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Evaluating the efficacy of inorganic fertilizers and biofertilizer consortium for enhanced crop yield and nutrient uptake in sorghum

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Abstract

To determine the optimal combination of inorganic nutrients in conjunction with a biofertilizer consortium to achieve maximum *rabi* sorghum yield. A field study was conducted at the Agricultural College Farm, Bapatla, Andhra Pradesh, India in the *rabi* season of 2018-19. The design followed was a randomized block design, with seven different nutrient management practices tested and each replicated thrice with treatments T_1: Control, T_2: 100% Recommended dose of NPK (100:60:40) fertilizers, T_3: 50% RDF+ Biofertilizer Consortium (BFC), T_4: 75% RDF+ BFC, T_5: 100% RDF+ BFC, T_6: 125% RDF+ BFC, T_7: BFC only. The study found that using 125% of the recommended along with a biofertilizer consortium (BFC) resulted in higher growth and yield traits. Notably, 125% RDF + BFC (T_6) treatment significantly increased grain and Stover yield by 30.3 and 26.5% compared to the control. Treatment (T_6) also showed the highest uptake of total nitrogen, phosphorus, and potassium, surpassing the 100% RDF + BFC. In summary, 125% RDF + BFC treatment resulted in enhancing growth, yield, and nutrient uptake in the study. Improvement in N uptake in the grain by (53.0%) and stover by (50.5%) compared with control treatment was observed with T_6 treatment. The application of 125% RDF + BFC is the most effective treatment for enhancing yield traits and overall crop yield, and for fostering microbial growth, thus promoting soil health in sorghum cultivation.

Keywords biofertilizers consortium, biological activity, nutrient uptake, yield

Introduction

Sorghum is vital for arid and semi-arid regions, covering 41.97 M ha globally with an annual production of 65.2 Mt. India ranks third in sorghum cultivation with an area 4.82 M ha and seventh in production with 4.4 Mt [1]. In India, sorghum was a major cereal in the 1950s, covering over 18 M ha. However, by 2020-21, the cultivated area had gradually decreased to 7.38 million hectares [2]. Recently, *rabi* sorghum has succeeded in rice fallow regions of coastal Andhra Pradesh [3], particularly under zero tillage conditions, where grain productivity has reached 7-8 tons per hectare. It now spans more than 11,000 hectares in Guntur district [4].To boost yield, we must focus on increasing productivity within existing cultivation areas. This involves effective

management of all inputs, particularly nutrients. Despite the potential of balanced N, P, and K fertilizer use to maintain productivity, overreliance on chemical fertilizers has led to declining soil health. Researchers [5-6] consistently show the benefits of organic fertilizers, and a combination of inorganic and organic enhances soil fertility [7-8]. Inorganic fertilizers offer quick nutrients, while organic fertilizers boost organic matter, soil structure, and buffering capacity [9]. Due to the increasing costs of chemical fertilizers, regional farmers are adopting more cost-effective alternatives like biofertilizers as they enhance organic matter content, boost enzyme activity, promote microbial populations, mitigate the adverse effects of chemical fertilizers, and consistently sustainably improve crop yields [10-11]. Integrated plant nutrition combines synthetic nutrients and biofertilizers, alongside nutrient recycling *viz*., organic materials. Biofertilizers are cost-effective, eco-friendly agents that enhance farm productivity through nutrient mobilization. Microorganisms are crucial in increasing the availability of N, P, and K. Various studies [12-13] have examined the effects of biological fertilizers on sorghum growth and yield. This study aimed to assess the impact of combining inorganic fertilizers and biofertilizers in sorghum cultivation during the rice fallow period.

