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Effect of Integrated Nutrient Management Practices on Available Nutrient Status of Soil under Rice-Sorghum Cropping System in Clay Loamy Soils

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted for two consecutive years 2020-2021 and 2021-2022 on clay loam soil at Agricultural College Farm, Bapatla to study the direct and residual effect of integrated use of organics and inorganics on soil nutrient status under rice-sorghum cropping system. The results revealed that at all the growth stages of rice, the highest available nitrogen, phosphorus and potassium were recorded with the application of 100% RDF + 25% N through GLM (T_8) and this was on par with T_9 (100% RDF + 12.5% N through FYM + 12.5% N through GLM), T_3 (125% RDF through inorganic fertilizers) and T_7 (100% RDF + 25% N through FYM, whereas the highest available sulphur was recorded in 100% RDF + 25% N through GLM (T_8) and it was on par with T_9 (100% RDF + 12.5% N through FYM + 12.5% N through GLM) and T_7 (100% RDF + 25% N through FYM during 2020 and 2021. In succeeding sorghum, significantly highest soil available N, P_2O_5, K_2O and sulphur were recorded in T_9 (100% RDF + 12.5% N through FYM + 12.5% N through GLM) and it was on par with T_8 (100% RDF + 25% N through GLM) and T_7 (100% RDF + 25% N through FYM) during both the years of study. Irrespective of the treatments applied to rice crop, the sub plot that received 100% RDF (S_3) in *rabi* recorded significantly highest soil available nutrients at all stages of crop which was on par with 75% RDF (S_2) except available sulphur whereas increased NPK levels from 75% RDF (S2) to 100% RDF(S3) did not show any significant difference and lowest was recorded in control (S_1) during both the years of study, respectively.

Keywords: Direct and residual effect; nutrient status; cropping system; available nutrients; fertilizer level.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most predominant cereal food crops in about 40 countries in the world. In India, it is grown in an area of 45.07 m ha with a total production of 122.27 m t and a productivity of 2713 kg ha^{-1}. In Andhra Pradesh, rice is cultivated in an area of 2.32 m ha with an annual production of 7.89 m t and productivity of 3395 kg ha^{-1} [1] Sorghum (*Sorghum bicolor* L. Moench) is a staple crop for millions of farmers in the semi-arid tropics and can be grown in different climates around the world in approximately 48 million ha area annually. In India, it is grown in an area of 4.24 m ha with a total production of 4.78 m t and a productivity of 1128 kg ha^{-1}. In Andhra Pradesh, sorghum is cultivated in an area of 0.12 m ha with an annual production of 0.37 m t and productivity of 3070 kg ha^{-1} [1]. Continuous practice of rice-sorghum sequence is a point of concern as cultivation of two cereal crops in a year involves heavy removal of nutrients, which diminishes the soil health and inturn productivity. The cereal-cereal sequence for longer periods with low system productivity, and often with poor crop management practices, results in loss of soil fertility due to emergence of multiple nutrient deficiencies [2], deterioration of soil physical properties [3] and decline of crop yields in high productivity areas [4]. To compensate this, there is a need to develop Integrated Nutrient Management (INM) system. The concept of integrated nutrient management seeks to sustain soil fertility through an integration of different nutrient sources and their application methods which produce maximum crop yield per unit input use [5]. A judicious combination of organic sources and inorganics has been found to mutually reinforce the efficiency of both the sources resulting in higher productivity and soil fertility.

2. MATERIALS AND METHODS

Field experiment were carried out during *kharif* and *rabi* seasons of 2020-21 and 2021-22 at Agricultural College Farm, Bapatla, geographically located at an altitude of 5.49 m above mean sea level, $15^{o}54'$ North latitude, $80^{0}30'$ East longitude and about 8 km away from Bay of Bengal. It is located in Krishna agro-climatic zone of Andhra Pradesh. The soil of experimental site was clay loam in texture, neutral in reaction (pH 7.41), low in electrical conductivity (0.45 dS m^{-1}), low in organic carbon (0.49%), low in available nitrogen (224.46 kg ha^{-1}), medium in available phosphorus (42.93 kg ha^{-1}), high in available potassium (381.65 kg ha^{-1}) and sufficient in available sulphur (13.51 mg kg^{-1}).

3. EXPERIMENTAL DESIGN AND TREATMENTS

During *Kharif,* the treatments consisted of T_1- Absolute Control, T_2- 100% RDF through inorganic fertilizers, T_3- 125% RDF through inorganic fertilizers, T_4- 75% RDF + 25% N through FYM, T_5- 75% RDF + 25% N through GLM, T_6- 75% RDF + 12.5% N through FYM + 12.5% N through GLM, T_7- 100 % RDF + 25% N through FYM, T_8- 100% RDF + 25% N through GLM, T_9- 100% RDF + 12.5% N through FYM + 12.5% N through GLM were imposed to rice crop during *kharif* season and replicated thrice. The *rabi* experiment was continued on the same site without disturbing the soil with sorghum as test crop to study the residual effect of different nutrient sources applied to preceding rice crop. During *rabi,* the treatments consisted of three levels of fertilizers *viz.,* S_1- Control, S_2- 75% RDF and S_3-100% RDF. Popular cultivars of rice and sorghum *viz*., BPT-5204 and MLSH-151 respectively, were chosen for the study.

4. RESULTS AND DISCUSSION

4.1 Effect of INM Practices on Available Nutrient Status of Soil in *Kharif* Rice

4.1.1 Available nitrogen

Data pertaining to the soil available nitrogen (Table 1) indicated that various nutrient management treatments imposed under rice crop have shown significant effect on available nitrogen at all growth stages of rice and during both the years of study.

