Internal utilization efficacy

The internal use efficiency of nitrogen (IUEN) and phosphorus (IUEP) was found to be non significant (Table 5). However, numerically higher values for IUEN (43.69 kg kg^{-1}) and IUEP (125.92 kg kg^{-1}) was recorded in treatment receiving fertilizer nutrients through LMH approach through actual soil test values whereas, lower value (38.99 and 112.39 kg kg^{-1} respectively) was recorded in STCR inorganic approach for the targeted yield of 65 q ha^{-1} by considering predicted soil test values. Significantly higher (39.53 kg kg^{-1}) IUE of potassium was recorded in absolute control (T_{12}) compared to all other treatments except STCR target 55 q ha^{-1} through integrated approach based on predicted soil test values (35.54 kg kg^{-1}) and STCR target 55 q ha^{-1} based on actual soil test values (34.59 kg kg^{-1}). However, significantly lower value was recorded in STCR target 65 q ha^{-1} through integrated approach based on actual soil test values (30.58 kg kg^{-1}). Utilization efficiency of nutrients in rice indicates the yield in relation to total nutrient uptake. Utilization efficiency of N, P_2O_5, and K_2O was calculated by ratio of yield to uptake and were higher with no or lower dose of nutrient applied than other treatments. Increase in nutrient levels decreased the utilization efficiency in rice. These results are in conformity with finding of Prakash *et al.* (2021) [8] who reported that utilization efficiency of NPK were higher with no nutrient applied (43.04%, 207.66% and 41.22%, respectively) treatments compared to fertilized treatments.

Conclusion

It may be concluded that application of fertilizer nutrients through STCR approach for the targeted yield of 65 and 55 q ha^{-1} is the best option for achieving higher productivity of aerobic rice compared to PoP and LMH approach, beside improving nutrient requirement, uptake and efficiency of the applied fertilizer nutrient. Since fertigation is widely practiced to irrigate crops and aerobic rice being one of the water saving technology, further studies are required to develop the STCR targeted yield equations for aerobic rice through fertigation using soluble fertilizers so that fertilizer doses can be reduced by minimizing the various losses and enhancing the fertilizer / nutrient use efficiency.

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