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Microbial Ecology, Soil Health and Crop Yield in Bengal Gram: Crop Ecosystem as Influenced by Residue Incorporation in Conjunction with FYM and Bio-fertilizers

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ABSTRACT

Crop residue incorporation studies in vertisols of Regional Agricultural Research Station, Lam, Guntur, AP during *kharif* 2017-18, 2018-19 and during *rabi* 2019-20 were carried in sequence in order to investigate the effect of recycling (incorporation) of foxtail millet residue on soil organic carbon, soil N, P, K, enzymatic activity viz., dehydrogenase, acid phosphatase and urease, soil microbial population viz., fungi, bacteria, actinomycetes, pseudomonads, PSB, *Azospirillum, Azotobacter* and *Rhizobium* and yield of Bengal gram under foxtail millet-Bengal gram sequence in vertisols. The experiments were laid out in randomized complete block design and replicated thrice. Analysis of three years of the experimental data revealed that application of 75% RDF+crop residue incorporation of foxtail millet followed by the application of bio-fertilizer consortia significantly influenced the soil organic carbon, soil N, P, enzymatic activity, soil microbial population and yield of succeeding chickpea which was on a par with 75% RDF+crop residue incorporation of foxtail millet along with the application of bio-fertilizer consortia and the spraying of 2% urea at pod filling stage to the succeeding chickpea and also recorded 32 and 31% yield increment over RDF, respectively. This study clearly indicated the role of incorporation of crop residue and bio-fertilizers on soil nutrients, soil health, crop growth and yield parameters under foxtail millet-Bengal gram sequence.

Key words: Crop residue, bio-fertilizers, RDF, enzymatic activity, foxtail millet, Bengal gram

INTRODUCTION

The plant nutrient availability in a soil is a measure of soil fertility, while the soil physical environment is the key factor in regulating the retention and movement of soil moisture, air, nutrients and temperature. Crop residue recycling is a key measure to enhance soil physical properties and in turn enhance the soil fertility and microbial population. The insufficient amount of crop residue on the soil surface can be detrimental for soil quality, resulting in loss of soil organic matter (SOM) and increase in soil erosion, whereas leaving excessive amounts can impair soil, seed contact, immobilize N and soil moisture.

There are reports of burning the crop residues. It is estimated that burning of paddy straw results in nutrient losses viz., 3.85 million MTs of organic carbon, 59000 MTs of nitrogen, 20000 MTs of phosphorus and 34000 MTs of potassium which also adversely affects the nutrient budget in the soil. An estimated 87 MTs of surplus crop residues is burnt in different croplands (TERI, 2019). The air pollution emission intensity of different crop residues also varies. The PM 2.5 emissions (g/kg) from the burning of different types of crop residues follows the order: sugarcane (12.0) > maize (11.2) > cotton (9.8) > rice (9.3) > wheat (8.5) (TERI, 2019). Crop residue burning also emits SO_2, NO_2, NH_3 and volatile organic compounds (VOCs) which are precursors for the formation of particulates in the atmosphere. In addition, it was estimated that more than 8.5 MTs of carbon monoxide is emitted to the atmosphere during the burning of crop residues. Crop residue is not a waste but rather a useful natural resource. About 25% of nitrogen (N) and phosphorus (P), 50% of sulphur (S) and 75% of potassium (K) uptake by cereal crops are retained in crop residues,

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making them valuable nutrient sources if they are incorporated back into the soil.

The incorporation of straw in soil has a favourable effect on the soil's physical, chemical and biological properties such as pH, organic carbon, water holding capacity and bulk density of the soil. On a long-term basis, crop residue incorporation increases the availability of zinc, copper, iron and manganese content in the soil and it also prevents the leaching of nitrates. Increased organic carbon increases the bacteria and fungi in soil. Higher organic matter improves soil microbial colonization (Piccoli *et al.,* 2020). Better nutrient availability depends on microbial biomass and its activities in soil. Interestingly, the microbial population is positively correlated with the phyto-biomass present in soil. Microbial activities strongly reflect the soil nutrient storage capacity and recycling, or, more particularly C, N, P, S, and soil organic matter which in turn stabilize the soil aggregation. Keeping these in view, this investigation was conducted in vertisols of Andhra Pradesh, with an objective of finding the impact of incorporation of preceding foxtail millet residue on succeeding chickpea.