Significantly higher available nitrogen in soil was recorded in the treatment T_8 *i.e.,* 100% RDF + 25% N through GLM (301.19, 278.46, 249.70 kg ha-1 and 307.05, 284.46, 254.87 kg ha-1) in 2020 and 2021, respectively at active tillering, panicle initiation and harvest stages of rice crop and it was on par with the treatments that received 100% RDF + 12.5% N through FYM + 12.5% N through GLM (T_9- 294.52, 274.84, 246.58 kg ha^{-1} and 299.25, 279.84, 250.25 kg ha^{-1}), 125% RDF through inorganic fertilizers (T_3- 290.76, 270.07, 244.49 kg ha^{-1} and 295.22, 276.84249.15 kg ha^{-1}) and 100% RDF + 25% N through FYM (T_7- 287.68, 268.65, 242.94 kg ha^{-1} and 292.41, 273.32, 247.98 kg ha^{-1}) during both the years of study, respectively. The lowest available nitrogen was recorded in the treatment T_1 *i.e.,* control (217.42, 210.20, 204.80 kg ha^{-1} in 2020 and 222.65, 215.53, 206.47 kg ha^{-1} in 2021) which received no fertilizers at all the three stages of crop growth.

Combined application of organics and inorganics recorded the highest available nitrogen content. This might be due to positive response of green manuring with inorganic fertilizers on soil N status and may be attributed to N mineralization from organic sources or by retaining N in labile microbial pool with the changing microbial flush. The moist soil conditions might have helped the mineralization of soil N and greater multiplication of soil microbes, which could convert organically bound nitrogen into readily available form leading to building up of higher available N. The inclusion of green leaf manure (*Sesbania aculeata*) in rice based cropping sequence reduced the loss of native nitrate N accumulated during aerobic cycle of the rice based cropping sequence and also conserved nitrate nitrogen, which would be lost upon flooding [6].

Table 1. Effect of integrated nutrient management practices on available nitrogen (kg ha^{-1}) in soil at different stages of rice

Treatments	***Kharif* (2020)**			***Kharif* (2021)**		
	Active tillering	**Panicle initiation**	**Harvest**	**Active tillering**	**Panicle initiation**	**Harvest**
T_1	217.42	210.20	204.80	222.65	215.53	206.47
T_2	269.03	248.07	225.40	273.36	252.72	228.06
T_3	290.76	270.07	244.49	295.22	276.84	249.15
T_4	256.78	239.05	218.47	261.78	242.05	220.80
T_5	264.07	244.51	221.16	269.65	247.51	224.16
T_6	260.63	242.98	220.84	264.29	245.98	223.65
T_7	287.68	268.65	242.94	292.41	273.32	247.98
T_8	301.19	278.46	249.70	307.05	284.46	254.87
T_9	294.52	274.84	246.58	299.25	279.84	250.25
SEm ±	9.60	9.29	8.81	9.71	10.02	8.16
CD (P=0.05)	29.04	28.11	26.67	29.38	30.34	24.69
CV (%)	6.30	6.43	6.62	6.50	6.74	6.04

4.1.2 Available phosphorus

Close perusal of the data pertaining to available phosphorus in soil (Table 2) revealed that irrespective of the year of study, the available phosphorus at all growth stages of rice crop was significantly influenced by combined application of organics and inorganics.

At all growth stages of rice, among the different sources of organic manures, T_8 *i.e*., 100% RDF + 25% N through GLM (75.18, 68.31, 62.72 kg ha^{-1} in 2020 and 77.64, 69.64, 64.08 kg ha^{-1} in 2021) recorded significantly highest available P_2O_5 however it was on par with the treatments that received 100% RDF + 12.5% N through FYM + 12.5% N through GLM (T_9- 73.23, 66.75, 59.24 kg ha^{-1} and 75.66, 68.50, 60.57 kg ha^{-1}), 125% RDF through inorganic fertilizers (T_3- 70.13, 64.24, 57.17 kg ha^{-1} and 72.46, 65.03, 58.16 kg ha^{-1}) and 100% RDF + 25% N through FYM (T_7- 68.36, 61.50, 56.46 kg ha^{-1} and 70.59, 63.37, 57.32 kg ha^{-1}) at tillering, panicle initiation and harvest stages of rice during 2020 and 2021, respectively. The lowest available P was recorded in the treatment T_1 *i.e*., control (45.12, 43.84, 42.13 kg ha^{-1} in 2020 and 47.45, 44.67, 43.25 kg ha^{-1} in 2021) which received no fertilizers at tillering, panicle initiation and harvest stages of rice.

Increase in available P with FYM application and green manuring might be due to additional application of P and mobilization of P in the soil. This increase in P might also be attributed to the decomposition of organic manures accompanied by release of appreciable quantity of CO_2 and organic acids. Available P content of the soil increased with the incorporation of organic manures as compared to its initial status. These results were in conformity with the findings of Mallareddy and Devenderreddy [7] who reported that the build up of available P in soil was due to release of organic acids during microbial decomposition of green manures which might have helped in the solubility of native P.

The build up in available P may be due to the influence of organic manures in increasing the labile P in soil though complexing of cations like Ca^{+2} and Mg^{+2} which are mainly responsible for fixation of P [8,9] Tolanur and Badanur [10] also reported that organic manures like FYM and green manuring with inorganic fertilizers had the beneficial effect on increasing the phosphate availability. These results are in general agreement with the findings of Pattanayak et al. [11], Parmer and Sharma [12], Singh et al. [13] and Verma et al. [14]. The maximum available P recorded in treatments with green leaf manuring may be due to the mobilization of soil P by the acidification of soil and the release of enzymes such as phosphatases and phytases of carboxylates such as gluconates and oxalates [15]. Similar results were observed by Hossain et al. [16] and Jemila et al. [17].

The soil available phosphorus was decreased with advancement of crop stage during both the years with the application of organic manures. This decrease in phosphorus might be attributed to absorption of P by the growing plants and/or due to refixation of solubilized phosphorus [18,19]

4.1.3 Available potassium

The data presented in Table 3 indicated that, among the different treatments imposed to *kharif* rice, combined application of organics and inorganics have shown significant effect on available potassium in soil at all the stages of crop.

