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Influence of redgram residue incorporation on soil physico-chemical properties in redgram-foxtail millet intercropping system

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ABSTRACT

A field experiment was conducted at RARS, Lam in *Kharif,* 2021 and 2022 to evaluate the effect of organics (Redgram residue and FYM) and bio-fertilizers (VAM and PSB) on phsico-chemical properties of soil under of Redgram and Foxtail millet in Redgram-Foxtail millet intercropping system. The experiment was laid out in Randomized Block Design comprising eight treatments replicated thrice and the treatment combinations include different organics (FYM @ 10 t ha^{-1}, Redgram residue @ 4 t ha^{-1}), Bio-fertilizers and microbial inoculants (Decomposing inoculum, VAM @ 12.5 kg ha^{-1}, PSB @ 1.25 L ha^{-1}) and Inorganic fertilizers (RDF @ 20-50 kg N-P_2O_5 ha^{-1}). Soil pH, EC and CEC were analyzed at mid-season and harvest stages of redgram and foxtail millet crops. Results revealed that among all the physico-chemical properties, CEC of soil was only significantly influenced by the redgram residue incorporation at all the stages of crop growth in both years (*Kharif* 2021 and 2022) in redgram and foxtail millet crops in redgram-foxtail millet intercropping with the highest CEC observed in treatment of soil with Redgram Residue Incorporation (RRI), Farmyard Manure (FYM) , Decomposing Inoculum (DI), Vesicular Arbuscular Mycorrhizae (VAM), and Phosphate Solubilizing Bacteria (PSB). However, pH and EC were not significantly influenced by redgram residue incorporation.

Keywords: *Decomposing Inoculum, Foxtail-millet, Redgram and Residue Incorporation.*

Soil fertility and health are critical components in sustainable agriculture, as they directly influence crop productivity, nutrient cycling, and long-term ecosystem balance. Maintaining optimal soil pH, electrical conductivity (EC), and cation exchange capacity (CEC) is essential for soil's ability to retain and supply nutrients to crops, thereby affecting plant growth and yield. Among various strategies to improve soil fertility, the use of integrated nutrient management practices—including organic amendments, biofertilizers, and crop residue incorporation—has shown promising results in enhancing soil properties and sustaining productivity. Redgram (*Cajanus cajan*) and foxtail millet (*Setaria italica*) are widely cultivated crops known for their resilience and nutritional value. However, soil nutrient depletion remains a challenge in regions where these crops are repeatedly grown. Utilizing redgram residue incorporation (RRI) in combination with other organic and inorganic inputs offers a viable approach to restoring soil health. The addition of decomposing inoculum (DI), farmyard manure (FYM), vesicular-arbuscular mycorrhizae (VAM), and phosphate-solubilizing bacteria (PSB) has the potential to enhance soil's physical and chemical properties, leading to improved nutrient availability, pH stability, and soil structure.

This study explores the effects of redgram residue incorporation treatments on soil pH, EC, and CEC during the mid-season and harvest stages in redgram and foxtail millet crops over two consecutive *Kharif* seasons (2021 and 2022). By assessing the impact of combination of redgram residue incorporation with different organics and inorganics, this research aims to determine the most effective treatment for maintaining soil health, improving fertility, and sustaining crop yield. The findings provide insights into the role of integrated nutrient management in promoting balanced soil chemistry, highlighting its significance for sustainable agricultural practices.

MATERIAL AND METHODS

The field experiment was conducted during *kharif,* 2021 and *kharif,* 2022 at the Regional

Agricultural Research Station (RARS), Lam, Guntur, which is situated in Krishna Zone of Andhra Pradesh (15^0 55' N latitude and 80^0 30' E longitude) at an altitude of 31.5 m above mean sea level. Experimental soil was silty clay loam in texture, moderately alkaline in reaction (8.35), non- saline (0.20 dS m^{-1}), medium in organic carbon, low in available nitrogen, high in available phosphorus, high potassium and deficient in available sulphur and Zinc; while sufficient in available iron, manganese and copper. The (gross) plot size used was 3.6 m × 7.5 m = 27.0 m^2. Redgram (LRG52) and Foxtail millet (SIA3156) were sown in 1:5 ratio. The experiment was laid out in a randomized block design with eight treatments replicated thrice and the treatmental combinations were T_1: Inorganic farming; T_2: RDF + FYM @ 10 t ha^{-1}; T_3: FYM @ 10 t ha^{-1}; T_4: Redgram Residue Incorporation by Shredding @ 4 t ha^{-1} + Decomposing inoculum + FYM @ 10 t ha^{-1} + VAM @ 12.5 kg ha^{-1} + PSB @ 1.25 L ha^{-1} (soil application); T_5: Redgram Residue Incorporation + RDF; T_6: Redgram Residue Incorporation + FYM @ 10 t ha^{-1}; T_7: Redgram Residue Incorporation + Decomposing inoculum + FYM @ 10 t ha^{-1}; T_8: Redgram Residue Incorporation + Decomposing inoculum + FYM @ 10 t ha^{-1} + VAM @ 12.5 kg ha^{-1}.

