Impact of row configuration and biofertilizers on yield and quality of sorghum (*Sorghum bicolor* (L.) Moench.) intercropped with cowpea in the Southern Laterites of Kerala, India

ABSTRACT

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani during December 2023 to April 2024 to assess the performance of sorghum in terms of yield and quality, when intercropped with cowpea at varying row configuration and biofertilizers. The field experiment was laid out in Randomized Block Design (RBD). The study comprised intercropping sorghum with cowpea, at three row ratios and four levels of biofertilizer application (r_1 – 1:1 row ratio, r_2 – 1:2 row ratio, r_3 – 2:1 row ratio; b_0 – No biofertilizer, b_1 – AMF, b_2 – Rhizobium and b_3 – AMF + Rhizobium). The treatment r_3 (2:1 row ratio) resulted in higher grain yield, grains per panicle, grain weight per panicle, and green stover yield of sorghum. Application of AMF and Rhizobium together (b_3) resulted in more number of grains per panicle, grain weight, grain yield and green stover yield of sorghum. The treatment combination r_2b_1 (sorghum intercropped with cowpea in 1:2 ratio along with AMF) showed the highest crude protein content in sorghum grains. Iron and copper content were increased with the application of AMF (b_1). However, application of AMF and Rhizobium (b_3) together resulted in higher magnesium content in sorghum grains.

Keywords: Sorghum, Cowpea, Intercropping, Arbuscular mycorrhizal fungi (AMF), Rhizobium, row ratio

1. INTRODUCTION

Millets, recognized as one of the ancient foods of man are invaluable for various reasons, notably their resilience to adverse environmental conditions and their significant nutritional value. Among millets, sorghum (*Sorghum bicolor* (L.) Moench.) has been acknowledged a versatile and nutrient-dense grain with a long history of cultivation spanning centuries. The grains of sorghum hold a diverse array of essential nutrients that underpin its health-promoting properties. On an average, the sorghum grains (per 100 g) have been reported to contain 193 Kcal energy, 7.1 g protein, 0.6 g fat, 39.8 g carbohydrates, 0.9 g fibre, 10 mg calcium, 3.5 mg iron and 1.7 mg niacin (Ajiboye *et al*., 2014; Hassan *et al*., 2021). Its high fibre content aids in maintaining digestive health by promoting regular bowel movements reduce the risk of digestive disorders. As a rich source of carbohydrates, sorghum facilitates sustained energy release, proving particularly beneficial for individuals with active lifestyles or higher energy demands (Saleh *et al*., 2013; Drub *et al*., 2021). Its low glycemic index aids in blood

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sugar regulation, crucial for diabetes management, while the dietary fibre assists in reducing cholesterol levels, thereby lowering the risk of cardiovascular diseases. (Duodu and Awika, 2019). Sole cropping of millets will not be an attractive option for majority of the farmers of Kerala, mainly due to the lack of thorough familiarity with these crops. Thus either inclusion of millets as intercrop in the existing cropping systems or intercropping, with millets as the base crop could prove lucrative, since intercropping ensures improved stability than sole cropping in terms of maintenance of soil fertility, yield enhancement and economic returns (Machado, 2009). Legumes are the major group of crops that are highly flexible as components in diverse cropping system. Further, the significance of legumes as intercrops in cereal/millet-based systems lies in their ability to fix atmospheric nitrogen. In Kerala, cowpea (*Vigna unguiculata* (L.) Walp) is one of pulses with high consumer preference and greater degree of adaptability. Interaction of Arbuscular mycorrhizal fungi (AMF) and *Rhizobium* with crops is a well-known phenomenon. Establishing a connection between cereal-legume intercropping *via* a shared mycorrhizal network enhances crop productivity (Hauggaard-Nielsen and Jensen, 2005). Additionally, interactions between roots and microorganisms have been found to influence nutrient mobilization, leading to effective nutrient acquisition (Li *et al.*, 2014). Both AMF and rhizobial inoculation have been reported to enhance the acquisition of nitrogen by the host crops.