The results revealed that significantly highest available potassium in soil was recorded in the treatment T_8 *i.e*., 100% RDF + 25% N through GLM (461.31, 443.61, 426.62 kg ha^{-1} in 2020 and 466.64, 448.12, 430.62 kg ha^{-1} in 2021) and it was on par with the treatments that received 100% RDF + 12.5% N through FYM **+** 12.5% N through GLM (T_9- 456.73, 437.54, 422.64 kg ha^{-1} and 460.06, 440.87, 425.13 kg ha^{-1}), 125% RDF through inorganic fertilizers (T_3- 453.79, 434.80, 420.40 kg ha^{-1} and 456.77, 438.13, 424.07 kg ha^{-1}) and 100% RDF + 25% N through FYM (T_7- 450.52, 430.92, 417.13 kg ha^{-1} and 454.19, 434.56, 420.45 kg ha^{-1}) at active tillering, panicle initiation and harvest stages of rice crop during 2020 and 2021, respectively. The lowest available potassium was recorded in the treatment T_1 *i.e*., control (376.15, 369.36, 361.53 kg ha^{-1} in 2020 and 378.48, 372.69, 363.20 kg ha^{-1} in 2021) which received no fertilizers at all the three stages of crop growth.

The green manures registered significantly highest K availability in soil due to its easy decomposition of mineral constituents and their effect on dislodging the exchangeable K into the soil solution. These results were in conformity with the findings of Maiti et al. [20], Vinay [21] and Upadhyay et al. [22]. When acid forming compounds are added in the form of compost to the soil, these acids affect potassium availability.

The effect is positive resulting in more availability of K to the plants. The hydrogen ions released from organic materials are exchanged with K on exchange site or set free from the fixed site of the clay micelle.

Thus, the overall status of soil regarding availability of potassium content was improved [23-26,13]. Verma et al. [14] also reported that continuous use of FYM and green manures enhanced the potassium status in the soil. The beneficial effect of green leaf manuring and FYM on available potassium might be due to reduction of potassium fixation, solubilisation and release due to the interaction of organic matter with clay besides the direct potassium addition to the potassium pool of soil. Similar results were also observed by Sarkar et al. [27], Chettri et al. [28] Elayaraja and Senthilvalava [29] Sharma et al. [30] and Karunakaran et al. [31].

On the other hand, the available potassium content was gradually decreased with advancement of crop stage *i.e.,* from tillering to harvest stage in both the years. These results were in accordance with the findings of Subhalakshmi and Pratapkumarreddy [32]. This might be due to the continuous depletion of K by crop uptake and also due to potassium fixation in soils [18].

4.1.4 Available sulphur

The data presented in Table 4 revealed that available sulphur in soil at different stages of rice was significantly influenced by the different treatments imposed during both the years of study.

Among the different treatments applied, the treatment that received T_8 *i.e.*, 100% RDF + 25% N through GLM (17.24, 17.11, 17.03 mg kg^{-1} in 2020 and 17.43, 17.18, 17.09 mg kg^{-1} in 2021) recorded significantly highest available sulphur and it was on par with the treatments that received 100% RDF + 12.5% N through FYM **+** 12.5% N through GLM (T_9- 17.05, 16.92, 16.84 mg kg^{-1} and 17.22, 16.99, 16.88 mg kg^{-1}), 100% RDF + 25% N through FYM (T_7- 16.96 16.81, 16.72 mg kg^{-1} and 17.14, 16.88, 16.79 mg kg^{-1}), 75% RDF + 25% N through GLM (T_5- 15.74, 15.60, 15.52 mg kg^{-1} and 15.91, 15.68, 15.56 mg kg^{-1}) and 75% RDF + 12.5% N through FYM **+** 12.5% N through GLM (T_6- 15.65, 15.52, 15.44 mg kg^{-1} and 15.83, 15.59, 15.48 mg kg^{-1}) during 2020 and 2021, respectively at active tillering, panicle initiation and harvest stages of rice crop. The lowest available sulphur was recorded in the treatment T_1 *i.e*., control (13.47, 13.45, 13.42 mg kg^{-1} in 2020 and 13.42, 13.40, 13.39 mg kg^{-1} in 2021) at all the three stages of crop growth.

The treatments that received only inorganics *i.e.,* T_2 (14.10, 14.07, 14.05 mg kg^{-1} in 2020 and 14.05, 14.02, 14.00 mg kg^{-1} in 2021) and T_3 (14.25, 14.22, 14.19 mg kg^{-1} in 2020 and 14.21, 14.17, 14.14 mg kg^{-1} in 2021) recorded lower available sulphur than the combined treatments at all the growth stages of rice.

Combined application of organics with inorganics have shown a slight increase in available sulphur which might be due to mineralization of organic source that contributed to accumulation of more amount of sulphur in soil [33]. Thus, addition of farmyard manure and green leaf manure in soil might be the possible reason of enhancement of sulphur content. These results were in agreement with findings of Singh et al. [34] and this increase might be due to addition of farmyard manure and green leaf manure which contained sulphur as a constituent element and thus, mineralization of this organic source might have released proportionate amount of sulphate that was adsorbed by colloidal complex and contributed to accumulation of more amount of sulphur over inorganic treatments [35,36]

However, the soil sulphate sulphur content was decreased with advancement of crop stage during both the years and in all the treatments. This might be due to the uptake of SO_4^{-2} by the growing plants leading to lowering the available sulphur content at harvest stage. The above statement was supported by Veeranagappa et al. [18].

Table 2. Effect of integrated nutrient management practices on available phosphorus (kg ha^{-1}) in soil at different stages of rice

Treatments	*Kharif (*2020)			*Kharif (*2021)		
	Active tillering	Panicle initiation	Harvest	Active tillering	Panicle initiation	Harvest
T_1	45.12	43.84	42.13	47.45	44.67	43.25
T_2	65.96	58.72	53.86	66.72	60.86	55.72

Treatments	*Kharif (*2020)			*Kharif (*2021)		
	Active tillering	Panicle initiation	Harvest	Active tillering	Panicle initiation	Harvest
T_3	70.13	64.24	57.17	72.46	65.03	58.16
T_4	58.70	53.36	49.23	60.50	55.69	50.45
T_5	63.75	57.62	51.58	64.38	58.45	53.91
T_6	60.78	55.49	50.85	62.08	57.75	51.60
T_7	68.36	61.50	56.46	70.59	63.37	57.32
T_8	75.18	68.31	62.72	77.64	69.64	64.08
T_9	73.23	66.75	59.24	75.66	68.50	60.57
SEm ±	2.89	3.12	2.81	2.99	2.68	2.49
CD(P=0.05)	8.75	9.01	8.51	9.06	8.13	7.54
CV (%)	7.89	9.18	9.07	7.81	7.69	8.80