Note: a) For organic farming (T_3, T_4, T_6, T_7, T_8) seed inoculation with *Rhizobium;* Pest management in organic farming will be through seed treatment with *Pseudomonas* @ 5g kg^{-1}, basal application of *Trichoderma viridae* @ 2.5 kg ha^{-1} and need based application neem oil @ 5ml L^{-1} and NSKE @ 50 ml L^{-1}.

b) For (T_1, T_2 & T_5) inorganic farming (IF) with (20-50-0 kg N-P_2O_5-K_2O ha^{-1}) through chemical fertilizers and pest management was through chemical means. Rhizospheric soil samples collected at mid-season and harvest stages of Redgram and Foxtail millet crops in *Kharif* 2021 and 2022 were analyzed for soil pH, EC, CEC by the methods as outlined below:

Soil Reaction

Soil water suspension prepared in the ratio of 1: 2.5 (20 g of soil and 50 mL distilled water) was used. Soil pH was measured with the help of glass electrode of digital pH meter as described by Jackson (1973).

Electrical Conductivity

Electrical conductivity was measured in 1: 2.5 soil extract with the help of digital conductivity bridge at room temperature as described by Jackson (1973) and expressed as dS m^{-1}.

Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC) of the soils was determined by equilibrating the soil with 1 N sodium acetate solution (pH 8.2) and the excess salts were removed by stabilizing with 99 per cent alcohol (Bower *et al.,* 1952). The adsorbed sodium was replaced by equilibrating with neutral normal ammonium acetate solution and the concentration of sodium in the leachate which is a measure of CEC was measured using ELICO Flame Photometer expressed in c mol (p^+) kg^{-1} soil.

Statistical analysis

The data were analysed statistically using Fisher's method of analysis of variance as suggested by Panse and Sukhatme (1978) for the randomized block design adopted in this study. Statistical significance was tested by applying F-test at 0.05 level of probability. Critical differences at 0.05 levels were worked out for the effects, which were significant.

RESULTS AND DISCUSSION

Soil pH

Data pertaining to pH of soil at mid-season and harvest stages of redgram and foxtail millet crops as influenced by individual or integrated use of inorganics, organics and biofertilizers with redgram residue incorporation were represented in table 1.

Redgram

In 2021, mid-season soil pH levels across treatments showed minor variations. The highest pH level of 8.30 was observed in the RDF-only treatment. The treatments involving RDF with FYM (8.18) and RRI with FYM, DI, VAM, and PSB (8.13) followed closely, with no significant differences among them. At harvest, the pH levels decreased slightly in most treatments, with the RDF-only treatment showing a drop to 8.04 and the lowest pH recorded in the FYM-only treatment at 7.90.

In 2022, the mid-season pH levels showed a similar trend, with the RDF-only treatment at 8.31 and the treatments involving RDF with FYM and RRI, FYM, DI, VAM, and PSB maintaining relatively lower pH levels at 8.32 and 8.20, respectively. By harvest in 2022, pH levels remained largely stable, with minor decreases observed in most treatments. The RDF-only treatment recorded a pH of 8.12, while the lowest

Table 1. Soil pH at mid-season and harvest stages of Redgram and Foxtail millet crops in *Kharif* 2021 and 2022 as influenced by Redgram residue management techniques in Redgram-Foxtail millet intercropping system.

Treatments	Redgram				Foxtail millet			
	Kharif 2021		*Kharif* 2022		*Kharif* 2021		*Kharif* 2022	
	Mid-season	Harvest	Mid-season	Harvest	Mid-season	Harvest	Mid-season	Harvest
T1: RDF	8.3	8.04	8.31	8.12	7.97	8.25	8.12	7.9
T2: RDF + FYM	8.18	8	8.32	8.04	7.93	8.22	8.15	8.05
T3: FYM	8.16	7.9	8.37	8.12	7.95	8.22	8.11	8.29
T4: RRI + FYM + DI + VAM +	8.13	7.96	8.2	8.1	7.88	8.19	7.96	8.13
T5: RRI + RDF	8.18	8.08	8.31	8.09	7.99	8.19	8.16	8.03
T6: RRI + FYM	7.95	7.94	8.29	8.11	7.91	8.25	8.13	7.98
T7: RRI + FYM + DI	8.1	7.93	8.13	8.08	7.96	8.2	8.17	8.11
T8: RRI + FYM + DI + VAM	8.24	7.94	8.17	8.13	7.93	8.24	8.02	8.15
SEm (±)	0.08	0.05	0.08	0.05	0.03	0.03	0.08	0.11
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	1.8	1.11	1.58	0.98	0.6	0.54	1.68	2.4

pH was again observed in the RDF + FYM treatment (8.04).