2. MATERIAL AND METHODS

The field experiment was conducted on a red, sandy clay loam soil at the Instructional Farm, College of Agriculture, Vellayani during December 2023 to April 2024, the sorghum variety CO-32. The soil of the experimental site was strongly acidic in reaction (pH – 5.46), medium in organic carbon (0.65 %), low in available nitrogen (216 kg ha^{-1}), high in available phosphorus (51.2 kg ha^{-1}) and medium in available potassium status (181.6 kg ha^{-1}). The experiment was laid out in randomized block design with 3 x 4 treatments replicated thrice. The study comprised intercropping sorghum with cowpea (in additive series), at three row ratios and four levels of biofertilizer application. Treatment details were as follows (r_1 – 1:1 row ratio, r_2 – 1:2 row ratio, r_3 – 2:1 row ratio; b_0 – No biofertilizer, b_1 – AMF, b_2 – Rhizobium and b_3 – AMF + Rhizobium). The spacing followed for sorghum was 45 cm x 15 cm and that for cowpea was 25 cm x 15 cm. Arbuscular mycorrhizal fungi (AMF) was applied to sorghum at the time of sowing. AMF at the rate of 10 kg ha^{-1} was mixed with powdered organic manure and applied along with the sowing of sorghum on the ridges. Seeds of cowpea were treated with *Rhizobium* culture as per the KAU POP. (KAU, 2016). Farm yard manure (10 t ha^{-1}) was applied uniformly to all the treatments before sowing. The nutrient recommendation followed for sorghum and cowpea were 75: 50: 50 kg NPK ha^{-1} and 20:30:10 kg NPK ha^{-1} respectively. The yield attributes and yield of sorghum were recorded following standard procedures. The crude protein content (on dry weight basis) of the sorghum grains was computed as the product of the nitrogen content in the grains and a constant (6.25) (Simpson *et al.*, 1965). Calcium, magnesium, iron, manganese and copper content in sorghum grains were analysed by using Atomic Absorption Spectrophotometer (Venugopal *et al.*, 2013).

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2,1 Description of study area: Altitude in meter above sea level, Average distribution of rainfall, maximum and minimum annual temperature, type of soil texture in a given site, etc….??????
2.2 Treatments, designs and experimental procedures
Eg:- Number of treatments, selected experimental design, number of replications and how the experiment could launched on the floor should be well stated
2.3 Soil Physio-chemical properties of the given site must be well stated since row configuration, bio-fertilizers and intercropping play key role in improving the soil fertility as well as grain quality. So to evaluate the effect of these factors it was mandatory to conduct the soil analysis?????????
Otherwise the contribution of these factors were valueless????????????
At the last soil Physio-chemical properties were written as follows:
Soil Texture (%)
- -Sandy
- -Silt
- -Clay
- -OC %
- -OM%,
- -TN%
- -P %
- -K%

Include the procedures how preformed in the lab???????????????????

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3. RESULTS AND DISCUSSION

3.1 Grains per panicle

Among the three row ratios, r_3 (sorghum intercropped with cowpea in 2:1 ratio) resulted in the highest number of grains per panicle (424.13). The treatment with AMF + Rhizobium (b_3) resulted in the highest number of grains per panicle (384.49). The treatment combinations r_3b_1 (sorghum intercropped with cowpea in 2:1 ratio along with AMF) and r_3b_3 (sorghum intercropped with cowpea in 2:1 ratio along with AMF and rhizobium) had significantly more number of grains per panicle. (436.07 and 424.93 respectively) (Table 1). Cowpea, being a legume with rapid growth and development is always competitive than cereals and millets. In 2:1 row ratio of sorghum: cowpea (r_3), the population of cowpea was lesser compared to sorghum. This might have given a competitive advantage for sorghum over cowpea, resulting in better utilisation of the resources leading to a higher sink capacity denoted by more number of grains per panicle. Application of AMF and Rhizobium together (b_3) resulted in more number of grains per panicle (384.49), grain weight per panicle (43.90 g) and consequently higher grain yield (2909 kg ha^{-1}) and green stover yield (11595 kg ha^{-1}) of sorghum. The combination of AMF and Rhizobium could have led to increased root colonization and biomass, enhancing the overall nutrient absorption capacity of sorghum. Arbuscular mycorrhizal fungi have been identified to have consistent effect on stomatal conductance, transpiration, CO_2 exchange, photosynthesis and chlorophyll content (Panwar, 1991; Sharma *et al*., 2014) and consequently influence the growth and development of crops. Mudalagiriyappan *et al*. (1997) have reported significant increase in growth rate and dry matter production of crops in response to AMF inoculation. In addition, AMF improves phosphorus uptake, which is vital for root development and overall plant vigour. Rhizobium enhances nitrogen availability (Pacovsky *et al*., 1985) as the Rhizobium associated with cowpea can fix atmospheric nitrogen, significantly enriching the soil with nitrogen, which is crucial for plant growth (Scowcroft and Gibson, 1975).