Table 3. Effect of integrated nutrient management practices on available potassium (kg ha^{-1}) in soil at different stages of rice

Treatments	*Kharif (*2020)			*Kharif (*2021)		
	Active Tillering	Panicle Initiation	Harvest	Active Tillering	Panicle Initiation	Harvest
T_1	376.15	369.36	361.53	378.48	372.69	363.20
T_2	419.16	402.81	386.32	422.50	405.34	388.79
T_3	453.79	434.80	420.40	456.77	438.13	424.07
T_4	408.45	392.83	379.14	407.61	395.20	381.45
T_5	414.56	398.52	383.71	417.23	401.93	385.56
T_6	405.94	395.60	381.25	410.21	399.64	384.40
T_7	450.52	430.92	417.13	454.19	434.56	420.45
T_8	461.31	443.61	426.62	466.64	448.12	430.62
T_9	456.73	437.54	422.64	460.06	440.87	425.13
SEm ±	12.47	12.03	12.18	14.08	13.5	13.17
CD (P=0.05)	37.65	36.33	36.78	42.61	40.87	39.85
CV (%)	6.02	6.25	6.24	6.25	6.23	6.33

Table 4. Effect of integrated nutrient management practices on available sulphur (mg kg^{-1}) in soil at different stages of rice

Treatments	*Kharif (*2020)			*Kharif* (2021)		
	Active Tillering	Panicle Initiation	Harvest	Active Tillering	Panicle Initiation	Harvest
T_1	13.47	13.45	13.42	13.42	13.40	13.39
T_2	14.10	14.07	14.05	14.05	14.02	14.00
T_3	14.25	14.22	14.19	14.21	14.17	14.14
T_4	15.52	15.37	15.28	15.73	15.42	15.34
T_5	15.74	15.60	15.52	15.91	15.68	15.56
T_6	15.65	15.52	15.44	15.83	15.59	15.48
T_7	16.96	16.81	16.72	17.14	16.88	16.79
T_8	17.24	17.11	17.03	17.43	17.18	17.09
T_9	17.05	16.92	16.84	17.22	16.99	16.88
SEm ±	0.55	0.55	0.57	0.55	0.54	0.54
CD (P=0.05)	1.66	1.65	1.64	1.62	1.63	1.64
CV (%)	6.11	6.13	6.39	6.06	6.03	6.10

4.2 Residual Effect of INM Practices on Available Nutrient Status of Soil under Sorghum in Rice-Sorghum Cropping System

4.2.1 Available Nitrogen

The data pertaining to available nitrogen was presented in the Tables 5 and 6. The various nutrient management treatments applied to preceding rice showed significant influence on available nitrogen by succeeding sorghum at all the stages during both the years of study.

The highest available nitrogen was recorded in the treatment T_9 (100% RDF + 12.5% N through FYM + 12.5% N through GLM) with 261.5, 254.6, 248.8 kg ha^{-1} in 2020-21 and 268.8, 261.0, 255.3 kg ha^{-1} in 2021-22 at vegetative, flowering and harvest stages, respectively and it was on par with treatments T_8 which received 100% RDF + 25% N through GLM (258.2, 251.7, 246.2 kg ha^{-1} in 2020-21 and 265.0, 258.1, 252.4 kg ha^{-1} in 2021-22), T_7 *i.e.*, 100% RDF + 25% N through FYM (255.9, 249.0, 243.0 kg ha^{-1} in 2020-21 and 262.9, 255.5, 249.5 kg ha^{-1} in 2021-22) and T_3 *i.e.,*125% RDF through inorganic fertilizers (252.6, 246.0, 240.3 kg ha^{-1} in 2020-21 and 259.6, 252.8, 246.4 kg ha^{-1} in 2021-22). It indicates the prominent residual effect of farmyard manure and green leaf manure when compared to all other treatments. This benefit owes to low decomposition and mineralization of major and minor nutrients and their addition to soil nutrient pool left behind in sufficient quantities after their absorption by rice crop [37] Urea which is most available form of nitrogen when applied to rice is subjected to leaching and volatilization losses in addition to crop uptake. Therefore, this resulted in lower availability of nitrogen after *kharif* rice.

Application of manures over the years increases the level of N, P, K, S, Ca and Mg in the soil. Thus, creating a reservoir of soil nutrients for several years after application. Use of farmyard manure and green leaf manure might have attributed to the mineralization of N in soil and high enzyme activities in the soil amended with organic manures might have increased the transformation of nutrients to available form. Role of farmyard manure and green leaf manure in releasing N and improving N availability in soil was reported by Singh et al. [38]

At all the stages of crop growth, the lowest available nitrogen in soil was recorded in control *i.e.,* T_1 (218.2, 212.9, 207.3 kg ha^{-1} in 2020-21 and 222.7, 216.7, 210.8 kg ha^{-1} in 2021-22) which received no fertilizers indicating its negligible residual effect.

Among the subplots, 100% RDF (S_3) recorded significantly highest available nitrogen (261.6, 255.2, 248.7 kg ha^{-1} in 2020-21 and 267.3, 261.1, 254.4 kg ha^{-1} in 2021-22) at vegetative, flowering and harvest stages, respectively which was on par with 75% RDF (S_2) and superior over control (S_1). Increase in available nitrogen with increase in the level of fertilizers might be attributed to the fact that with higher fertilizer dose, higher amount of fertilizer N could be converted into available form by the biochemical reaction of fertilizer N with soil organic matter [9] The above results were also corroborated with Katkar et al. [39] Gadhiya et al. [40], Jat and Nanwal [41] and Deekshitha et al. [42] The interaction between nutrient management treatments applied during *kharif* season and different levels of fertilizers during *rabi* season was found non-significant.

4.2.2 Available Phosphorus

The data presented in the Tables 7 and 8 revealed that different INM treatments adopted in *kharif* showed significant residual effect on available phosphorus by sorghum in *rabi*.