Methodology

Experimental procedures

In 2018–19, a field experiment was conducted at the Agricultural College Farm, Bapatla, located in the coastal region of the Krishna Agro-climatic Zone, Andhra Pradesh, India. During the growing season, temperatures ranged from 25.6 to 34.7°C, with an average of 31.6°C, and relative humidity varied from 40.6 to 77.9%. Precipitation during this period was 54 mm. The soil had a near-neutral pH of 6.94, low organic carbon (0.4%), 224 kg of available N, medium available P (38 kg P_2O_5), and high K (482 kg K_2O). The treatments were *viz*., T_1: Control, T_2: 100% Recommended dose of fertilizers, T_3: 50% RDF+ Biofertilizer Consortium (BFC), T_4: 75% RDF+ BFC, T_5: 100% RDF+ BFC, T_6: 125% RDF+ BFC, T_7: BFC only (RDF =100, 60, 40 N, P and K) (Biofertilizer Consortium= Azospirillum, PSB and KRB in liquid form) was conducted in a RBD and each replicated three times. All other agronomic practices were followed for crop management. Sorghum hybrid CSH-16 was sown at 12 kg/ha, spaced 45 cm × 15 cm. Nitrogen (100 kg/ha) was split into two applications, and P and K were applied initially. Post-harvest, paraquat was used on rice stubbles to prevent ratooning. Manual weeding took place at 20 and 35 DAS, with two irrigations after 30 DAS.

Data recorded

Growth and biometric measurements were recorded. Above-ground dry matter was assessed by air and sun drying, followed by constant-temperature hot air oven drying at 60° ± 2°C. Grain and straw yields were determined from the net plot area, expressed in t ha^{-1}. The biological yield was calculated based on net plot harvest. Determining the nitrogen, phosphorus, and potassium as the procedures described by Prasad et al., [14] were followed. Total bacteria, fungi, and actinomycetes were estimated by the serial dilution and plating technique as described by Olsen and Bakken [15].

Statistical analysis

Data of all parameters was analyzed statistically by performing an analysis of variance (ANOVA) following the procedure outlined by Gomez and Gomez [16]. LSD values were calculated for parameters displaying significance ($p<0.05$) to enable the comparison of treatment effects, employing Tukey's HSD test.

Results and Discussion

Growth and yielding traits

Combining fertilizer doses with a biofertilizers consortium significantly improved growth and yield traits. Maximum plant height (216.1 cm) at harvest stage was seen in the 125% RDF+ BFC (T_6)

treatment and remained on par with T_5 and T_2. Control (T_1) had the minimum height (161.0 cm) at harvest (Table 1). Enhanced plant height is linked to soil nutrient enrichment, providing ample nutrients for growth processes, aligning with prior studies [17-18]. Among the treatments, T_6 recorded the longest earhead (33.2 cm), comparable to T_5 (32.5 cm) and T_2 (32.1 cm), and control had the shortest (27.3 cm) earhead (Table 1). This increased earhead length likely resulted from enhanced cell enlargement, larger leaf production, and improved plant photosynthesis efficiency, in line with previous studies [17, 19]. An increase in filled grains was observed with higher doses of inorganic fertilizers and their combination with biofertilizers. The treatment T_6 had the highest filled grains per earhead followed by T_5 (Figure 1) highlighting the positive response of the crop to higher fertilizer doses, potentially enhancing grain production through improved nutrient transport in phloem tissues. Similar results were reported by different studies [17, 19]. Earhead m^{-2} and harvest index were not significantly affected by varying fertilizer doses in combination with biofertilizers.

Table 1. Growth and yielding traits of sorghum as influenced by inorganic fertilizers combined with biofertilizers consortium on rice fallow sorghum

Treatment	Plant height (cm)	Ear head m^{-2}	Ear head length (cm)	Filled grains ear $head^{-1}$
Control	161.0^{d}	13.6	27.3^{c}	1032^{c}
100% RDF	206.3^{ab}	14.2	32.1^{ab}	1198^{abc}
50% RDF+BFC	183.5^{bcd}	13.7	29.5^{abc}	1149^{bc}
75% RDF+BFC	195.7^{abc}	14.0	31.4^{abc}	1197^{abc}
100% RDF+BFC	209.6^{ab}	14.3	32.5^{ab}	1283^{ab}
125% RDF+BFC	216.1^{a}	14.5	33.2^{a}	1359^{a}
BFC only	172.8^{cd}	13.5	28.8^{bc}	1050^{c}
SEm±	11.2	0.33	1.22	49.6
LSD (p=0.05)	33.9	NS	3.80	152.8