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3.2 Grain weight per panicle

Grain weight per panicle showed significant variation in response to row ratio. Sorghum intercropped with cowpea in 2:1 ratio (r_3) showed the highest grain weight per panicle (45.38 g). Application of both AMF and rhizobium (b_3) resulted in the highest grain weight per panicle (43.90 g). Sorghum intercropped with cowpea in 2:1 ratio along with AMF + Rhizobium (r_3b_3) proved to be superior with higher (47.20 g) grain weight per panicle (Table 1). Root-associated symbiosis plays a vital role in supporting sustainable agriculture by enhancing plant growth and improving soil quality, ultimately benefiting the health of host plants (Loo *et al*., 2022). AMF and Rhizobium are two symbionts which has prominent roles in nutrient acquisition by the associating crops. The extraradical hyphae of AMF in the soil help the host plant acquire nutrients like nitrogen and phosphorus in return for the carbon provided by the host in their symbiotic relationship (Kowal *et al*., 2022; Marro *et al*., 2022). In addition, both AMF and Rhizobia drive nitrogen cycling in the soil (Nelson *et al*., 2016). As suggested by Liu *et al*. (2022), AMF might have promoted N storage in the soil by means of insoluble, recalcitrant proteins released by it, while rhizobia might have release nitrogen into the soil through the decay of root nodules of the legume (Fustec *et al.*, 2010), which in the present study was cowpea. Thus the dual effect of AMF and Rhizobium might have benefitted sorghum resulting in better yield attributes.

3.3 Grain yield

Sorghum and cowpea intercropped in 2:1 ratio (r_3) proved to be superior with the highest grain yield of sorghum (3122 kg ha^{-1}). The treatment b_3 (AMF + Rhizobium) showed the highest (2909 kg ha^{-1}) grain yield of sorghum followed by b_1 (AMF) (2852 kg ha^{-1}). The treatment combination r_3b_1 (sorghum intercropped with cowpea in 2:1 ratio along with AMF) showed higher grain yield of sorghum (3187 kg ha^{-1}) (Table 1). The higher yield of sorghum in the 2:1 row ratio could be attributed to several reasons, the first and foremost being based on plant population. It was logical to reason out that the higher plant population of sorghum in 2:1 row ratio as compared to 1:1 and 1: 2 row ratios, which had only one row of sorghum for every one and two rows of cowpea respectively might have contributed to a better yield. The sorghum - cowpea intercropping system might have optimized the growth conditions for sorghum while benefiting from the presence of cowpea.

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3.4 Green stover yield

The treatment r_3 (sorghum intercropped with cowpea in 2:1 ratio) resulted in the highest (11731 kg ha^{-1}) green stover yield. Application of both AMF and Rhizobium (b_3) exhibited the highest green stover yield of sorghum (11595 kg ha^{-1}). The treatment combination, r_2b_3 (sorghum intercropped with cowpea in 2:1 ratio along with AMF and rhizobium) resulted in the highest green stover yield (12286 kg ha $^{-1}$) of sorghum (Table 1).The combination of AMF and Rhizobium could have led to increased root colonization and biomass, enhancing the overall nutrient absorption capacity of sorghum. Arbuscular mycorrhizal fungi have been identified to have consistent effect on stomatal conductance, transpiration, CO_2 exchange, photosynthesis and chlorophyll content (Sharma *et al.*, 2014; Panwar, 1991) and consequently on growth and development of plants.

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Table 1. Effect of row ratio and biofertilizers on grains per panicle, grain weight per panicle, grain yield and green stover yield of sorghum

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Treatment	Grains per panicle (nos)	Grain weight per panicle (g)	Grain yield (kg ha^{-1})	Green stover yield (kg ha^{-1})
Row ratio (R)				
r_1 – 1:1	322.71	41.16	2602	10897
r_2 – 1:2	323.08	42.93	2615	11085
r_3 – 2:1	424.13	45.38	3122	11731
SE m (±)	2.06	0.18	13	31
CD (0.05)	6.073	0.556	39.0	90.3
Biofertilizer (B)				
b_0 – no biofertilizer	305.93	41.70	2528	11075
b_1 – AMF	369.91	43.18	2852	10842
b_2 – Rhizobium	366.24	43.84	2832	11438
b_3 – AMF + Rhizobium	384.49	43.90	2909	11595