MATERIALS AND METHODS

A field study was carried out at Regional Agricultural Research Station, Lam Farm located at Guntur (latitude: 16°18′, longitude : 80°29′ and altitude: 33 MSL). The climate was sub-tropical with mean annual rainfall of 950 mm. The soil of experimental field was clay loam in texture, alkaline in reaction (pH 8.3), non-saline and low in available N (226 kg/ha), high in P_2O_5 (82.1 kg/ha) and high in K_2O (1220 kg/ha) and low in organic carbon (0.49%), respectively. The experiment was conducted for three successive *kharif* (Foxtail millet) and *rabi* (chickpea) seasons i.e. 2017-18, 2018-19 and 2019-20 in Krishna agro-climatic zone of Andhra Pradesh.

The experiment had seven treatments viz., T_1: RDF for both foxtail millet and Bengal gram, T_2: RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing, T_3: RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing fb the application of FYM @ 5 t/ha, T_4: 75% RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing fb application of bio-fertilizer consortia, T_5: 50% RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing fb application of bio fertilizer consortia, T_6: 75% RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing+2% urea spray at pod filling stage and T_7: 50% RDF to succeeding Bengal gram+foxtail millet crop residue incorporation before Bengal gram sowing+2% urea spray at pod filling stage and replicated thrice with a randomized block design (RBD). Recommended dose of 40 kg N, 20 kg P_2O_5/ha were applied in two split doses to foxtail millet during *kharif* as basal and at tillering stage. Further the RDF @ 20 N, 50 P_2O_5 and 40 S/ha were applied to the succeeding Bengal gram immediately after incorporation of foxtail millet crop residue incorporation to the experimental plots. Before incorporation of preceding foxtail millet crop residue, bio-fertilizer consortia (5 kg/ha of PSB, KRB and VAM @ 12.5 kg/ha) with 200 kg of well decomposed FYM was applied in the field and thoroughly mixed with rotavator. The Bengal gram sowing was taken up as per the package of the practices of the zonal research and extension counsel of ANGRAU. Soil sampling for analyzing the soil nutrient status, microbial analysis and enzyme analysis was done during harvesting. After soil sampling soil nutrient, organic carbon, soil enzymes and microbial analysis were done by following standard procedures. Data pertaining to yield and yield attributes were collected and statistically analyzed as per the design of the experiment.

RESULTS AND DISCUSSION

Soil productivity depends on soil structure, nutrients status and various soil chemical, biochemical and biological activities. The productive soils enhance crop growth and yield which need to be sustained for many years. The sustainable soil productivity mainly depends on organic carbon content of the soil and it can be maintained by incorporation of organic matter into the soil. Crop residue management is a well-known and widely accepted practice for controlling various soil physical, chemical and biological functions. Crop residues incorporate a large number of nutrients in the soil for crop production and affect soil water movement, runoff and infiltration. In a conservation agriculture (CA) system, successful management of crop residues is an integral part, and the maximum benefit of CA can only be achieved with *in situ* management (Jat *et al.*, 2019). The annual cycling of plant nutrients is important in the plant–soil ecosystem in order to maintain a productive agricultural system and to facilitate better nutrient mobilization within the system (Liu *et al.*, 2020). Apart from this, carbon-enriched crop residues serve as the main food source for soil microorganisms and initiate the biological nutrient cycling framework. Throughout microbial decomposition of crop residues, different chemicals are released in soil and can be properly utilized by plants and other living organisms (Meena and Lal, 2018). Plant nutrients (NPK) availability from crop residues mostly depends on different soil physical, chemical and biological processes. The soil nutrient status, organic carbon content, enzyme activity, microbial population, crop growth and yield parameters in response to incorporation of foxtail millet crop residue to vertisol soil during Bengal gram production are presented and discussed hereunder.

The pooled analysis of soil samples collected at 75 DAS and at harvest for available soil nitrogen, phosphorus and potassium showed that the availability of soil phosphorus and potassium was found to be significant between different treatments but nitrogen was found non-significant (Table 1). Highest available nitrogen content (342 kg/ha) of the soil was recorded in the treatment incorporated with RDF+crop residue+FYM @ 5 t/ha followed by 75% RDF+crop residue+bio-fertilizer consortia (326 kg/ha) and least in case of RDF for both foxtail millet and Bengal gram (200 kg/ha). The available P_2O_5 and K_2O also followed the similar trend as that of available nitrogen where more available P_2O_5 and K_2O were found in the soils of the plot with RDF+crop residue+FYM @ 5 t/ha (79.2 and 1013 kg/ha, respectively) and least in case of treatments with only application of RDF (51.7 and 896 kg/ha, respectively). The available soil nitrogen, phosphorus and potassium contents were recorded more in the treatments incorporated with crop residue and it further increased with incorporation of FYM and bio-fertilizers. This might be due to increase in mineralization process by soil microorganisms and nitrogen