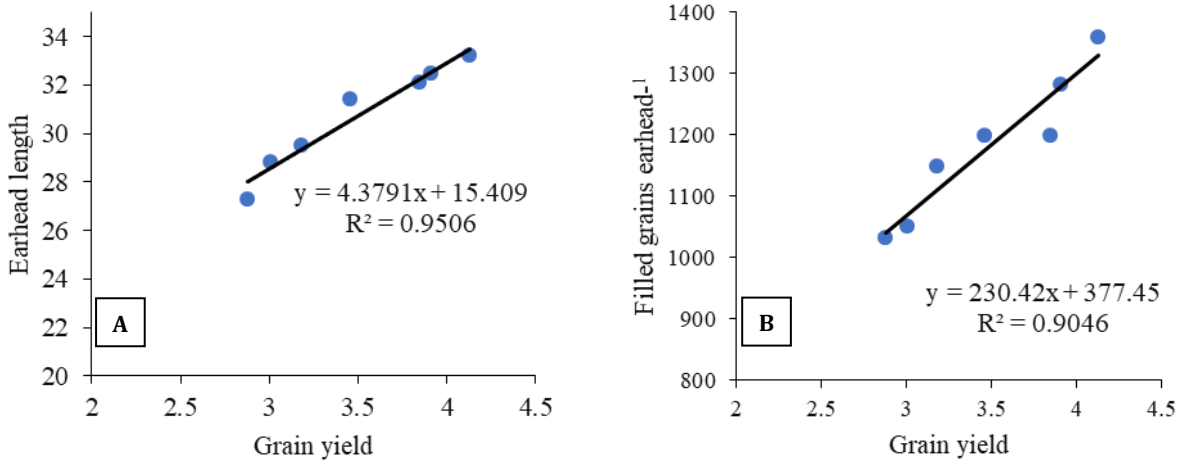

Figure 1. Correlation between grain yield (GY) and earhead length of sorghum (A) GY and filled grains $earhead^{-1}$ (B) As influenced by fertilizers combined with biofertilizers consortium on rice fallow sorghum

Grain and stover yield

The results exhibited a statistically significant effect ($p < 0.05$) on sorghum yield, within yields apparent among the treatments. The highest grain and stover yields were achieved in 125% RDF+ BFC which were 30.3 and 26.5% higher respectively over the control (2.88 and 5.52 t ha^{-1}) plot. The yields of sorghum in rice fallow conditions showed significant variation as the levels of inorganic fertilizers increased. In contrast, the control yielded the lowest grain yield at 2.88 t/ha. Sorghum yield significantly decreased in the order 125%RDF+ BFC > 100%RDF+ BFC > 100%RDF> 75%RDF+ BFC> 50%RDF+ BFC> BFC only> Control (Table 2). Stover yields under rice fallows were similar to the trend observed for grain yields. Treatment T_6 resulted in the highest stover yield at (7.52 t ha^{-1}) achieved, similar outcomes were reported in earlier studies by researchers such as [19, 20-23]. Microbial inoculants improve nutrient availability either by fixing atmospheric nitrogen in the rhizosphere and biofertilizers, on the other hand, transform fixed and insoluble forms into soluble forms, making them readily available to plants [24]. Studies [8, 25-26] revealed that combining inorganic and organic fertilizers significantly increased grain yield in rice, pearl millet, and barley by enhancing soil properties. This yield enhancement can be attributed to the improved and continuous nutrient availability of the plants, promoting grain yield. Similar findings align with the research of [19, 27].

Table 2. Grain, straw, biological yields and harvest index of sorghum as influenced by inorganic fertilizers combined with biofertilizers consortium on rice fallow sorghum

Treatment	Grain yield (t ha^{-1})	(% increase over control)	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Control	2.88^{c}	–	5.53^{c}	8.49^{g}	34.2
100% RDF	3.85^{ab}	33.60	7.13^{ab}	10.98^{c}	35.1
50% RDF+BFC	3.18^{c}	10.40	6.05^{bc}	9.23^{e}	34.5
75% RDF+BFC	3.46^{bc}	20.13	6.50^{abc}	9.96^{d}	34.7
100% RDF+BFC	3.91^{ab}	35.76	7.21^{ab}	11.12^{b}	35.3
125% RDF+BFC	4.13^{a}	43.40	7.52^{a}	11.65^{a}	35.5
BFC only	3.02^{c}	4.86	5.70^{c}	8.72^{f}	34.6
SEm±	1.98	–	4.19	2.81	1.10
LSD (p=0.05)	6.12	–	12.92	9.21	NS