Significantly higher available phosphorus was recorded in the treatment T_9 *i.e.,* 100% RDF + 12.5% N through FYM + 12.5% N through GLM with 70.3, 63.3, 58.6 kg ha^{-1} in 2020-21 and 74.8, 67.7, 63.1 kg ha^{-1} in 2021-22 at vegetative, flowering and harvest stages, respectively and it was on par with treatments T_8 which received 100% RDF + 25% N through GLM (67.2, 61.8, 56.8 kg ha^{-1} in 2020-21 and 71.4, 66.0, 61.1 kg ha^{-1} in 2022), T_7 *i.e.*, 100 % RDF + 25% N through FYM (66.1, 60.6, 55.1 kg ha^{-1} in 2020-21 and 70.5, 64.6, 59.5 kg ha^{-1} in 2021-22) and T_3 *i.e.,* 125% RDF through inorganic fertilizers (64.8, 58.5, 53.1 kg ha^{-1} in 2020-21 and 69.0, 62.8, 57.6 kg ha^{-1} in 2021-22). The lowest available phosphorus was recorded in T_1 *i.e.,* control (49.9, 45.5, 42.8 kg ha^{-1} in 2020-21 and 53.1, 48.9, 46.2 kg ha^{-1} in 2021-22) indicating its negligible residual effect at all the stages of crop growth, respectively.

Superiority of treatments which received farmyard manure and green leaf manure in terms of soil available phosphorus might be due to the persistant material in organic manures *viz.,* cellulose. It requires more time for its decomposition, hence, about 25 to 33% of nitrogen and small fraction of phosphorus and potassium may be available to immediate crop *i.e*., rice and the rest to subsequent crop *i.e*., sorghum [43,42] Mahala et al. [44] Mallareddy and Devenderreddy [7] and Subbaiah et al. [37] also noticed the significant residual effect of organics on succeeding crop in terms of the available phosphorus in soil. High analysis fertilizers might have provided N and P to meet the requirements of rice crop only. It is established that only 30 percent of N and 15 percent of P in inorganic fertilizers is utilized by *kharif* crop and the rest is subjected to loss thus reducing its use efficiency.

Irrespective of the INM treatments in *kharif*, application of 100% RDF (S_3) in *rabi* recorded significantly highest available P_2O_5 (70.1, 62.2, 56.7 kg ha^{-1} and 74.5, 66.2, 60.8 kg ha^{-1}) at all stages of crop which was on par with 75% RDF (S_2) *i.e.,* 65.2, 58.2, 52.6 kg ha^{-1} and 69.8, 62.2, 57.1 kg ha^{-1} and lowest was recorded in control (S_1) during 2020-21 and 2021-22, respectively. The interaction between main plots and subplots was found non-significant.

However, the soil available phosphorus was decreased with advancement of crop stage during both the years and in all the treatments. This decrease in phosphorus might be attributed to absorption of P by the growing plants and/or due to refixation of solubilized phosphorus [18,19] Bhargavi et al. [45] reported that the highest available phosphorus was recorded with sunhemp- rice- rice and build up of available phosphorus in soil was due to release of organic acids during microbial decomposition of green manure which helped in the solubility of native phosphorus in soil. As the phosphorus requirement of rice was meagre, organic and inorganic additions increased the soil phosphorus content.

4.2.3 Available potassium

Available potassium in sorghum at various growth stages was significantly influenced by various integrated nutrient management treatments imposed in preceding rice and levels of NPK applied to sorghum during both the years of experimentation (Tables 9 and 10).

Among the main plots, the treatment that received 100% RDF + 12.5% N through FYM + 12.5% N through GLM (T_9- 447.9, 433.4, 424.7 kg ha^{-1} in 2020-21 and 457.0, 441.2, 433.1 kg ha^{-1} in 2021-22) recorded significantly highest available potassium in soil at vegetative, flowering and harvest stages, respectively and it was on par with treatments T_8 which received 100% RDF + 25% N through GLM (445.3, 430.5, 422.2 kg ha^{-1} in 2020-21 and 453.7, 438.4, 430.7 kg ha^{-1} in 2022), T_7 *i.e*.,100% RDF + 25% N through FYM (442.7, 428.8, 419.4 kg ha^{-1} in 2020-21 and 451.1, 436.3, 427.9 kg ha^{-1} in 2021-22) and T_3 *i.e.,* 125% RDF through inorganic fertilizers (438.0, 424.1, 416.1 kg ha^{-1} in 2020-21 and 446.9, 432.0, 424.8 kg ha^{-1} in 2021-22). The lowest available potassium was recorded in T_1 *i.e.,* control (376.6, 366.0, 357.0 kg ha^{-1} in 2020-21 and 382.3, 371.5, 362.7 kg ha^{-1} in 2021-22) indicating its negligible residual effect.

Application of FYM and green leaf manure along with inorganics to preceding rice have improved the available K_2O content in soil under sorghum when compared to all other treatments. The buildup of soil available K due to FYM and green leaf manure application may be due to addition of K through solubilizing action of certain organic acids produced during decomposition of organics, reduction of potassium fixation, its greater capacity to hold K in the available form. Similar results were also observed by Sarkar et al. [27] Chettri et al. [28] Santhosh et al. [46] and Sankaramoorthy and Rangaswamy [47].

Irrespective of the integrated nutrient management practices followed in preceding rice crop, the application of 100% RDF (S_3) recorded highest available K in soil under sorghum (S_3- 438.7, 421.2, 411.2 kg ha^{-1} in 2020-21 and 448.1, 429.8, 420.4 kg ha^{-1} in 2021-22) and it was on par with 75% RDF (S_2) but superior over control during both the years of study at vegetative, flowering and harvest stages, respectively. Interaction effect was found to be statistically insignificant.

On the other hand, the available potassium content gradually decreased with advancement of crop stage *i.e.,* from vegetative to harvest stage in both the years. This might be due to the continuous depletion of K by crop uptake and also due to potassium fixation in soils [18] These results were in coincidence with Subhalakshmi and Pratapkumarreddy and Deekshitha et al. [32,42].