Foxtail Millet

In 2021, mid-season soil pH levels in foxtail millet were relatively consistent, with the RDF-only treatment showing a pH of 7.97, while the treatment involving RRI with FYM, DI, VAM, and PSB recorded a slightly lower pH of 7.88. At harvest, pH levels slightly increased in most treatments, with the RDF-only treatment rising to 8.25 and the RRI, FYM, DI, VAM, and PSB treatment at 8.19.

In 2022, mid-season pH levels again showed minimal variation between treatments, with the RDF-only treatment at 8.12 and the treatment involving RRI with FYM, DI, VAM, and PSB recording 7.96. By harvest, the RDF-only treatment showed a pH of 7.90, and the RRI, FYM, DI, VAM, and PSB treatment remained at 8.13.

However, there was no significant difference in soil pH among the treatments in both the intercrops *viz.,* redgram and foxtail millet during both *kharif* 2021 and 2022.

Overall, the treatments incorporating redgram residue incorporation with organic and inorganic inputs, such as FYM, DI, VAM, and PSB, effectively maintained soil pH levels in both redgram and foxtail millet crops. While RDF alone led to slight pH decreases, the integrated use of organics and biofertilizers ensured better pH stability, particularly in foxtail millet, which showed more pronounced pH fluctuations across seasons. These findings highlight the importance of using organic amendments and biofertilizers to maintain balanced soil pH, which is crucial for nutrient availability and long-term soil health.

Results obtained corroborate with the findings of Sandhya *et al.* (2013), Parewa *et al.* (2014), Nagar *et al.* (2016), Sharma *et al.* (2017), Tiwari *et al.* (2017), Kalaiyarasi *et al.* (2019), Kannan *et al.* (2021), Wahane *et al.* (2022).

Electrical Conductivity

Data regarding electrical conductivity of soil at mid-season and harvest stages of redgram and foxtail millet crops as influenced by individual or integrated use of inorganics, organics and biofertilizers with redgram residue incorporation were represented in table 4.2.

Redgram

In 2021, mid-season electrical conductivity (EC) levels showed little variation across treatments. The significantly highest EC value, 0.17 dS m^{-1}, was observed in both the RDF + FYM and FYM-only treatments, while the RDF-only treatment had the lowest EC at 0.14 dS m^{-1}, which was on par with several other treatments. At harvest, the EC levels remained consistent across all treatments, with no significant changes observed. The EC levels remained around 0.14 – 0.15 dS m{ ^{1} for all treatments.

In 2022, the mid-season EC levels again showed minimal differences between treatments, with most treatments recording values around 0.14 – 0.16 dS m^{-1}. The significantly highest mid-season EC was observed in the RRI + RDF treatment (0.16 dS m^{-1}). By harvest, EC levels were mostly stable, with no significant differences among treatments, as most treatments remained between 0.14–0.16 dS m^{-1}.

Foxtail Millet

In 2021, mid-season EC levels in foxtail millet ranged from 0.13 dS m^{-1} in the RDF-only and RRI + RDF treatments to 0.16 dS m{ ^{1} in treatments involving RRI + FYM + DI. At harvest, the EC levels increased across treatments, with the RDF-only treatment recording the significantly highest EC at 0.20 dS m^{-1}, while the lowest harvest EC level was observed in the FYM-only treatment at 0.16 dS m^{-1}.

In 2022, mid-season EC levels were significantly highest in the RDF-only treatment at 0.24 dS m^{-1}, while other treatments, such as RRI + FYM, DI, VAM, and PSB, had EC levels ranging from 0.15–0.19 dS m^{-1}. At harvest, the RDF-only treatment again recorded the significantly highest EC at 0.28 dS m^{-1}, while other treatments showed lower EC values, ranging from 0.19 to 0.26 dS m^{-1}.

Overall, the EC levels across both crops and years showed only minor fluctuations. The RDF-only treatments tended to have slightly higher EC values at harvest, particularly in foxtail millet. Organic inputs, such as FYM and combinations with biofertilizers, helped maintain more stable EC levels. There were no significant differences in EC values between treatments in most cases, except for foxtail millet in 2022, where significant differences were observed at mid-season.