Table 1. Influence of application of biofertilizers and foxtail millet crop residue on soil chemical and biochemical properties, yield and economics of millet-Bengal gram sequence

Treatment	OC (%)	Available nitrogen (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Dehydrogenase activity (µg of TPF/g/day)	Phosphatase (Acid) µg PNP/g/h	Urease activity (µ NH_4 N/g/h	Plant height (cm)	100-seed weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)	BCR
T_1 : RDF for both foxtail millet and Bengal gram	0.17	200	51.7	896.0	36.00	28.00	17.00	50.25	24.84	2470.60	4299.00	36.63	1.40
T_2 : RDF+Crop residue (foxtail millet) for Bengal gram	0.28	276.00	65.90	1010.50	54.00	39.00	23.00	49.12	24.98	2567.30	4778.66	34.89	1.50
T_3 : RDF+Crop residue (foxtail millet)+FYM @ 5 t/ha	0.29	342.00	79.20	1013.00	62.00	40.00	30.00	51.95	25.53	2813.30	5199.33	34.96	1.60
T_4 : 75% RDF+crop residue+bio-fertilizer consortia	0.20	326.50	64.40	895.50	81.00	55.00	34.00	51.10	24.82	2603.70	4418.66	37.50	1.40
T_5 : 50% RDF+crop residue+bio-fertilizer consortia	0.28	219.50	47.18	947.50	63.00	42.00	28.00	48.23	24.03	2171.60	3608.00	36.92	1.30
T_6 : 75% RDF+crop residue+bio fertilizer consortia+ 2% urea spray at pod filling stage	0.20	265.50	62.98	900.00	52.00	41.00	23.00	51.16	25.06	2758.60	4525.00	38.42	1.50
T_7 : 50% RDF+crop residue+bio fertilizer consortia+ 2% urea spray at pod filling stage	0.31	237.50	48.84	954.00	78.00	48.00	31.00	49.60	25.22	2635.60	4672.00	36.51	1.50
S. Em±	0.02	30.40	5.39	69.07	1.47	1.59	1.56	1.80	0.546	128.77	204.91	1.55	-
C. D. (P=0.05)	0.09	94.51	16.81	NS	4.47	4.84	4.74	NS	NS	385.26	635.45	NS	-
C.V. (%)	15.14	15.31	15.01	13.26	8.50	11.20	9.50	6.40	3.77	8.38	8.42	8.31	-

fixation by incorporation of bio-fertilizers. After incorporation of crop residues, soil microorganisms colonize the residues, and decompose to convert them to simple organic matter and subsequent mineralization to convert them to inorganic available nutrients. The nutrient distribution was significantly increased by repeated residue decomposition, and previous researchers established that the greater organic and inorganic phosphorus accumulation in the soil surface with the practice of conservation tillage compared to conventional tillage.

Dehydrogenase activity was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (81 µg of TPF/g/day) followed by the treatment with 50% RDF+crop residue+bio- fertilizer consortia+2% urea spray at pod filling (75th day of crop growth) stage (78 µg of TPF/g/day) and least in the treatment with RDF for both foxtail millet and Bengal gram (36 µg of TPF/g/day). Acid phosphatase activity was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (55 µgm PNP/g/h) followed by the treatment with 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (48 µg PNP/g/h) and least in the treatment with RDF for both foxtail millet and Bengal gram (28 µgm PNP/g/h). Urease activity was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (34 µg NH_4N/g/h) followed by the treatment with 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (31 µg NH_4N/g/h) and least in the treatment with RDF for both foxtail millet and Bengal gram (17 µg NH_4N/g/h).

Soil organic C not only represented a source of enzyme production but also a substrate for enzyme degradation, and thus impacted the enzyme activities in soil (Hok *et al.*, 2018). After five years of crop residue incorporation in soil, Li *et al.* (2019) reported increased phosphatase, urease and invertase activity in soil, which was directly related to SOM content. The soil enzymatic activity was considered as sensitive indicator to reflect management and cropping system induced change in soil C dynamics. Change in enzyme activities influenced by RS incorporation should be ascribed to C input and nutrient availability in soil (Saikia *et al.*, 2019).

