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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

Kasapogu Rachel Madhurima [a*], Shalini Pillai, P. [a], Rajasree G. [a], Usha C. Thomas [a] and Chitra N. [b]

[a] Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram, Kerala-695522, India.
[b] Department of Agricultural Microbiology, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram, Kerala-695522, India.

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 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

**Corresponding author: E-mail: rachelmadhurima@gmail.com;*

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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.19.4 per cent yield increase was observed in the treatment r_3 than r_2. 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. Sorghum grain yield was reduced in the absence of biofertilizer (b_0). 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: Arbuscular mycorrhizal fungi (AMF); cowpea; intercropping; rhizobium; row ratio; Sorghum.

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 holds a diverse array of essential nutrients that confer 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 [1,2]. 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 [3,4]. Its low glycemic index aids in blood sugar regulation, crucial for diabetes management, while the dietary fibre assists in reducing cholesterol levels, thereby lowering the risk of cardiovascular diseases [5]. 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. 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. AMF enhance the uptake of phosphorus (P), nitrogen (N), and micronutrients like zinc (Zn), which are critical for plant growth, especially in nutrient-poor soils [15]. By enhancing root health and competing for space and resources, AMF can reduce the susceptibility of plants to soil-borne diseases [6]. Rhizobium inoculation has been shown to significantly improve the yield and nitrogen content of leguminous crops, which also benefits intercropped non-leguminous crops by improving overall soil nitrogen levels [7]. Both AMF and rhizobial inoculation have been reported to enhance the acquisition of nitrogen by the host crops.

2. MATERIALS AND METHODS

2.1 Description of Study Area

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 used for the study was 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} (Table 1). The mean maximum temperature ranged between 32.17ºC to 34.23ºC and the mean minimum temperature ranged between 20.01ºC to 25.76ºC. A total rainfall of 136.3 mm was received during the experimental period.

2.2 Treatments, Design and Experimental Procedures

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.

Table 1. Chemical properties of soil of the experimental site

S. No	Parameter	Content	Rating	Method adopted
1	Soil reaction (pH)	5.46	Strongly acidic	1:2.5 soil solution ratio using pH meter [13]
2	Electrical conductivity (dS m^{-1})	0.45	Normal	1:2.5 soil solution ratio using conductivity bridge [13]
3	Organic carbon (%)	0.65	Medium	Walkley and Black rapid titration method [13]
4	Available N (kg ha^{-1})	216	Low	Alkaline permanganate method [14]
5	Available P (kg ha^{-1})	51.2	High	Bray colorimetric method [13]
6	Available K (kg ha^{-1})	181.6	Medium	Ammonium acetate method [13]

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 [8]. Farmyard 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) [9]. Calcium, magnesium, iron, manganese and copper content in sorghum grains were analysed by using Atomic Absorption Spectrophotometer [10]. The data generated from the field experiment were statistically analyzed using analysis of variance (ANOVA) technique as applied to randomized block design [11]. The General R based Analysis Platform Empowered by Statistics (GRAPES 1.0.0) software developed by Gopinath *et al*. [12] was used for undertaking statistical analysis.

2.3 Chemical Properties of Soil of the Experimental Site

The soil of the experimental site was red, sandy clay loam in texture, strongly acidic in reaction, high in organic carbon, high in available phosphorus and medium in available nitrogen and potassium status (Table 1).

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 2). 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. AMF improve the uptake of key nutrients like phosphorus (P), which is essential for grain development in cereals. Phosphorus plays a critical role in energy transfer and photosynthesis, both of which are crucial for reproductive development, including grain formation [15]. Similarly, the application of rhizobium to cowpea enhances biological nitrogen fixation, which improves soil nitrogen levels. This indirectly benefits sorghum in intercropping systems by increasing nitrogen availability for both crops. The increased nitrogen can enhance the grain-filling period, leading to more grains per panicle [7].

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 2). 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 [16]. 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 [17, 18]. In addition, both AMF and Rhizobia drive nitrogen cycling in the soil [19]. As suggested by Liu *et al*. [20], 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 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 2). 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.