Results obtained were similar to the findings of Sandhya *et al.* (2013), Sharma *et al.* (2017), Nagar *et al.* (2016), Tiwari *et al.* (2017), Wahane *et al.* (2022), Kannan *et al.* (2021), Kalaiyarasi *et al.* (2019).

Cation Exchange Capacity

CEC (Cation Exchange Capacity, binding capacity of the clay-humus complex) is a measure of the soil's ability to hold nutrients and water and deliver them during the crop growing season. Results pertaining to cation exchange capacity of soil at harvest stage of redgram and foxtail millet crops as influenced by individual or integrated use of inorganics, organics and biofertilizers with redgram residue incorporation were represented in table 3 and figure 1.

Redgram

Thorough examination of the data presented in table 3, it was found that soil CEC under redgram at harvest was significantly influenced by the treatments; RDF alone showing significantly lower

Table 2. EC of soil (dS m^{-1}) at mid-season and harvest stages of Redgram and Foxtail millet crops in *Kharif* 2021 and 2022 as influenced by Redgram residue management techniques in Redgram-Foxtail millet intercropping system

Treatments	Redgram				Foxtail millet			
	Kharif 2021		*Kharif* 2022		*Kharif* 2021		*Kharif* 2022	
	Mid-season	Harvest	Mid-season	Harvest	Mid-season	Harvest	Mid-season	Harvest
T1: RDF	0.14	0.14	0.15	0.14	0.13	0.2	0.24	0.28
T2: RDF + FYM	0.17	0.14	0.15	0.15	0.14	0.17	0.16	0.23
T3: FYM	0.17	0.14	0.14	0.15	0.13	0.16	0.16	0.22
T4: RRI + FYM + DI + VAM + PSB	0.16	0.14	0.14	0.16	0.15	0.16	0.18	0.22
T5: RRI + RDF	0.14	0.14	0.16	0.16	0.13	0.17	0.18	0.24
T6: RRI + FYM	0.16	0.15	0.14	0.15	0.15	0.15	0.15	0.23
T7: RRI + FYM + DI	0.15	0.15	0.15	0.14	0.16	0.17	0.19	0.26
T8: RRI + FYM + DI + VAM	0.15	0.14	0.15	0.14	0.15	0.16	0.16	0.19
SEm (±)	0.01	0	0.01	0.01	0.01	0.01	0	0.02
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	0.01	NS
CV (%)	8.37	5.4	6.21	7.47	7.83	9.96	4.83	14.27

Table 3. CEC of soil (c mol (p$^+$) kg^{-1}) at harvest stage of Redgram and Foxtail millet crops in *Kharif* 2021 and 2022 as influenced by Redgram residue management techniques in Redgram-Foxtail millet intercropping system

Treatments	Redgram		Foxtail millet	
	Kharif 2021	*Kharif* 2022	*Kharif* 2021	*Kharif* 2022
T1: RDF	33.5	32.03	35.6	32.02
T2: RDF + FYM	37.5	36.1	39.2	38.35
T3: FYM	36.37	35.2	40.13	35.55
T4: RRI + FYM + DI + VAM + PSB	42.37	40	44.13	40.88
T5: RRI + RDF	35.73	34.27	37.83	34.25
T6: RRI + FYM	38.53	36.8	41.37	38.45
T7: RRI + FYM + DI	39.17	37.7	41.6	39.02
T8: RRI + FYM + DI + VAM	41.67	39.43	44.1	41.18
SEm (±)	1.78	1.3	1.51	1.61
CD (p = 0.05)	5.4	3.95	4.57	4.87
CV (%)	8.09	6.2	6.44	7.43