Table 5. Residual effect of INM practices in preceding rice and NPK levels on available nitrogen (kg ha^{-1}) in soil at different stages of sorghum (*Rabi*, 2020-21)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	196.8	222.3	235.6	**218.2**	191.3	216.5	230.8	**212.9**	185.6	210.5	225.8	**207.3**
T_2	214.5	239.4	251.7	**235.2**	207.7	235.4	247.1	**230.1**	201.4	229.7	238.2	**223.1**
T_3	228.6	258.3	270.8	**252.6**	222	253.6	262.3	**246.0**	216.2	248.6	256.1	**240.3**
T_4	216.3	242.9	253.5	**237.6**	209.8	237.3	249.5	**232.2**	202.3	231.5	241.8	**225.2**
T_5	217.5	244.3	255.8	**239.2**	211.3	239.7	250.4	**233.8**	205.5	232.3	243.7	**227.2**
T_6	221.1	247.3	258.6	**242.3**	214.8	241.4	252.6	**236.3**	207.4	236.3	246.6	**230.1**
T_7	231.9	262.2	273.6	**255.9**	226.4	256.2	264.5	**249.0**	220.1	250.4	258.5	**243.0**
T_8	234.2	264.6	275.8	**258.2**	228.4	258.6	268.1	**251.7**	222.9	253.6	262.2	**246.2**
T_9	237.2	268.0	279.4	**261.5**	231.8	261	271.1	**254.6**	225.8	255.2	265.3	**248.8**
Mean	**222.0**	**249.9**	**261.6**		**215.9**	**244.4**	**255.2**		**209.7**	**238.7**	**248.7**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	5.73	17.18	7.09		5.16	15.47	6.56		5.55	16.63	7.23	
S	3.81	11.97	7.74		3.95	11.33	8.48		3.80	10.86	6.54	
M X S	10.84	NS			11.56	NS			8.69	NS		
S X M	9.73	NS			10.12	NS			8.10	NS		

Table 6. Residual effect of INM practices in preceding rice and NPK levels on available nitrogen (kg ha-1) in soil at different stages of sorghum (*Rabi*, 2021-22)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	200.5	226.8	240.9	**222.7**	194.7	220.8	234.5	**216.7**	188.1	214.8	229.4	**210.8**
T_2	219.8	245.7	256.4	**240.6**	213.3	242.6	252.2	**236.0**	205.8	234.1	243.8	**227.9**
T_3	235.9	265.6	277.2	**259.6**	227.5	260.2	270.7	**252.8**	220.5	255.2	263.6	**246.4**
T_4	221.7	247.5	258.8	**242.7**	212.3	244.6	255.4	**237.4**	206.8	237.2	246.4	**230.1**
T_5	222.8	249.7	260.3	**244.3**	215.7	244.4	254.6	**238.2**	209.2	239.6	248.2	**232.3**
T_6	226.5	252.7	263.1	**247.4**	218.4	246.8	257.1	**240.8**	211.2	241.8	251.3	**234.8**
T_7	238.7	269.6	280.3	**262.9**	231.7	263.5	271.3	**255.5**	225.8	257.6	265.1	**249.5**
T_8	241.5	271.3	282.2	**265.0**	233.7	265.1	275.6	**258.1**	227.2	260.4	269.5	**252.4**
T_9	244.4	275.2	286.8	**268.8**	236.4	268.2	278.5	**261.0**	230.5	262.9	272.6	**255.3**

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
Mean	**228.0**	**256.0**	**267.3**		**220.4**	**250.7**	**261.1**		**213.9**	**244.8**	**254.4**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	6.48	18.53	7.83		6.34	18.29	7.87		5.64	16.92	7.19	
S	4.38	12.52	7.08		4.21	12.04	6.26		4.05	11.62	6.74	
M X S	10.14	NS			8.73	NS			9.16	NS		
S X M	9.46	NS			8.42	NS			8.48	NS		

Table 7. Residual effect of INM practices in preceding rice and NPK levels on available phosphorus (kg ha^{-1}) in soil at different stages of sorghum (*Rabi*, 2020-21)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	39.1	53.4	57.2	**49.9**	37.1	48	51.3	**45.5**	34.1	45.4	49	**42.8**
T_2	47.6	61.4	67.1	**58.7**	43.6	53.7	58.9	**52.1**	40.6	48.3	53.8	**47.1**
T_3	54.2	67.5	72.6	**64.8**	50.3	60.8	64.5	**58.5**	47.2	53.7	58.5	**53.1**
T_4	46.5	62.4	67.8	**58.9**	44.4	54.7	59.6	**52.9**	41.5	49.3	52.4	**48.2**
T_5	48.2	63.3	68.6	**60.0**	46.2	55.5	60.4	**54.0**	42.3	50.0	54.2	**48.8**
T_6	50.6	65.1	69.4	**61.7**	48.8	58.9	61.7	**56.5**	44.4	51.8	56.7	**51.0**
T_7	54.7	69.5	74.2	**66.1**	52.6	62.8	66.3	**60.6**	48.7	56.4	60.2	**55.1**
T_8	55.4	70.9	75.3	**67.2**	54	63.5	67.8	**61.8**	50.4	58.1	61.8	**56.8**
T_9	59.1	73.3	78.6	**70.3**	55.2	65.7	69	**63.3**	52.1	60.3	63.5	**58.6**
Mean	**50.6**	**65.2**	**70.1**		**48.0**	**58.2**	**62.2**		**44.6**	**52.6**	**56.7**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	2.48	7.16	9.76		2.07	6.02	10.11		2.13	6.17	11.33	
S	1.91	5.46	7.76		1.72	4.93	6.75		1.65	4.73	6.64	
M X S	3.39	NS			2.38	NS			2.15	NS		
S X M	3.23	NS			2.34	NS			2.09	NS		

Table 8. Residual effect of INM practices in preceding rice and NPK levels on available phosphorus (kg ha^{-1}) in soil at different stages of sorghum (*Rabi*, 2021-22)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	41.6	57.1	60.7	**53.1**	39.5	52.4	54.8	**48.9**	36.4	49.8	52.3	**46.2**
T_2	49.3	64.8	70.5	**61.5**	45.1	56.4	61.5	**54.3**	42.5	51.7	55.3	**49.8**
T_3	57.6	72.2	77.3	**69.0**	53.8	65.4	69.2	**62.8**	50.7	58.3	63.8	**57.6**
T_4	48.2	66.7	71.5	**62.1**	46.8	58.4	62.2	**55.8**	43.4	53.8	56.2	**51.1**
T_5	50.6	67.5	72.1	**63.4**	48.7	59.1	64.7	**57.5**	44.9	54.1	58.5	**52.5**
T_6	52.1	70.5	74.9	**65.8**	50.6	62.5	65.1	**59.4**	46.6	55.5	60.6	**54.2**
T_7	57.1	74.8	79.5	**70.5**	55	67.3	71.6	**64.6**	51.2	61.8	65.5	**59.5**
T_8	58.2	75.5	80.6	**71.4**	57.4	68.2	72.3	**66.0**	53.6	63.3	66.4	**61.1**
T_9	62.4	78.7	83.4	**74.8**	58.5	70.2	74.3	**67.7**	55.4	65.7	68.3	**63.1**
Mean	**53.0**	**69.8**	**74.5**		**50.6**	**62.2**	**66.2**		**47.2**	**57.1**	**60.8**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	2.60	7.56	9.77		1.93	5.51	8.83		2.30	6.78	11.56	
S	2.02	5.79	8.24		1.62	4.83	6.04		1.72	4.91	6.88	
M X S	3.77	NS			2.27	NS			2.34	NS		
S X M	3.61	NS			2.23	NS			2.48	NS		