SE m (±)	2.38	0.21	15	35
CD (0.05)	7.012	0.642	45.0	104.3
Row ratio (R) x Biofertilizer (B)				
r_1b_0 – 1:1 + No biofertilizer	244.73	40.93	2217	11512
r_1b_1 – 1:1 + AMF	331.99	41.23	2660	10640
r_1b_2 – 1:1 + Rhizobium	351.20	42.33	2756	10680
r_1b_3 – 1:1 + (AMF + Rhizobium)	363.00	40.13	2775	10758
r_2b_0 – 1:2 + No biofertilizer	254.80	41.97	2274	9940
r_2b_1 – 1:2 + AMF	341.73	41.73	2709	10131
r_2b_2 – 1:2 + Rhizobium	330.27	43.67	2651	11982
r_2b_3 – 1:2 + (AMF + Rhizobium)	365.53	44.37	2827	12286
r_3b_0 – 2:1 + No biofertilizer	418.27	42.20	3091	11773
r_3b_1 – 2:1 + AMF	436.07	46.57	3187	11755
r_3b_2 – 2:1 + Rhizobium	417.27	45.53	3088	11652
r_3b_3 – 2:1 + (AMF + Rhizobium)	424.93	47.20	3125	11742
SE m (±)	4.11	0.37	27	61
CD (0.05)	12.146	1.12	78.1	180.7
Sole crop	414.00	42.40	3114	12896

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3.5 Crude protein content in sorghum grains

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Sorghum intercropped with cowpea in 1:2 ratio (r_2) exhibited highest crude protein content in the grains of sorghum (8.86 %). Application of AMF (b_1) resulted in the highest crude protein content (8.98 %). The treatment combination r_2b_1 (sorghum intercropped with cowpea in 1:2 ratio along with AMF) showed highest crude protein content of sorghum (10.16 %) (Fig 1). AMF improves the absorption of nitrogen and phosphorus, essential for protein formation. Sorghum plants with AMF show higher yields and better nutritional profiles, including increased protein content (Watts-Williams *et al*., 2021).

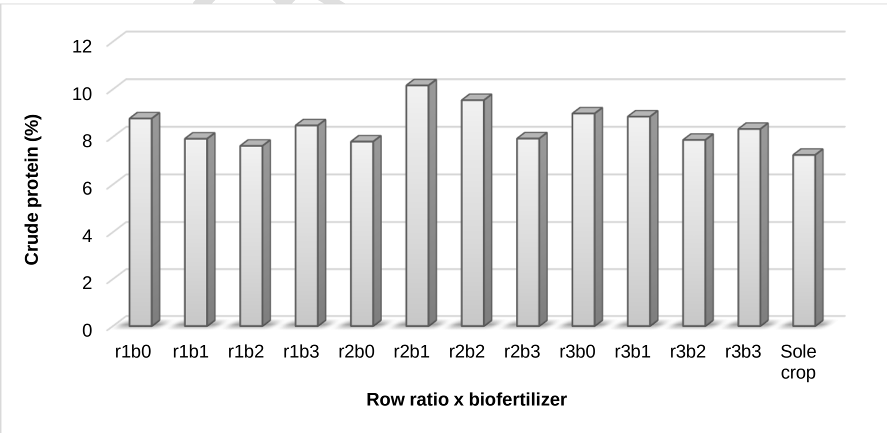

Fig. 1. Effect of row ratio x biofertilizer on crude protein content in sorghum grains, per cent (dry weight basis)

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3.6 Mineral content in sorghum grains