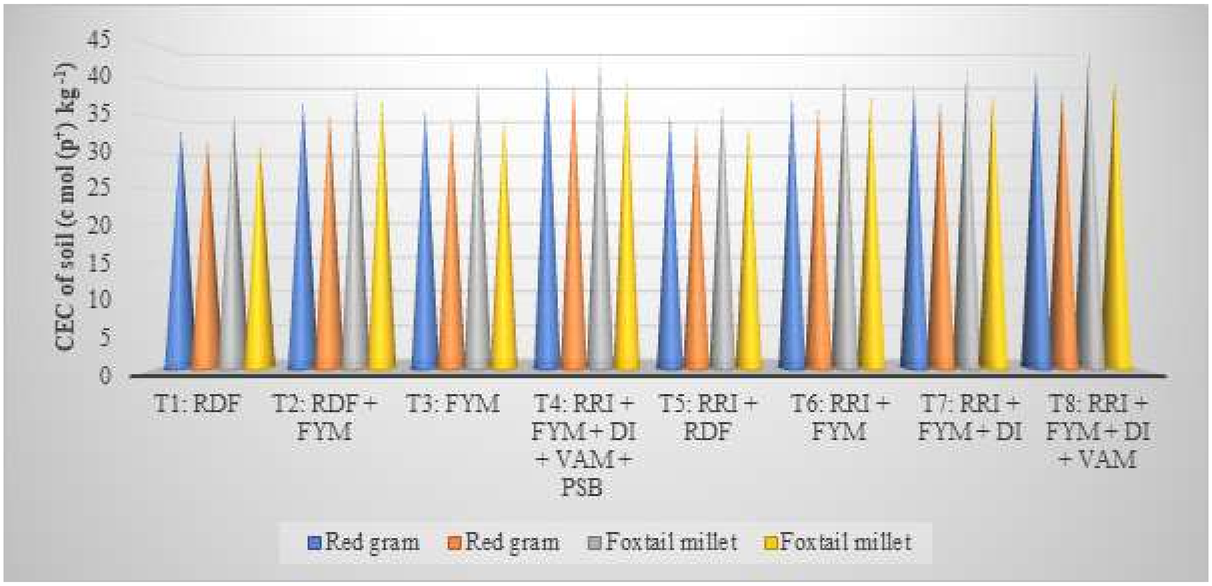

Fig. 1. CEC of soil (c mol (p$^+$) kg^{-1}) at harvest stage of Redgram and Foxtail millet crops in *Kharif* 2021 and 2022 as influenced by Redgram residue management techniques in Redgram - Foxtail millet intercropping system

CEC of 33.50 and 32.03 c mol (*pz*) kg^{-1} respectively during *kharif* 2021 and 2022. Significantly higher CEC of 42.37 and 40.00 c mol (*pz*) kg^{-1} was attained when T_4 (RRI + FYM + DI + VAM + PSB) was applied. However, it was on par with T_6 (RRI + FYM), T_7 (RRI + FYM + DI, T_8 (RRI + FYM + DI+VAM) and T_2 (RDF+FYM).

Foxtail Millet

In foxtail millet, the CEC of soil at the harvest also showed significant differences among the treatments. Significantly higher CEC of 44.13 c mol (*pz*) kg^{-1}) was observed in the treatment receiving RRI + FYM + DI + VAM + PSB during *kharif* 2021; while during *kharif* 2022, RRI + FYM + DI + VAM (T8) was significantly superior with a CEC of 41.18 c mol (*pz*) kg^{-1}. Among all the treatments, RDF (T_1) showed significantly lower CEC of 35.60 and 32.02 c mol (*pz*) kg^{-1} respectively during *kharif* 2021 and 2022.

Higher CEC in the treatments embracing organics could be due to the formation of clay-humus complexes. Significantly higher CEC in redgram residue management treatment could be due to the clay-humus compounds formed during the process of humification having high CEC. Organic matter has a very high CEC ranging from 250 to 400 c mol (p^+) kg^{-1} soil (Moore, 1998). Humus, the end product of decomposed organic matter, has the highest CEC because organic colloids have large quantities of negative charges. Humus has a CEC two to five times greater than montmorillonite clay and up to 30 times greater than kaolinite clay, so is very important in improving soil fertility (Brady and Weil, 2008).

These observations are consistent with the findings of Parewa *et al.* (2014), Rehman *et al.* (2019), Wahane *et al.* (2022), Rathore *et al.* (2011).

CONCLUSION

This study demonstrates that the integrated use of redgram residue incorporation (RRI) with farmyard manure (FYM), decomposing inoculum (DI), vesicular-arbuscular mycorrhizae (VAM), and phosphate-solubilizing bacteria (PSB) alongside recommended doses of fertilizers (RDF) is superior to using RDF alone in promoting soil health and sustaining crop productivity. The combined treatment effectively stabilized soil pH, especially beneficial in foxtail millet, and minimized fluctuations in electrical conductivity, helping to mitigate potential risks associated with soil salinization. Enhanced cation exchange capacity (CEC) observed in integrated treatments reflects improved nutrient retention and soil structure, which are crucial for supporting healthy plant growth.

Additionally, treatments involving biofertilizers and organic amendments led to higher crop yields in both redgram and foxtail millet, underscoring the value of integrated nutrient management for productive, resilient cropping systems. This approach ensures more balanced soil chemical properties, thereby optimizing nutrient cycling and reducing the risk of nutrient depletion over time. The study supports the adoption of integrated nutrient strategies as a practical and sustainable approach to maintaining soil fertility and promoting agricultural sustainability.

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