Table 9. Residual effect of INM practices in preceding rice and NPK levels on available potassium (kg ha^{-1}) in soil at different stages of sorghum (*Rabi*, 2020-21)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	353.5	379.8	396.5	**376.6**	346.1	368.3	383.5	**366.0**	340.4	358.2	372.5	**357.0**
T_2	370.8	398.8	416.0	**395.2**	364.3	386.9	400.2	**383.8**	357.1	374.2	389.4	**373.6**
T_3	405.3	446.7	462.1	**438.0**	395.9	432.7	443.5	**424.1**	392.2	421.5	434.8	**416.1**
T_4	373.1	399.4	418.5	**397.0**	367.4	388.1	402.3	**385.7**	360.8	376.2	391.1	**376.0**
T_5	374.4	401.7	421.5	**399.2**	366.6	389.5	404.0	**387.0**	362.0	378.6	394.3	**378.3**
T_6	379.7	403.9	423.7	**402.4**	372.1	392.6	406.8	**390.5**	365.7	380.5	396.2	**380.8**
T_7	410.5	450.7	466.8	**442.7**	402.1	436.7	447.5	**428.8**	394.2	425.7	438.4	**419.4**
T_8	412.7	453.1	469.9	**445.3**	403.8	438.2	449.6	**430.5**	397.2	428.8	440.5	**422.2**
T_9	415.2	455.3	473.1	**447.9**	405.7	441.6	452.9	**433.4**	399.6	430.9	443.8	**424.7**
Mean	**388.4**	**421.0**	**438.7**		**380.4**	**408.3**	**421.2**		**374.3**	**397.2**	**411.2**	

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	12.85	38.52	9.26		12.31	36.90	9.16		11.38	34.12	8.66	
S	6.58	18.86	8.21		4.89	14.02	6.30		5.54	15.90	7.31	
M X S	19.73	NS			14.67	NS			16.63	NS		
S X M	18.50	NS			14.80	NS			15.78	NS		

Table 10. Residual effect of INM practices in preceding rice and NPK levels on available potassium (kg ha^{-1}) in soil at different stages of sorghum (*Rabi*, 2021-22)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	356.9	384.5	405.7	**382.3**	349.7	373.6	391.2	**371.5**	343.6	363.4	381.1	**362.7**
T_2	374.5	404.1	423.6	**400.8**	368.5	391.5	407.8	**389.3**	361.4	380.7	397.0	**379.7**
T_3	411.7	455.4	473.7	**446.9**	401.1	440.3	454.7	**432.0**	398.5	430.6	445.4	**424.8**
T_4	377.3	405.7	426.2	**403.1**	370.3	393.8	409.7	**391.3**	364.8	382.2	399.3	**382.1**
T_5	378.9	407.5	429.9	**405.4**	371.6	394.7	411.2	**392.5**	366.1	384.3	402.0	**384.1**
T_6	383.3	409.2	431.6	**408.0**	376.5	397.1	414.5	**396.0**	369.1	386.8	404.3	**386.7**
T_7	416.8	459.5	477.2	**451.1**	408.5	444.2	456.1	**436.3**	400.0	434.4	449.1	**427.9**
T_8	418.0	462.8	480.3	**453.7**	409.3	446.6	459.2	**438.4**	403.5	437.4	451.1	**430.7**
T_9	421.9	464.7	484.4	**457.0**	411.0	449.2	463.5	**441.2**	405.4	439.3	454.5	**433.1**
Mean	**393.3**	**428.1**	**448.1**		**385.2**	**414.6**	**429.8**		**379.2**	**404.3**	**420.4**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	10.58	31.71	7.50		10.32	30.95	7.56		10.83	32.46	8.10	
S	7.38	21.16	9.06		5.79	16.61	7.34		6.20	17.79	8.03	
M X S	22.13	NS			17.37	NS			18.60	NS		
S X M	19.56	NS			15.95	NS			17.01	NS		

Table 11. Residual effect of INM practices in preceding rice and NPK levels on available sulphur (mg kg^{-1}) in soil at different stages of sorghum (*Rabi*, 2020-21)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	13.37	13.38	13.40	**13.38**	13.34	13.36	13.38	**13.36**	13.31	13.34	13.36	**13.34**
T_2	13.96	14.00	14.03	**14.00**	13.95	13.98	14.00	**13.98**	13.92	13.95	13.98	**13.95**
T_3	14.08	14.13	14.17	**14.13**	14.07	14.11	14.14	**14.11**	14.06	14.08	14.11	**14.08**
T_4	15.22	15.29	15.34	**15.28**	15.15	15.21	15.25	**15.20**	15.12	15.14	15.16	**15.14**
T_5	15.24	15.31	15.37	**15.31**	15.17	15.24	15.28	**15.23**	15.14	15.16	15.19	**15.16**
T_6	15.26	15.33	15.39	**15.33**	15.19	15.25	15.30	**15.25**	15.16	15.18	15.21	**15.18**
T_7	16.62	16.68	16.74	**16.68**	16.52	16.57	16.62	**16.57**	16.46	16.49	16.54	**16.50**
T_8	16.65	16.72	16.76	**16.71**	16.55	16.61	16.65	**16.60**	16.47	16.51	16.56	**16.51**
T_9	16.67	16.74	16.79	**16.73**	16.57	16.63	16.67	**16.62**	16.49	16.54	16.58	**16.54**
Mean	**15.23**	**15.29**	**15.33**		**15.17**	**15.22**	**15.25**		**15.13**	**15.15**	**15.19**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	0.40	1.20	7.85		0.35	1.06	6.94		0.35	1.04	6.85	
S	0.21	NS	7.26		0.19	NS	6.37		0.18	NS	6.33	
M X S	0.64	NS			0.56	NS			0.55	NS		
S X M	0.59	NS			0.52	NS			0.51	NS		