The treatment combination r_2b_1 (sorghum intercropped with cowpea in 1:2 ratio along with AMF) exhibited higher calcium content in sorghum grain. (345.67 mg 100 g^{-1}) (Table 2). AMF increases the root surface area, leading to improved calcium absorption. Intercropping with cowpea enhances nutrient cycling and availability in the soil (Abroulaye et al., 2023). The treatment b_3 (AMF + Rhizobium) resulted in the highest magnesium content in sorghum grain (156.22 mg 100 g^{-1}) (Table 2). The application of AMF and Rhizobium could have enhanced the microbial activity in the rhizosphere, increasing nutrient mobilization processes. Enhanced microbial activity could have improved the solubility of magnesium compounds in the soil, making magnesium more available for uptake (Barea *et al*. 2005). Application of AMF (b_1) resulted in the highest iron content in sorghum grain (5.29 mg 100 g^{-1}) (Table 2). AMF inoculation has been reported to significantly increase the release of phytosiderophores, which are crucial for mobilizing Fe in the soil. This process might have facilitated the uptake of Fe by sorghum roots (Prity *et al*., 2020). AMF might have also enhanced the soil microbial activity, which in turn improved the bioavailability of Fe and other nutrients, further supporting the nutritional quality of sorghum grains. In contrast, application of Rhizobium (b_2) proved to be superior with the highest manganese content (1.64 mg 100 g^{-1}) in the grains of sorghum (Table 2). The treatment combination r_1b_2 (sorghum intercropped with cowpea in 1:1 ratio along with Rhizobium) showed the highest manganese content in sorghum grain (1.77 mg 100 g^{-1}). Intercropping has been reported to offer a potential facilitating mechanism in which crop species can chemically mobilize unavailable forms of one or more limiting soil nutrients, including micronutrients like iron, zinc, and manganese, by releasing acid phosphatases, protons, carboxylates and chelating substances (Li *et al*., 2014). The treatment b_1 (AMF) exhibited higher copper content (0.33 mg 100 g^{-1}) and was statistically on par with b_2 (Rhizobium) (Table 2). AMF associations significantly improve nutrient uptake, including copper, in sorghum, leading to enhanced grain quality. The presence of AMF can increase the bioavailability of micronutrients, including copper, which is crucial for plant health and nutrition (Watts-Williams et al., 2021).

Table 2. Effect of row ratio and biofertilizer on calcium, magnesium, iron, manganese and copper content in sorghum grains, mg 100 g^{-1} (on dry weight basis)

Treatment	Calcium	Magnesium	Iron	Manganese	Copper
Row ratio (R)					
r_1 – 1:1	339.83	146.00	4.52	1.48	0.25
r_2 – 1:2	334.08	144.83	4.34	1.45	0.27
r_3 – 2:1	335.67	145.50	4.45	1.48	0.22
SE m (±)	1.68	0.36	0.045	0.01	0.02
CD (0.05)	NS	NS	NS	NS	NS
Biofertilizer (B)					
b_0 – no biofertilizer	336.56	141.44	3.55	1.25	0.22
b_1 – AMF	339.33	137.78	5.29	1.50	0.33
b_2 – Rhizobium	337.67	146.33	4.46	1.64	0.29
b_3 – AMF + Rhizobium	332.56	156.22	4.59	1.50	0.16
SE m (±)	1.95	0.42	0.05	0.02	0.02
CD (0.05)	NS	1.240	0.154	0.061	0.064

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Row ratio (R) x Biofertilizer (B)					
r_1b_0	342.00	142.33	3.57	1.25	0.24
r_1b_1	335.67	138.00	5.30	1.47	0.33
r_1b_2	344.33	146.00	4.57	1.77	0.30
r_1b_3	337.33	157.67	4.66	1.43	0.16
r_2b_0	335.00	140.00	3.51	1.24	0.21
r_2b_1	345.67	137.67	5.10	1.46	0.42
r_2b_2	332.33	145.67	4.47	1.57	0.31
r_2b_3	323.33	156.00	4.67	1.54	0.14
r_3b_0	332.67	142.00	3.57	1.25	0.21
r_3b_1	336.67	137.67	5.47	1.56	0.24
r_3b_2	336.33	147.33	4.33	1.60	0.25
r_3b_3	337.00	155.00	4.43	1.54	0.17
SE m (±)	3.37	0.728	0.09	0.02	0.03
CD (0.05)	9.959	NS	NS	0.106	NS
Sole crop	332.00	136.00	4.48	1.26	0.23

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4. CONCLUSION

From the present study it could be concluded that, intercropping sorghum with cowpea in 2:1 row ratio and inoculating sorghum with AMF and cowpea with Rhizobium (r_3b_3) could be recommended as a viable option for higher productivity and profitability of sorghum. However, with respect to the grain quality, the treatment combination r_2b_1 (sorghum + cowpea in 1:2 row ratio + AMF for sorghum) was observed to yield superior results.

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REFERENCES

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