The soil microbial population viz., bacteria,

Table 2. Influence of application of bio-fertilizers and foxtail millet crop residue on microbial population of soil under millet-Bengal gram sequence

Treatment	Bacteria (10^5 CFU/g)	Fungi (10^3 CFU/g)	Actinomycetes (10^5 CFU/g)	Fluorescent pseudomonads (10^3 CFU/g)	PSB (10^5 CFU/g)	*Azospirillum* (10^4 CFU/g)	*Azotobacter* (10^4 CFU/g)	*Rhizobium* (10^4 CFU/g)
T_1 : RDF for both foxtail millet and Bengal gram	23.00	2.33	15.33	7.00	15.00	15.00	19.00	32.00
T_2 : RDF+Crop residue (foxtail millet) for Bengal gram	24.33	2.66	17.66	8.00	18.00	17.00	22.00	40.00
T_3 : RDF+Crop residue (foxtail millet)+FYM @ 5 t/ha	27.66	3.00	19.33	10.00	18.00	20.00	21.00	47.00
T_4 : 75% RDF+crop residue+bio-fertilizer consortia	28.66	3.33	20.33	18.00	38.00	25.00	29.00	51.00
T_5 : 50% RDF+crop residue+bio-fertilizer consortia	25.33	2.86	18.00	16.00	19.00	19.00	21.00	48.00
T_6 : 75% RDF+crop residue+bio-fertilizer consortia+ 2% urea spray at pod filling stage	27.00	2.90	18.33	23.00	25.00	22.00	26.00	45.00
T_7 : 50% RDF+crop residue+bio fertilizer consortia+ 2% urea spray at pod filling stage	25.00	3.00	15.66	15.00	20.00	19.00	25.00	43.00
S. Em±	2.32	0.27	1.21	2.09	1.29	1.19	1.96	2.09
C. D. (P=0.05)	7.04	0.81	3.69	6.36	3.91	3.62	5.95	6.36
C. V. (%)	7.50	11.00	9.50	12.50	8.30	9.00	10.60	8.50

fungi, actinomycetes and functional groups was determined during 75th day of crop growth and presented in Table 2. Bacterial population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (28.66 x 10^6 CFU/g) and least in the treatment with RDF for both foxtail millet and Bengal gram (23.00 x 10^6 CFU/g). Fungal population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (3.33 x 10^3 CFU/g) and least in the treatment with RDF for both foxtail millet and Bengal gram (2.33 x 10^3 CFU/g). Actinomycetes population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (20.33 x 10^4 CFU/g) followed by the treatment with 50% RDF+crop residue+FYM @ 5 t/ha (19.33 x 10^3 CFU/g) and least in the treatment with RDF for both foxtail millet and Bengal gram (15.33 x 10^3 CFU/g). The population of Fluorescent pseudomonads was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (23 x 10^3 CFU/g) followed by the treatment with 75% RDF+crop residue+bio-fertilizer consortia (18 x 10^3 CFU/g) and least in the treatments with RDF for both foxtail millet and Bengal gram (7 x 10^3 CFU/g).

The PSB population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (38 x 10^5 CFU/g) followed by the treatment with 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (25 x 10^5 CFU/g) and least in the case of treatments with RDF for both foxtail millet and Bengal gram (15 x 10^5 CFU/g). The *Azospirillum* population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (25 x 10^4 CFU/g) followed by the treatment with 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (22 x 10^4 CFU/g) and least in the case of treatments with RDF for both foxtail millet and Bengal gram (15 x 10^4 CFU/g).

The *Azotobacter* population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (29 x 10^4 CFU/g) followed by the treatment with 75% RDF+crop residue+bio fertilizer consortia+2% urea spray at pod filling stage (26 x 10^4 CFU/g) and least in the case of treatments with RDF for both foxtail millet and Bengal gram (19 x 10^4 CFU/g). The *Rhizobium* population was more in the treatment with 75% RDF+crop residue+bio-fertilizer consortia (51 x 10^4 CFU/g) followed by the treatment with 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (48 x 10^4 CFU/g) and least in the case of treatments with RDF for both foxtail millet and Bengal gram (32 x 10^4 CFU/g).

The above results showed that total microflora and functional group microorganisms population were more in the plots incorporated with crop residues and farm yard manure. Majority of the soil microorganisms were heterotrophic in nature, their growth and development required organic matter in the soil. The findings of this study with regard to microbial population are in agreement with the earlier studies. It had been reported that proper retention of crop residues had a significant impact on the regulation of the soil microbial biomass. Better nutrient availability depends on microbial biomass and its activities in soil. Microbial activities strongly reflected the soil nutrient storage capacity and recycling, or, more particularly C, N, P, S and soil organic matter. The enhanced microbial activity in the top layer of soil by the application of crop residue mulching was reported by Samui *et al.* (2020) and also it might be due to the alteration of plant-soil micro-climate, increased water and nutrient availability and regulation of soil temperature (Mondal *et al.*, 2020).