Table 2. Effect of row ratio and biofertilizers on grains per panicle, grain weight per panicle, grain yield and green stover yield of sorghum

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

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.

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 2). 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 and consequently on growth and development of plants.

3.5 Crude Protein Content In Sorghum Grains

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 [21].

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 3). AMF increases the root surface area, leading to improved calcium absorption. Intercropping with cowpea enhances nutrient cycling and availability in the soil [22]. The treatment b_3 (AMF + Rhizobium) resulted in the highest magnesium content in sorghum grain (156.22 mg 100 g^{-1}) (Table 3). The application of AMF and Rhizobium could have enhanced the microbial activity in the rhizosphere, increasing nutrient mobilization processes. Application of AMF (b_1) resulted in the highest iron content in sorghum grain (5.29 mg 100 g^{-1}) (Table 3). 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 [23]. 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 (b2)

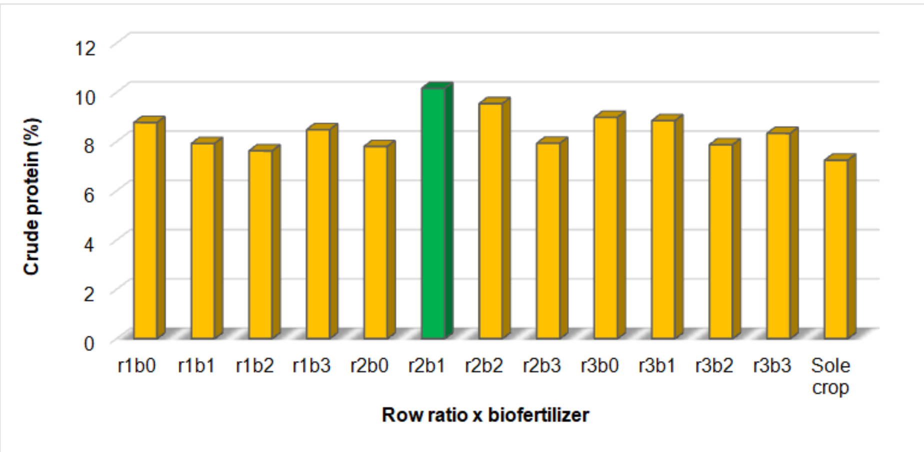

Fig. 1. Effect of row ratio x biofertilizer on crude protein content in sorghum grains, per cent (dry weight basis)

Table 3. 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
Row ratio (R) x Biofertilizer (B)					
r_1b_0 – 1:1 + No biofertilizer	342.00	142.33	3.57	1.25	0.24
r_1b_1 – 1:1 + AMF	335.67	138.00	5.30	1.47	0.33
r_1b_2 – 1:1 + Rhizobium	344.33	146.00	4.57	1.77	0.30
r_1b_3 – 1:1 + (AMF + Rhizobium)	337.33	157.67	4.66	1.43	0.16
r_2b_0 – 1:2 + No biofertilizer	335.00	140.00	3.51	1.24	0.21
r_2b_1 – 1:2 + AMF	345.67	137.67	5.10	1.46	0.42
r_2b_2 – 1:2 + Rhizobium	332.33	145.67	4.47	1.57	0.31
r_2b_3 – 1:2 + (AMF + Rhizobium)	323.33	156.00	4.67	1.54	0.14
r_3b_0 – 2:1 + No biofertilizer	332.67	142.00	3.57	1.25	0.21
r_3b_1 – 2:1 + AMF	336.67	137.67	5.47	1.56	0.24
r_3b_2 – 2:1 + Rhizobium	336.33	147.33	4.33	1.60	0.25
r_3b_3 – 2:1 + (AMF + Rhizobium)	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

NS – not significant

proved to be superior with the highest manganese content (1.64 mg 100 g^{-1}) in the grains of sorghum (Table 3). 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}). 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 3). 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 [21].

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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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