Table 12. Residual effect of INM practices in preceding rice and NPK levels on available sulphur (mg kg^{-1}) in soil at different stages of sorghum (*Rabi*, 2021-22)

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
T_1	13.30	13.33	13.39	**13.34**	13.26	13.31	13.33	**13.30**	13.25	13.28	13.31	**13.28**
T_2	13.94	13.98	14.00	**13.97**	13.92	13.95	13.98	**13.95**	13.91	13.93	13.95	**13.93**
T_3	14.07	14.10	14.13	**14.10**	14.04	14.08	14.11	**14.08**	14.04	14.07	14.09	**14.07**
T_4	15.34	15.39	15.43	**15.39**	15.22	15.26	15.30	**15.26**	15.17	15.22	15.25	**15.21**
T_5	15.36	15.42	15.45	**15.41**	15.24	15.29	15.32	**15.28**	15.19	15.23	15.27	**15.23**
T_6	15.38	15.44	15.48	**15.43**	15.26	15.31	15.35	**15.31**	15.20	15.25	15.29	**15.25**
T_7	16.73	16.77	16.83	**16.78**	16.59	16.64	16.69	**16.64**	16.55	16.59	16.62	**16.59**
T_8	16.74	16.81	16.85	**16.80**	16.60	16.66	16.71	**16.66**	16.57	16.61	16.64	**16.61**
T_9	16.76	16.83	16.88	**16.82**	16.62	16.68	16.73	**16.68**	16.59	16.63	16.66	**16.63**
Mean	**15.29**	**15.34**	**15.38**		**15.19**	**15.24**	**15.28**		**15.16**	**15.20**	**15.23**	

	Vegetative			Mean	Flowering			Mean	Harvest			Mean
	S1	**S2**	**S3**		**S1**	**S2**	**S3**		**S1**	**S2**	**S3**	
	SEm±	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**		**SEm±**	**CD (p=0.05)**	**CV (%)**	
M	0.37	1.11	7.25		0.36	1.09	7.18		0.37	1.11	7.30	
S	0.18	NS	6.11		0.19	NS	6.33		0.18	NS	6.08	
M X S	0.54	NS			0.56	NS			0.53	NS		
S X M	0.51	NS			0.52	NS			0.51	NS		

4.2.4 Available Sulphur

Data pertaining to soil available sulphur was presented in Tables 11 and 12. The results revealed that irrespective of the year of study, the available sulphur status at vegetative, flowering and harvest stages of sorghum crop was significantly influenced by different nutrient management practices followed in *kharif* season.

The results revealed that, significantly highest available sulphur was recorded in treatment T_9 which received 100% RDF + 12.5% N through FYM + 12.5% N through GLM (16.73, 16.62, 16.54 mg kg^{-1} and 16.82, 16.68, 16.63 mg kg^{-1}) and it was on par with treatments T_8 which received 100% RDF + 25% N through GLM (16.71, 16.60, 16.51 mg kg^{-1} and 16.80, 16.66, 16.61 mg kg^{-1}) and T_7 *i.e.,*100% RDF + 25% N through FYM (16.68, 16.57, 16.50 mg kg^{-1} and 16.78, 16.64, 16.59 mg kg^{-1}) at vegetative, flowering and harvest stages in 2020-21 and 2021-22, respectively implies the better residual effect of integrated nutrient management treatments when compared to all other treatments. The lowest available sulphur was observed in T_1 *i.e.*, control (13.38, 13.36, 13.34 mg kg^{-1} and 13.34, 13.30, 13.28 mg kg^{-1}) during 2020-21 and 2021-22, respectively at all the three stages of sorghum.

The treatments that received inorganics *i.e.,* T_2- 14.00, 13.98, 13.95 mg kg^{-1} and 13.97, 13.95, 13.93 mg kg^{-1} and T_3- 14.13, 14.11, 14.08 mg kg^{-1} and 14.10, 14.08, 14.07 mg kg^{-1} recorded lower available sulphur compared to combined application of organics and inorganics at vegetative, flowering and harvest stages during 2020-21 and 2021-22, respectively.

Among the levels of fertilizers applied to sorghum, 100% RDF (S_3- 15.33, 15.25, 15.19 mg kg^{-1} in 2020-21 and 15.38, 15.28, 15.23 mg kg^{-1} in 2021-22) recorded significantly highest available sulphur when compared to 75% RDF (S_2- 15.29, 15.22, 15.15 mg kg^{-1} and 15.34, 15.24, 15.20 mg kg^{-1}in 2020) and control (S_1- 15.23, 15.17, 15.13 mg kg^{-1} in 2020-21 and 15.29, 15.19, 15.16 mg kg^{-1} in 2021-22) during both the years of study at all the stages of crop growth, while the interaction between different nutrient management treatments and levels of fertilizers was found to be non-significant.

5. CONCLUSION

Application of 100% RDF + 25% N through GLM in *kharif* improved soil available nutrient status (N, P, K and S). Accordingly, Green leaf manure had shown better direct effect in *kharif* among the different organics applied to rice. Substitution of 100% RDF + 12.5% N through FYM + 12.5% N through GLM has shown better residual effect in *rabi* season. Thus, application of 100% RDF + 25% N through GLM in *kharif* and 100% RDF in *rabi* is optimum for improving soil nutrient status of sorghum crop in rice-sorghum cropping system. In succeeding *rabi* sorghm, the subplot that received 100% RDF was on par with 75% RDF in terms of soil available nutrient status except available sulphur during both the years of experimentation. From this study, it can be concluded that substitution of 25% nitrogen through FYM, GLM and their combination in *kharif* rice reduces 25% of recommended dose of fertilizers to the succeeding *rabi* sorghum crop during both the years of study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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