Nutrient (NPK) uptake

Nitrogen content in grain and stover was significantly influenced by the varying levels of recommended fertilizers combined with a biofertilizer consortium. The treatment with 125% RDF+ BFC (T_6) exhibited the highest nitrogen content in grain (1.55%) and stover (0.63%), followed by T_5 (100% RDF+ BFC) with 1.51% in grain and 0.56% in straw, and T_2 (100% RDF) with 1.46% in grain and 0.54% in stover (Table 3). Conversely, the control (T_1) had the lowest nitrogen content (1.10% in grain and 0.39% in straw). Regarding nitrogen uptake, T_6 had the maximum uptake, followed by T_5. In terms of total nitrogen uptake, T_6 had the highest at 107.9 kg ha^{-1}, followed by T_5 with 91.8 kg ha^{-1}, while the control had the lowest at 51.6 kg ha^{-1}. These results align with previous studies [20-21, 23, 28]. The 125% RDF + BFC treatment exhibited increased nitrogen content and uptake in both grain and stover. Among the treatments, the T_6 treatment showed the highest uptake of nutrients (NPK), followed by the 100% RDF + BFC treatment, indicating a substantial uptake of N, P, and K. Biofertilizers, when used alongside chemical fertilizers, boost soil fertility and sustainable crop production by increasing plant biomass and nutrient uptake [29]. Sorghum exhibited a rise in its overall absorption of N, P, and K with variations in the levels from 51.6 to 107.9, 12.4 to 29.5, and 49.7 to 126.5 kg/ha, respectively, corresponding to the rising NPK levels from 0 to 125% (RDF) (Figure 2). Increasing NPK supply to crops boosted nutrient availability, leading to greater biomass

yield and increased N, P, and K uptake. This positively influenced crop growth and yield [30].

Table 3. Nitrogen content (%) and uptake (kg ha^{-1}) in the grain and the stover of sorghum as influenced by inorganic fertilizers combined with biofertilizers consortium on rice fallow sorghum

Treatment	Grain		Stover		Total uptake (kg ha^{-1})
	Content	Uptake	Content	Uptake	
Control	1.10^{c}	28.8^{c}	0.39^{c}	22.8^{c}	51.6^{d}
100% RDF	1.46^{a}	52.4^{ab}	0.54^{abc}	37.7^{abc}	90.1^{b}
50% RDF +BFC	1.33^{abc}	37.5^{c}	0.41^{bc}	24.3^{c}	61.8^{cd}
75% RDF +BFC	1.40^{ab}	42.9^{bc}	0.42^{bc}	26.4^{bc}	69.3^{c}
100% RDF +BFC	1.51^{a}	53.4^{ab}	0.56^{ab}	38.4^{ab}	91.8^{b}
125% RDF +BFC	1.55^{a}	61.8^{a}	0.63^{a}	46.1^{a}	107.9^{a}
BFC only	1.18^{bc}	32.7^{d}	0.40^{bc}	24.0^{c}	56.7^{d}
SEm±	0.05	2.63	0.02	2.15	2.84
LSD (p=0.05)	0.20	8.10	0.07	6.61	9.14

RDF, Recommended dose of fertilizers; BFC, Biofertilizers consortium. Significant differences between means within the same column are denoted by different letters ($p<0.05$) according to Tukey's honestly significant difference test

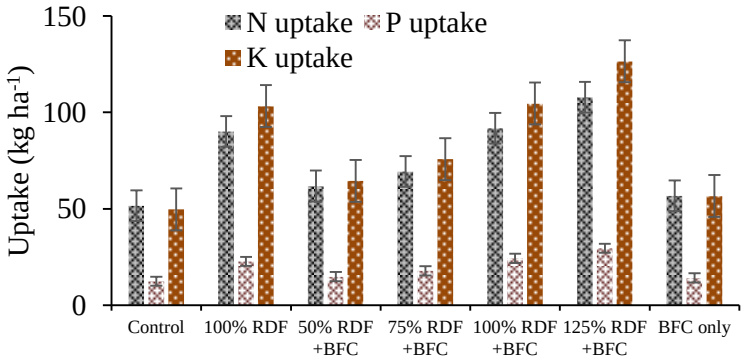

Figure 2. Total macro nutrients (N, P, K) uptake as influenced by inorganic fertilizers combined With biofertilizers consortium on rice fallow sorghum