Incorporation of residues of leguminous crops like clusterbean before sowing the next crop was reported to increase the soil microbial biomass and dehydrogenase activity (DHA) as compared to the control (with the application of crop residue) treatment (Samui et al., 2020). Residue retention under CA had also been reported as beneficial for the reduction of soil nematode population in a wheat-soybean cropping system (Smitha *et al.,* 2019). Higher organic matter improved soil microbial colonization (Piccoli *et al.,* 2020). Microbial activities strongly reflected the soil nutrient storage capacity and recycling, or, more particularly C, N, P, S, and soil organic matter. Crop residue incorporation had been the essential component with key multi-functional roles in soil biological properties of soil (Bhaduri *et al.,* 2017). Crop residues and rhizo-deposition, root and shoot C were nutrient and energy sources for microbial activity and thus straw incorporation improved soil physical environment for microbial growth.

The plant height at flag leaf stage was highest (51.95 cm) in the plots applied with RDF+crop residue (foxtail millet)+FYM @ 5 t/ha followed by 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (51.16 cm), 75% RDF+crop residue+bio-fertilizer consortia (51.10 cm) and least (49.12 cm) in the plots applied with RDF+crop residue (foxtail millet) for Bengal gram (Table 1).

Test weight was more in the plots inoculated with RDF+crop residue (foxtail millet)+FYM @ 5 t/ha (25.53 g) followed by 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (25.22 g), 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (25.06 g), and least in 50% RDF+crop residue+bio-fertilizer consortia (24.03 g). Seed yield/ha was more in the plots with RDF+crop residue (foxtail millet)+FYM @ 5 t/ha (2813.3 kg/ha) followed by 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (2758.6 kg/ha), 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (2635.6 kg/ha) and least in case of 50% RDF+crop residue+bio-fertilizer consortia (2171.6 kg/ha).

Straw yield/ha was more in the plots with RDF+crop residue (foxtail millet)+FYM @ 5 t/ha (5199.33 kg/ha) followed by RDF+crop residue (foxtail millet; 4778.66 kg/ha), 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (4672.00 kg/ha) and least in case of 50% RDF+crop residue+bio-fertilizer consortia (3608.00 kg/ha). Harvest index was more in the plots with 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage (38.42) followed by 75% RDF+crop residue+bio-fertilizer consortia (37.50) and least in case of RDF+crop residue (foxtail millet) for Bengal gram (34.89). BCR was more in the plots with RDF+crop residue (foxtail millet)+FYM @ 5 t/ha (1.6) followed by BCR of 1.5 in the plots with RDF+crop residue (foxtail millet) for Bengal gram, 50% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage, 75% RDF+crop residue+bio-fertilizer consortia+2% urea spray at pod filling stage and least in the plots with 50% RDF+crop residue+bio-fertilizer consortia (1.3).

The crop growth and productivity depend on soil fertility and other soil characters. The soil physico-chemical properties are influenced by many factors and among them important one is soil organic matter. The soil organic matter content in the soil can be enhanced by incorporation of crop residues and organic manures. In the same line, plant growth and yield enhanced with the incorporation of organic matter to the soil. Earlier studies also revealed that crop residue incorporation enhanced crop growth and yield. Piccoli *et al.* (2020) established that incorporation of crop residues resulted in 12 and 16% higher yield in maize and sugar beet, respectively, than other sources. Similarly, Hijbeek *et al* (2017) observed a 12.3% yield increase in wheat when straw was left over in the field. Long-term rice residue incorporation (13 years) resulted in 53.25 and 34.89% higher yield in wheat as compared to residue removal and residue burning, respectively. They also reported a similar trend in the case of maize, and concluded that overall soil physical, chemical and biological properties, particularly the increase in the soil organic matter improved significantly. Improved C stock and microbial activities were major reasons behind this greater soil productivity. Further, agricultural wastes incorporation improved the soil physical and biological properties (Bera *et al.*, 2017; Saikia *et al.*, 2019).

Crop residue incorporation enriched the soil organic matter content which in turn enhanced the microbial population. The microbial activity increased the mineralization of organic matter and enhanced the soil organic carbon and major nutrients content. These soil parameters led to better crop growth and yield. This study clearly elucidated the importance of crop residue incorporation in enhancing the soil health, and crop growth and yield.

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