Soil microbial count and soil nutrient status after harvest

Microbial populations in the experimental soil significantly increased 15 days after the application of biofertilizers compared to their initial levels. Notably, the treatment involving 125% RDF+ BFC (T6) consistently displayed the highest microbial populations at both stages, with bacterial, fungal, and actinomycetes populations all peaking in this treatment (Figure 3). In contrast, the control treatment had the lowest microbial populations. These findings underscore the positive impact of combining inorganic fertilizers with biofertilizers on enhancing soil microbial communities, thereby contributing to improved soil health and ultimately boosting crop productivity results align with previous research [24, 31]. After harvest, soil NPK status revealed the available nitrogen at (242.8 kg ha^{-1}) in (T_6), followed by T_5 at 241.7 kg ha^{-1} with low nitrogen in the control (Table 4). The rise in available nitrogen in T_6 was attributed to the higher fertilizer dose with the biofertilizer consortium, promoting nitrogen mineralization from manures, resulting in greater availability compared to inorganic fertilizers alone. Similarly, available phosphorus exhibited a similar trend, with the highest content (90.0 kg ha^{-1}) in T_6, followed by T_5 at 89.8 kg ha^{-1}, facilitated by the biofertilizer consortium's

ability to solubilize insoluble phosphorus. Potassium availability was significantly influenced by various inorganic fertilizer levels with biofertilizers, reaching its peak at 446.2 kg ha^{-1} in T_4, on par with T_3 (445.5 kg ha^{-1}) and T_7 (433.4 kg ha^{-1}), attributed to low potassium application and increased plant uptake (Table 4), as well as reduced fixation and increased K_2O release through organic matter interaction with clay, supported by previous studies [19, 24, 32].

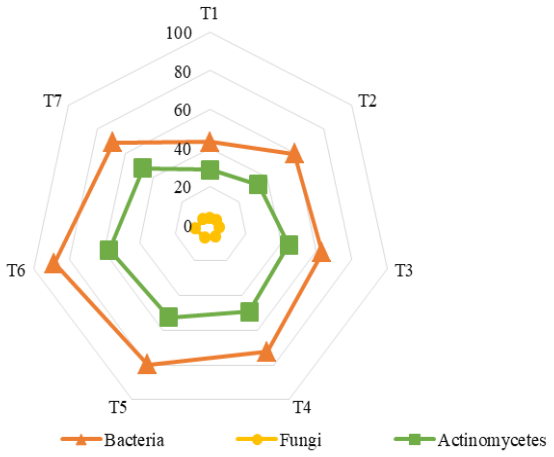

Figure 3. Radar chart visualization of biological activity of bacteria (x10^6), fungi (x10^4), and actinomycetes (x10^6) in the soil as influenced by fertilizers combined with biofertilizers consortium on rice fallow sorghum

Table 4. Soil N P K (kg ha^{-1}) status after harvest of rice fallow-sorghum as influenced by inorganic fertilizers combined with biofertilizers consortium on rice fallow sorghum

Treatment	Nitrogen	Phosphorus	Potassium
Control	173	25.5	430.7
100% RDF	234.5	75.3	418.7
50% RDF +BFC	222.8	53.2	445.5
75% RDF +BFC	237.3	65.2	446.2
100% RDF +BFC	241.7	89.8	424.3
125% RDF +BFC	242.8	90	427.5
BFC only	177.9	28.5	433.4
SEm±	14.8	3.2	24.5
LSD (p=0.05)	45.7	9.9	75.6

Conclusion

In summary, the study highlights a significant enhancement in sorghum yield and its related characteristics by applying 125% of the RDF in conjunction with a biofertilizer consortium. This approach also improved the biological activity and nutrient absorption by sorghum. Therefore, it is recommended for adoption, especially in the coastal regions of Andhra Pradesh, particularly in the context of cultivating *rabi* sorghum.

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